ELECTRICAL ENGINEER'S POCKET-BOOK:

*A HAND-BOOK
OF USEFUL DATA FOR ELECTRICIANS AND
ELECTRICAL ENGINEERS.*

BY

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WITH THE COLLABORATION OF EMINENT
SPECIALISTS.

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PREFACE.

It is with some little trepidation that this book is put before the public, in view of the frequent important, and even radical, changes that up to the present have characterized the development of electrical engineering. It has, however, been thought that the science has now reached a stage which renders necessary some manual that will be of assistance to the active worker in the various branches.

This book is not an encyclopedia, nor is it intended for a text-book, but it is hoped that as a compendium of useful data it may assist the practicing electrician and engineer.

The matter included is representative of American practice, and no effort has been made to include any other, except in special cases. No excuse is offered for the very considerable amount of matter taken from trade publications of the larger electrical manufacturers, as in this country the engineers retained by such works are specialists — often the best in their various branches; and it is an accident of condition only that in some cases has compelled the use of more of the publications of one company than of another, based upon available published material.

Manufacturers have been most kind in supplying any special data and descriptions asked for; and the author's thanks are in particular due to a large circle of associates for suggestions, revisions, critical proof-reading, and the various other details involved in a compilation of this kind, of whom the following deserve especial mention for valuable aid rendered: Messrs. F. E. Idell, W. D. Weaver, T. C. Martin, Prof. Samuel Sheldon, E. B. Raymond, John S. Griggs, Jr., William Wallace Christie, J. J. Crain, Grahame H. Powell, Prof. Francis B. Crocker, A. N. Mansfield, E. M. Hewlett, C. F. Scott, H. S. Putnam, Charles Henry Davis, Townsend Wolcott, Walter S. Moody, Herbert Laws Webb, Charles Thom, William Maver, Jr., Joseph Appleton, Prof. Alex. G. McAdie, Thorburn Reid, Max Osterberg, Max Loewenthal, J. G. White & Co. The especial thanks of the author are due to the indefatigable co-operation of Mr. Charles E. Speirs, of the D. Van Nostrand Co., who has rendered most valuable assistance in properly getting the matter into shape for publication.

In closing, the author begs that readers will not hesitate to point out errors found in the text or tables, as many will doubtless crop out in the close examination by numerous readers.

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CONTENTS.

SYMBOLS, UNITS, INSTRUMENTS.

CHAPTER I.

ELECTRICAL ENGINEERING SYMBOLS.

The following list of symbols has been compiled from various sources as being those most commonly in use in the United States. Little variation will be found from similar lists already published except the elimination of some that may be considered exclusively foreign. The list has been revised by competent authorities and may be considered as representing the best usage.

Fundamental.

l,	Length. c.m. = centimeter; in., or ″ = inch, ft. or ′ = foot.
M,	Mass. gr. = mass of 1 gramme; kg. = 1 kilogramme.
T, t,	Time. s = second.

Derived: *geometric.*

S, s,	Surface.
V,	Volume.
α, β,	Angle.

Mechanical.

v,	Velocity.
m,	Momentum.
ω,	Angular velocity.
a,	Acceleration.
g,	Acceleration due to gravity = 32.2 feet per second.
F, f,	Force.
W,	Work.
P,	Power.
δ,	Dyne, 10 δ = 10 dynes.
ϵ,	Ergs.
ft. lb.,	Foot-pound.
H.p., h.p.; HP,	Horse-power.
I.H.P.,	Indicated horse-power.
B.H.P.,	Brake horse-power.
E.H.P.,	Electrical horse-power.
J,	Joules' equivalent.
p,	Pressure.
K,	Moment of inertia.

Derived Electrostatic.

q,	Quantity.
i,	Current.
e,	Potential Difference.
r,	Resistance.
k,	Capacity.
sk,	Specific Inductive capacity.

Derived Magnetic.

m,	Strength of pole.
$\mathfrak{M}$,	Magnetic moment.
$\mathfrak{J}$,	Intensity of magnetization.
$\mathcal{H}$,	Horizontal intensity of earth's magnetism.
$\mathcal{H}$,	Field intensity.
Φ,	Magnetic Flux.
$\mathcal{B}$,	Magnetic flux density or magnetic induction.
$\mathcal{H}$,	Magnetizing force.
$\mathcal{F}$,	Magnetomotive force.
$\mathcal{R}$,	Reluctance, Magnetic resistance.
μ,	Magnetic permeability.
κ,	Magnetic susceptibility.
ν,	Reluctivity (specific magnetic resistance).

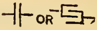
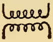
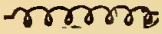
Derived electromagnetic.

R,	Resistance, Ohm.
Ω,	do, megohm.
E,	Electromotive force, volt.
U,	Difference of potential, volt.
I,	Intensity of current, Ampere.
Q,	Quantity of electricity, Ampere-hour; Coulomb.
C,	Capacity. Farad.
W,	Electric Energy, Watt-hour; Joule.
P,	Electric Power, Watt; Kilowatt.
ρ,	Resistivity (specific resistance), Ohm-centimeter.
G,	Conductance, Mho.
γ,	Conductivity (specific conductivity.
L,	Inductance (coefficient of Induction), Henry.
v,	Ratio of electro-magnetic to electrostatic unit of quantity = 3×10^{10} centimeters per second approximately.

Symbols in general use.

D,	Diameter.
r,	Radius.
t,	Temperature.
θ,	Deflection of galvanometer needle.

N, *n*,	Number of anything.
π,	Circumference ÷ diameter : 3.141592.
ω,	$2\pi N = 6.2831 \times$ frequency, in alternating current.
~	Frequency, periodicity, cycles per second.
G,	Galvanometer.
S,	Shunt.
N, n,	North pole of a magnet.
S, s,	South pole of a magnet.
A.M.	Ammeter.
V.M.	Voltmeter.
A.C.	Alternating current.
D.C.	Direct current.
P.D.	Potential difference.
C.G.S.	Centimeter, Gramme, Second system.
B. & S.	Brown & Sharpe wire gauge.
B.W.G.,	Birmingham Wire gauge.

R.p.m.,	Revolutions per minute.
C.P.	Candlepower.
—o—	Incandescent lamp.
	Arc lamp.
	Condenser.
	Battery of cells.
	Dynamo or motor, d.c.
	Dynamo or motor, a.c.
	Converter.
	Static transformer.
	Inductive resistance.
	Non-inductive resistance.

CHAPTER II.

ELECTRICAL ENGINEERING UNITS.

Index Notation.

Electrical units and values oftentimes require the use of large numbers of many figures both as whole numbers and in decimals. In order to avoid this to a great extent the index method of notation is in universal use in connection with all electrical computations.

In indicating a large number, for example, say, a million, instead of writing 1,000,000, it would by the index method be written 10^6; and 35,000,000 would be written 35×10^6.

A decimal is written with a minus sign before the exponent, or, $\frac{1}{100} = .01 = 10^{-2}$; and .00048 is written 48×10^{-5}.

The velocity of light is 30,000,000,000 cms. per sec., and is written 3×10^{10}.

In multiplying numbers expressed in this notation the significant figures are multiplied, and to their product is annexed 10, with an index equal to the *sum* of the indices of the two numbers.

In dividing, the significant figures are divided, and 10, with an index equal to the *difference* of the two indices of the numbers is annexed to the dividend.

Fundamental Units.

The physical qualities, such as force, velocity, momentum, etc., are expressed in terms of *length*, *mass*, *time*, and for electricity the system of terms in universal use is that known as the C. G. S. system,

viz.:— The unit of length is the *Centimeter*.
The unit of mass is the *Gramme*.
The unit of time is the *Second*.

Expressed in more familiar units, the *Centimeter* is equal to .3937 inch in length; the *Gramme* is equal to 15.432 grains, and represents the *mass* or *quantity* of a cubic centimeter of water at 4° C, or 39.2° Fah.; the *Second* is the $\frac{1}{86164.09}$ part of a sidereal day, or the $\frac{1}{86400}$ part of a mean solar day.

These units are also often called *absolute units*.

Derived Geometric Units.

The unit of area or surface is the *square centimeter*.
The unit of *volume* is the *cubic centimeter*.

Derived Mechanical Units.

Velocity is the rate of change of position, and is uniform velocity when equal distances are passed over in equal spaces of time; unit velocity is a rate of change of *one centimeter per second.*

Angular Velocity is the angular distance about a center passed through in one second of time. Unit angular velocity is the velocity of a body moving in a circular path, whose radius is unity, and which would traverse a unit angle in unit time. Unit angle is 57°, 17′, 44.8″ approximately; i.e., an angle whose arc equals its radius.

Momentum is the quantity of motion in a body, and equals the *mass* times the *velocity*.

Acceleration is the rate at which velocity changes; the unit is an acceleration of one centimeter per second per second. The acceleration due to gravity is the increment in velocity imparted to falling bodies by gravity, and is usually taken as 32.2 feet per second, or 981 centimeters per second. This value differs somewhat at different localities. At the North Pole $g = 983.1$; at the equator $g = 978.1$; and at Greenwich it is 981.1.

Force acts to change a body's condition of rest or motion. It is that which tends to produce, alter, or destroy motion, and is measured by the change of momentum produced.

The unit of force is that force which, acting for one second on a mass of one gramme, gives the mass a velocity of one centimeter per second; this unit is called a *dyne*. The force of gravity or weight of a mass in dynes may be found by multiplying the mass in grammes by the value of g at the particular place where the force is exerted. The pull of gravity on one pound in the United States may be taken as 445,000 dynes.

Work is the product of a force into the distance through which it acts. The unit is the *erg*, and equals the work done in pushing a mass through a distance of one centimeter against a force of one dyne. As the "weight" of one gramme is 1×981, or 981 dynes, the work done in raising a weight of one gramme through a height of one centimeter against the force of gravity, or 981 dynes, equals $1 \times 981 = 981$ ergs.

One kilogramme-meter $= 100000 \times 981$ ergs.

Kinetic energy is the work a body is able to do by reason of its motion.

Potential energy is the work a body is able to do by reason of its position.

The unit of energy is the *erg*.

Power is the rate of working, and the unit is the *watt* $= 10^7$ ergs per sec. *Horse-power* is the unit of power in common use and, although a somewhat arbitrary unit, it is difficult to compel people to change from it to any other. It equals 33,000 lbs. raised one foot high in one minute, or 550 foot-pounds per second.

1 ft.-lb. $= 1.356 \times 10^7$ ergs.

1 watt $= 10^7$ ergs per second.

1 horse-power $= 550 \times 1.356 \times 10^7$ ergs $= 746$ watts. If a current of I amperes flow through R ohms under a pressure of E volts, then $\frac{EI}{746} = \frac{I^2R}{746} = \frac{E^2}{746\,R}$ represents the horse-power involved.

The French "*force de cheval*" $= 736$ watts $= 542.48$ ft. lbs. per sec. $= .9863$ H. P., and 1 H.P. $= 1.01389$ "*force de cheval*."

Heat. The Joule $WJ = 10^7$ ergs, and is the work done, or heat generated, by a watt second, or ampere flowing for a second through a resistance of an ohm.

If H = heat generated in gramme calories,
I = current in amperes,
E = e.m.f. in volts,
R = resistance in ohms, and
t = time in seconds,

then $H = 0.24 I^2Rt = 0.24\ EIt$. gramme *calories* or therms.

Then
$$IEt = I^2Rt = \frac{E^2t}{R} = EQ = \text{Joules}.$$

or, as 1 horse-power $= 550$ foot-pounds of work per second,
$$\text{Joules} = \tfrac{550}{746}\,EQ = .7373\ EQ \text{ ft. lbs.}$$

Heat Units.

The *British Thermal Unit* is the amount of heat required to raise the temperature of one pound of water from 60° F. to 61°, = 1 pound-degree-Fah. = 251.9 French units.

The *therm*, or French *calorie*, is the amount of heat required to raise the temperature of a mass of 1 gramme of water from 4° C. to 5° C. = 1 gramme-degree-centigrade.

Water at 4° C. is at its maximum density.

Joules equivalent, J, is the amount of energy equal to a heat unit.

For a B.T.U., or pound-degree-Fah., $J = 1.07 \times 10^{10}$ ergs., or = 778 foot-pounds.

For one pound-degree — Centigrade, $J = 1.93 \times 10^{10}$ ergs.

For a *calorie* $J = 4.189 \times 10^7$ ergs.

The heat generated in t seconds of time is

$$\frac{I^2Rt}{J} = \frac{EIt}{J}, \text{ where } J = 4.189 \times 10^7,$$

and I, R, and E are expressed in practical units.

Electrical Units.

There are two sets of electrical units derived from the fundamental C. G. S. units; viz., the *electrostatic* and the *electromagnetic*. The first is based on the force exerted between two quantities of electricity, and the second upon the force exerted between a current and a magnetic pole. The ratio of the *electrostatic* to the *electromagnetic* units has been carefully determined by a number of authorities, and is found to be some multiple or sub-multiple of a quantity represented by v, whose value is approximately 3×10^{10} centimeters per second. Convenient rules for changing from one to the other set of units will be stated later on in this chapter.

Electrostatic Units.

As yet there have been no names assigned to these. Their values are as follows: —

The unit of quantity is that quantity of electricity which repels with a force of *one dyne* a similar and equal quantity of electricity placed at unit distance (one centimeter) in air.

Unit of current is that which conveys a unit of quantity along a conductor in unit time (one second).

Unit difference of potential or *unit electro-motive force* exists between two points when *one erg* of work is required to pass a unit quantity of electricity from one point to the other.

Unit of resistance is possessed by that conductor through which unit current will pass under unit electro-motive force at its ends.

Unit of capacity is that which, when charged by unit potential, will hold one unit of electricity; or that capacity which, when charged with one unit of electricity, has a unit difference of potential.

Specific inductive capacity of a substance is the ratio between the capacity of a condenser having that substance as a dielectric to the capacity of the same condenser using dry air at 0° C. and a pressure of 76 centimeters as the dielectric.

Magnetic Units.

Unit Strength of Pole (symbol m) is that which repels another similar and equal pole with unit force (one dyne) when placed at unit distance (one centimeter) from it.

Magnetic Moment (symbol $\mathfrak{M}$) is the product of the strength of either pole into the distance between the two poles.

Intensity of Magnetization is the magnetic moment of a magnet divided by its volume. (symbol $\mathfrak{J}$).

Intensity of Magnetic Field (symbol $\mathfrak{H}$) is measured by the force it exerts upon a unit magnetic pole, and therefore the unit is that intensity of field which acts on a unit pole with a unit force (one dyne).

Magnetic Induction (symbol $\mathfrak{B}$) is the magnetic flux or the number of magnetic lines per unit area of cross-section of magnetized material, the area being at every point perpendicular to the direction of flux. It is equal to the magnetizing force or field intensity $\mathfrak{H}$ multiplied by the *permeability* μ: the unit is the *gauss*.

Magnetic Flux (symbol Φ) is equal to the average field intensity multiplied by the area. Its unit is the *maxwell*.

Magnetizing Force (symbol $\mathfrak{H}$) per unit of length of a solenoid equals

$4\pi NI \div L$ where $N =$ the number of turns of wire on the solenoid; $L =$ the length of the solenoid in cms., and $I =$ the current in absolute units.

Magnetomotive Force (symbol $\mathfrak{F}$) is the total magnetizing force developed in a magnetic circuit by a coil, equals $4\pi NI$, and the unit is the *gilbert.*

Reluctance, or *Magnetic Resistance* (symbol $\mathfrak{R}$), is the resistance offered to the magnetic flux by the material magnetized, and is the ratio of magnetomotive force to magnetic flux; that is, unit magnetomotive force will generate a unit of magnetic flux through unit reluctance: the unit is the *oersted;* i.e., the reluctance offered by a cubic centimeter of vacuum.

Magnetic Permeability (symbol μ) is the ratio of the magnetic induction $\mathfrak{B}$ to the magnetizing force $\mathfrak{H}$, that is $\frac{\mathfrak{B}}{\mathfrak{H}} = \mu$.

Magnetic Susceptibility (symbol κ) is the ratio of the intensity of magnetization to the magnetizing force, or $\kappa = \frac{\mathfrak{J}}{\mathfrak{H}}$.

Reluctivity, or *Specific Magnetic Resistance* (symbol ν), is the reluctance per unit of length and of unit cross-section that a material offers to being magnetized.

Electromagnetic Units.

Resistance (symbol R) is that property of a material that opposes the flow of a current of electricity through it; and the unit is that resistance which, with an electro-motive force or pressure between its ends of one unit, will permit the flow of a unit of current.

The practical unit is the *ohm*, and its value in C.S.G. units is 10^9. The standard unit is a column of pure mercury at 0° C., of uniform cross-section, 106.3 centimeters long, and 14.4521 grammes weight. For convenience in use for very high resistances the prefix *meg* is used; and the *megohm*, or million ohms, becomes the unit for use in expressing the insulation resistances of submarine cables and all other high resistances.

Electro-motive Force (symbol E) is the electric pressure which forces the current through a resistance, and unit E.M.F. is that pressure which will force a unit current one ampere through a unit resistance. The unit is the volt, and the practical standard adopted by the international congress of electricians at Chicago in 1893 is the Clark cell, directions for making which will be given farther on. The E.M.F. of a Clark cell is 1.434 volt at 15° C.

The value of the volt in C.G.S. units is 10^8. For small E.M.F's. the unit millivolt, or one-thousandth volt, is used.

Difference of Potential, as the name indicates, is simply a difference of electric pressure between two points. The unit is the *volt.*

Current (symbol I) is the intensity of the electric current that flows through a circuit. A unit current will flow through a resistance of one ohm, with an electro-motive force of one volt between its ends. The unit is the ampere, and is practically represented by the current that will electrolytically deposit silver at the rate of .001118 gramme per second. Its value in C.G.S. units is 10^{-1}. For small values the milliampere is used, and it equals one-thousandth of an ampere.

The Quantity of Electricity (symbol Q) which passes through a given cross-section of an individual circuit in t seconds when a current of I amperes is flowing is equal to It units. The unit is therefore the ampere-second. Its name is the *Coulomb*, and its value in C.G.S. units is 10^{-1}.

Capacity (symbol C) is the property of a material condenser for holding a charge of electricity. A condenser of unit capacity is one which will be charged to a potential of one volt by a quantity of 1 coulomb. The unit is the *farad*, its C.G.S. value is 10^{-9}; and this being so much larger than ever obtains in practical work, its millionth part, or the *micro-farad*, is used as the practical unit, and its value in absolute units is 10^{-15}. A condenser of one-third micro-farad capacity is the size in most common use in the United States.

Electric Energy (symbol W) is represented by the work done in a circuit or conductor by a current flowing through it. The unit is the *Joule*, its absolute value is 10^7 ergs, and it reprepresents the work done by the flow for one second of unit current (1 ampere) through 1 ohm.

Electric Power (symbol P) is measured in *watts*, and is represented by a current of 1 ampere under a pressure of 1 volt, or 1 Joule per second. The

Synopsis of Symbols for Physical Quantities and Abbreviations for Units.

Physical Quantities.	Symbols.	Defining Equations.	Dimensions of the Physical Quantities.	Names of the C. G. S. Units.	Values in C.G.S. Units.	Practical Units.	Abbreviations of the Practical Units.
Fundamental.							
Length	L, l	. . . . .	L	Centimeter.	. . .	Meter.	m
Mass	M	. . . . .	M	Mass of 1 gramme.	. . .	Mass of a kilogram.	kg
Time*	T, t	. . . . .	T	Second.	. . .	Minute; hour.	m; h
Geometric.							
Surface	S, s	$S = L.L$	L^2	Square centimeter.	. . .	Square meter.	m²
Volume	V	$V = L.L.L$	L^3	Cubic centimeter.	. . .	Cubic meter.	m³
Angle	α, β	$\alpha = \frac{\text{arc}}{\text{radius}}$	A number.	Radian.	. . .	Degree; minute; second; grade.	
Mechanical.							
Velocity	v	$v = \frac{L}{T}$	LT^{-1}	Centimeter per second.	. . .	Meter per second.	m; s
Momentum	m	$m = mv.$					
Angular Velocity	ω	$\omega = \frac{v}{L}$	T^{-1}	Radian per second.	. . .	Revs. (turns) per minute.	t; m
Acceleration	a	$a = \frac{v}{T}$	LT^{-2}	Centimeter per second per second.	. . .	Meter per second per second.	m; s²
Acceleration due to gravity . . .	g						
Force	F, f	$F = Ma$	LMT^{-2}	Dyne.	. . .	Gramme; kilogr'm.	g; kg
Work	W	$W = FL$	L^2MT^{-2}	Erg.	. . .	Kilogrammeter.	kgm
Power	P	$P = \frac{W}{T}$	L^2MT^{-3}	Erg per second.	. . .	Kilogrammeter per second.	kgm; s
Heat, Joule's equivalent . . . , .	J						

* The International Bureau of Weights and Measures has established an important distinction in the notation of time, according as it refers to the *epoch* (date of time or day) or the *duration* of a phenomenon. In the former case the reference letters are used as indices, and in the latter they are on the same line with the numbers; for instance, an experiment began at $2^h\ 15^m\ 46^s$. lasted 2h. 15m. 46s., and ended at $4^h\ 31^m\ 32^s$. This method is to be recommended.

Pressure	p	$p = \frac{F}{S}$	$L^{-1}MT^{-2}$	Dyne per square centimeter.		Kilogramme per square centimeter.	kg ; cm^2
Moment of Inertia	K	$K = ML^2$	L^2M	Gramme-mass-centimeter-squared.			
Electrostatic.							
Quantity	q	$q = uQ = \sqrt{F \times dis^2}$	$M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}$				
Current	i	$i = vI$	$M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}$				
Potential	e	$e = \frac{E}{v}$	$M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}$				
Resistance	r	$r = \frac{R}{v^2}$	$L^{-1}T^1$				
Capacity	k	$K = v^2C$	L				
Specific Inductive Capacity . . .	sk	—	A number.				
Magnetic.							
Strength of Pole	m	$F = \frac{m^2}{L^2}$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-1}$				
Magnetic Moment	$\mathfrak{M}$	$\mathfrak{M} = ml$	$L^{\frac{5}{2}}M^{\frac{1}{2}}T^{-1}$				
Intensity of Magnetization	$\mathfrak{I}$	$\mathfrak{I} = \frac{\mathfrak{M}}{V}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$				
Field Intensity	$\mathcal{H}$	$\mathcal{H} = \frac{F}{m}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gauss.*	. . .	*Gauss.*	
Flux of (Magnetic) Force	Φ	$\Phi = \mathcal{H}S$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-1}$	*Maxwell.*	. . .	*Maxwell.*	
Magnetic Induction	$\mathcal{B}$	$\mathcal{B} = \mu\,\mathcal{H}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gauss.*	. . .	*Gauss.*	
Magnetizing Force†	$\mathcal{H}$	$\mathcal{H} = \frac{4\pi NI}{L}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gauss.*	. . .	*Gauss.*	
Magnetomotive Force	$\mathfrak{F}$	$\mathfrak{F} = 4\pi NI$	$L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gilbert.*	. . .	*Gilbert*; 1 *Gilbert* = 0.7958 amp.-turns.	
Reluctance (Magnetic Resistance) .	$\mathcal{R}$	$\mathcal{R} = \nu\frac{L}{S}$	L^{-1}	*Oersted.*	. . .	*Oersted.*	
(Magnetic) Permeability	μ	$\mu = \frac{\mathcal{B}}{\mathcal{H}}$	A Number.				
(Magnetic) Susceptibility	κ	$\kappa = \frac{\mathfrak{I}}{\mathcal{H}}$	A Number.				
Reluctivity (Specific Magnetic Resistance)	ν	$\nu = \frac{1}{\mu}$	A Number.				

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† N is the number of windings, and L the length of the solenoid generating the magnetizing force.

Synopsis of Symbols for Physical Quantities and Abbreviations for Units.— *Continued.*

Physical Quantities.	Symbols.	Defining Equations.	Dimensions of the Physical Quantities.	Names of the C.G.S. Units.	Values in C. G. S. Units.	Practical Units.	Abbreviations of the Practical Units.
Electromagnetic.							
Resistance	R, r	$R=\frac{E}{I}$	LT^{-1}	. . . .	10^9	Ohm.	ohm
Electromotive Force, or Difference of Potential	E, e	$E=RI$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-2}$	. . . .	10^8	Volt.	v
Intensity of Current	I, i	$I=\frac{E}{R}$	$L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	. . . .	10^{-1}	Ampere.	
Quantity of Electricity	Q, q	$Q=IT$	$L^{\frac{1}{2}}M^{\frac{1}{2}}$	. . . .	10^{-1}	Coulomb ; ampere-hour.	c ; a-h
Capacity	C, c	$C=\frac{Q}{E}$	$L^{-1}T^2$	. . . .	10^{-9}	Farad.	F
Electric Energy	W	$W=EIT$	L^2MT^{-2}	. . . .	10^7	Joule ; watt-hour.	J ; w-h
Electric Power	P	$P=EI$	L^2MT^{-3}	. . . .	10^7	Watt ; kilowatt.	w ; kw
Resistivity (Specific Resistance) . .	ρ	$\rho=\frac{RS}{L}$	L^2T^{-1}	. . . .	. . .	Ohm-centimeter.	ohm-cm
Conductance	G, g	$G=\frac{1}{R}$	$L^{-1}T$	. . . .	. . .	Mho.	mho
Conductivity (Specific Conductance)	γ	$\gamma=\frac{1}{\rho}$	$L^{-2}T$				
Coefficient of Induction (Inductance)	L, l	$L=\frac{\Phi}{I}$	L	. . . .	10^9	Henry.	H
Impedance	Z, z	$Z=\frac{E}{I}$	LT^{-1}			Ohm.	
Reactance	X, x		LT^{-1}			Ohm.	

watt equals 10^7 absolute units, and 746 watts equals 1 horse-power. In electric lighting and power the unit *kilowatt*, or 1000 watts, is considerably used to avoid the use of large numbers.

Resistivity (symbol ρ) is the specific resistance of a substance, and is the resistance in ohms of a centimeter cube of the material to a flow of current between opposite faces.

Conductance (symbol G) is that property of a metal or substance by which it conducts an electric current, and equals the reciprocal of its resistance. The unit proposed for conductance is the *Mho*, but it has not come into prominent use as yet.

Conductivity (symbol v) is the specific conductance of a material, and is therefore the reciprocal of its resistivity. It is often expressed in comparison with the conductivity of some standard metal such as silver or copper, and is then stated as a percentage.

Inductance (symbol L), or coefficient of self-induction, of a circuit is that coefficient by which the time rate of change of the current in the circuit must be multiplied in order to give the E.M.F. of self-induction in the circuit. The practical unit is the *henry*, which equals 10^9 absolute units, and exists in a circuit when a current varying 1 *ampere* per *second* produces a *volt* of electro-motive force in that circuit. As the *henry* is so large as to be seldom met with in practice, 1 thousandth of it, or the *milli-henry*, is the unit most in use.

Below will be found a few rules for reducing values stated in electrostatic units to units in the electro-magnetic system. To reduce

electrostatic *potential* to *volts*, multiply by 300;
" *capacity* to *micro-farads*, divide by 900,000;
" *quantity* to *coulombs*, divide by 3×10^9;
" *current* to *amperes*, divide by 3×10^9;
" *resistance* to *ohms*, multiply by 9×10^{11}.

INTERNATIONAL ELECTRICAL UNITS.

At the International Congress of Electricians, held at Chicago, August 21, 1893, the following resolutions met with unanimous approval, and being approved for publication by the Treasury Department of the United States Government, Dec. 27, 1893, and legalized by act of Congress and approved by the President, July 12, 1894, are now recognized as the International units of value for their respective purposes.

RESOLVED, That the several governments represented by the delegates of the International Congress of Electricians be, and they are hereby, recommended to formally adopt as legal units of electrical measure the following: —

1. As a unit of *resistance*, the *International ohm*, which is based upon the ohm equal to 10^9 units of resistance of the C.G.S. system of electro-magnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at a temperature of melting ice, 14.4521 grammes in mass, of a constant cross-sectional area, and of the length 106.3 centimeters.

2. As a unit of *current*, the *International ampere*, which is one-tenth of the unit of current of the C.G.S. system of electro-magnetic units, and which is represented sufficiently well for practical use by the unvarying current which, when passed through a solution of nitrate of silver in water, in accordance with the accompanying specification (A) deposits silver at the rate of 0.001118 gramme per second.

3. As a unit of *electro-motive force* the *international volt* which is the E.M.F. that, steadily applied to a conductor whose resistance is one International ohm, will produce a current of one international ampere, and which is represented sufficiently well for practical use by $\frac{1000}{1434}$ of the E.M.F. between the poles or electrodes of the voltaic cell known as Clark's cell at a temperature of 15° C, and prepared in the manner described in the accompanying specification (B).

4. As the unit of *quantity*, the *International coulomb*, which is the quantity of electricity transferred by a current of one international ampere in one second.

5. As the unit of *capacity* the *international farad*, which is the capacity

of a conductor charged to a *potential* of one *international volt* by one international coulomb of electricity.

6. As the unit of *work*, the *joule*, which is 10^7 units of work in the C.G.S. system, and which is represented sufficiently well for practical use by the energy expended in one second by an international ampere in an international ohm.

7. As the unit of *power*, the *watt*, which is equal to 10^7 units of power in the C.G.S. system, and which is represented sufficiently well for practical use by the work done at the rate of one joule per second.

8. As the unit of *induction*, the *henry*, which is the induction in the circuit when the E.M.F. induced in this circuit is one international volt, while the inducing current varies at the rate of one international ampere per second

Specification A.

In employing the silver voltameter to measure currents of about one ampere, the following arrangements shall be adopted:

The kathode on which the silver is to be deposited shall take the form of a platinum bowl not less than 10 cms. in diameter, and from 4 to 5 cms. in depth.

The anode shall be a disk or plate of pure silver some 30 sq. cms. in area, and 2 or 3 cms. in thickness.

This shall be supported horizontally in the liquid near the top of the solution by a silver rod riveted through its center.

To prevent the disintegrated silver which is formed on the anode from falling upon the kathode, the anode shall be wrapped around with pure filter paper, secured at the back by suitable folding.

The liquid shall consist of a neutral solution of pure silver nitrate, containing about 15 parts by weight of the nitrate to 85 parts of water.

The resistance of the voltameter changes somewhat as the current passes. To prevent these changes having too great an effect on the current, some resistance, besides that of the voltameter, should be inserted in the circuit. The total metallic resistance of the circuit should not be less than 10 ohms.

Method of making a Measurement. — The platinum bowl is to be washed consecutively with nitric acid, distilled water, and absolute alcohol; it is then to be dried at 160° C., and left to cool in a desiccator. When cold it is to be weighed carefully.

It is to be nearly filled with the solution, and connected to the rest of the circuit by being placed on a clean copper support to which a binding-screw is attached

The anode is then to be immersed in the solution so as to be well covered by it, and supported in that position; the connections to the rest of the circuit are then to be made.

Contact is to be made at the key, noting the time. The current is to be allowed to pass for not less than half an hour, and the time of breaking contact observed.

The solution is now to be removed from the bowl, and the deposit washed with distilled water, and left to soak for at least six hours. It is then to be rinsed successively with distilled water and absolute alcohol, and dried in a hot-air bath at a temperature of about 160° C. After cooling in a desiccator it is to be weighed again. The gain in mass gives the silver deposited.

To find the time average of the current in amperes. this mass, expressed in grammes, must be divided by the number of seconds during which the current has passed and by 0.001118.

In determining the constant of an instrument by this method the current should be kept as nearly uniform as possible, and the readings of the instrument observed at frequent intervals of time. These observations give a curve from which the reading corresponding to the mean current (time average of the current) can be found.

The current is calculated from the voltameter results, corresponding to this reading.

The current used in this experiment must be obtained from a battery and not from a dynamo, especially when the instrument to be calibrated is an electrodynamometer.

Specification B. — The Volt.

The cell has for its positive electrode, mercury, and for its negative electrode, amalgamated zinc; the electrolyte consists of a saturated solution of zinc sulphate and mercurous sulphate. The electromotive force is 1.434 volts at 15° C., and, between 10° C. and 25° C., by the increase of 1° C. in temperature, the electromotive force decreases by .00115 of a volt.

1. Preparation of the Mercury.—To secure purity it should be first treated with acid in the usual manner, and subsequently distilled in vacuo.

2. Preparation of the Zinc Amalgam.—The zinc designated in commerce as "commercially pure" can be used without further preparation. For the preparation of the amalgam one part by weight of zinc is to be added to nine (9) parts by weight of mercury, and both are to be heated in a porcelain dish at 100° C. with moderate stirring until the zinc has been fully dissolved in the mercury.

3. Preparation of the Mercurous Sulphate.—Take mercurous sulphate, purchased as pure, mix with it a small quantity of pure mercury, and wash the whole thoroughly with cold distilled water by agitation in a bottle; drain off the water and repeat the process at least twice. After the last washing, drain off as much of the water as possible. (For further details of purification, see Note A.)

4. Preparation of the Zinc Sulphate Solution.—Prepare a neutral saturated solution of pure re-crystallized zinc sulphate, free from iron, by mixing distilled water with nearly twice its weight of crystals of pure zinc sulphate and adding zinc oxide in the proportion of about 2 per cent by weight of the zinc sulphate crystals to neutralize any free acid. The crystals should be dissolved by the aid of gentle heat, but the temperature to which the solution is raised must not exceed 30° C. Mercurous sulphate, treated as described in 3, shall be added in the proportion of about 12 per cent by weight of the zinc sulphate crystals to neutralize the free zinc oxide remaining, and then the solution filtered, while still warm, into a stock bottle. Crystals should form as it cools.

5. Preparation of the Mercurous Sulphate and Zinc Sulphate Paste.—For making the paste, two or three parts by weight of mercurous sulphate are to be added to one by weight of mercury. If the sulphate be dry, it is to be mixed with a paste consisting of zinc sulphate crystals and a concentrated zinc sulphate solution, so that the whole constitutes a stiff mass, which is permeated throughout by zinc sulphate crystals and globules of mercury.

If the sulphate, however, be moist, only zinc sulphate crystals are to be added; care must, however, be taken that these occur in excess, and are not dissolved after continued standing. The mercury must, in this case also, permeate the paste in little globules. It is advantageous to crush the zinc sulphate crystals before using, since the paste can then be better manipulated.

To set up the Cell.—The containing glass vessel, represented in the accompanying figure, shall consist of two limbs closed at bottom, and joined above to a common neck fitted with a ground-glass stopper. The diameter of the limbs should be at least 2 cms. and their length at least 3 cms. The neck should be not less than 1.5 cms. in diameter. At the bottom of each limb a platinum wire of about 0.4 mm. in diameter is sealed through the glass

To set up the cell, place in one limb mercury, and in the other hot liquid amalgam, containing 90 parts mercury and 10 parts zinc. The platinum wires at the bottom must be completely covered by the mercury and the amalgam respectively. On the mercury, place a layer one cm. thick of the zinc and mercurous sulphate paste described in 5. Both this paste and the zinc amalgam must then be covered with a layer of the neutral zinc sulphate crystals one cm. thick. The whole vessel must then be filled with the saturated zinc sulphate solution, and the stopper inserted so that it shall just touch it, leaving, however, a small bubble to guard against breakage when the temperature rises.

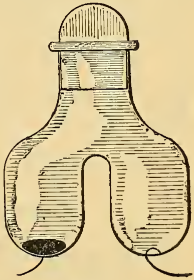


FIG 1.

Before finally inserting the glass stopper, it is to be brushed round its upper edge with a strong alcoholic solution of shellac, and pressed firmly in place. (For details of filling the cell see Note B.)

Table of Equivalents of Units of Energy and Work.

	Erg.	Mega-erg.	Gram-degree C.	Kilo-gram-degree C.	Pound-degree C.	Pound-degree F.	Watt-second.	Gram-centi-meter.	Kilo-gram-meter.	Foot-pound.	H.P. sec., Eng-lish.	H. P. sec., metric.
Erg	1	$\frac{1}{10^6}$	$\frac{24068}{10^{12}}$	$\frac{24068}{10^{15}}$	$\frac{531}{10^{13}}$	$\frac{955}{10^{13}}$	$\frac{1}{10^7}$	$\frac{101,937}{10^8}$	$\frac{101,937}{10^{13}}$	$\frac{737,337}{10^{13}}$	$\frac{13406}{10^{14}}$	$\frac{13592}{10^{14}}$
Mega-erg	10^6	1	$\frac{24068}{10^6}$	$\frac{24068}{10^9}$	$\frac{531}{10^7}$	$\frac{955}{9^7}$	0.1	1019.37	$\frac{101,937}{10^7}$	$\frac{737,337}{10^7}$	$\frac{13,406}{10^8}$	$\frac{13592}{10^8}$
Gram-degree C. . .	41,548,700	41.5487	1	.001	.002205	.003968	4.15487	42,353.5	0.423535	3.06355	.00557	.005647
Kilogram-degree C .	41,548×10^6	41,548.7	1000	1	2.2046	3.9683	4154.87	42,353,500	423.535	3063.55	5.57	5.64703
Pound-degree C . .	18,846×10^6	18,846.5	453.59	.45359	1	1.8	1884.65	19,211,400	192.114	1389.6	2.52653	2.56149
Pound-degree F . .	10,470×10^6	10,470.1	251.995	251995	.555556	1	1047.03	10,673,000	106.730	772	1.40364	1.42305
Watt-second . . .	10^7	10	0.24068	$\frac{24068}{10^8}$	.000531	.000955	1	10,193.7	0.101937	.737337	.0013406	.0013592
Gram-centimeter . .	981	.000981	.0000235	$\frac{2361}{10^{11}}$	$\frac{5205}{10^{11}}$	$\frac{937}{10^{10}}$	.000098	1	0.00001	$\frac{723328}{10^5}$	$\frac{13152}{10^{11}}$	$\frac{13334}{10^{11}}$
Kilogram-meter . .	98.1×10^6	98.1	2.36108	.002361	.005205	.009370	9.81	100,000	1	7.23328	.013152	.013334
Foot-pound	135,626×10^2	13.5626	.326425	.000326	.000720	.001295	1.35626	13,825.3	0.138253	1	$\frac{181182}{10^8}$	.001843
Horse-power sec., Eng.	745,943×10^4	7459.43	179.486	.179486	.3957	.71243	745.943	7,603,920	76.0392	550	1	1.01383
Horse-power sec., met'c	73,575×10^5	7357.5	0.177075	177.075	0.390375	0.70275	735.75	7,500,000	75	542.496	.986356	1

Notes to the Specifications.

(*A*). **The Mercurous Sulphate.**—The treatment of the mercurous sulphate has for its object the removal of any mercuric sulphate which decomposes in the presence of water into an acid and a basic sulphate. The latter is a yellow substance—turpeth mineral—practically insoluble in water; its presence, at any rate in moderate quantities, has no effect on the cell. If, however, it be formed, the acid sulphate is also formed. This is soluble in water, and the acid produced affects the electromotive force. The object of the washings is to dissolve and remove this acid sulphate, and for this purpose the three washings described in the specification will suffice in nearly all cases. If, however, much of the turpeth mineral be formed, it shows that there is a great deal of the acid sulphate present; and it will then be wiser to obtain a fresh sample of mercurous sulphate, rather than to try by repeated washings to get rid of all the acid.

The free mercury helps in the process of removing the acid; for the acid mercuric sulphate attacks it, forming mercurous sulphate.

Pure mercurous sulphate, when quite free from acid, shows on repeated washing a faint yellow tinge, which is due to the formation of a basic mercurous salt distinct from the turpeth mineral, or basic mercuric sulphate. The appearance of this primrose yellow tinge, which is due to the formation of a basic mercurous salt distinct from the turpeth mineral, or basic mercuric sulphate, may be taken as an indication that all the acid has been removed; the washing may with advantage be continued until this tint appears.

(*B*). **Filling the Cell.**—After thoroughly cleaning and drying the glass vessel, place it in a hot-water bath. Then pass through the neck of the vessel a thin glass tube reaching to the bottom to serve for the introduction of the amalgam. This tube should be as large as the glass vessel will admit. It serves to protect the upper part of the cell from being soiled with the amalgam. To fill in the amalgam, a clean dropping-tube about 10 cms. long, drawn out to a fine point, should be used. Its lower end is brought under the surface of the amalgam heated in a porcelain dish, and some of the amalgam is drawn into the tube by means of the rubber bulb. The point is then quickly cleaned of dross with filter paper, and is passed through the wider tube to the bottom, and emptied by pressing the bulb. The point of the tube must be so fine that the amlagam will come out only on squeezing the bulb. This process is repeated until the limb contains the desired quantity of the amalgam. The vessel is then removed from the water-bath. After cooling, the amalgam must adhere to the glass, and must show a clean surface with a metallic luster.

For insertion of the mercury, a dropping-tube with a long stem will be found convenient. The paste may be poured in through a wide tube reaching nearly down to the mercury and having a funnel-shaped top. If the paste does not run down freely it may be pushed down with a small glass rod. The paste and the amalgam are then both covered with the zinc sulphate crystals before the concentrated zinc sulphate solution is poured in. This should be added through a small funnel, so as to leave the neck of the vessel clean and dry.

For convenience and security in handling, the cell may be mounted in a suitable case so as to be at all times open to inspection.

In using the cell, sudden variations of temperature should, as far as possible, be avoided, since the changes in electromotive force lag behind those of temperature.

CHAPTER III.

DESCRIPTION OF INSTRUMENTS.

Although no attempt will be made here to fully describe all the different instruments used in electrical testing, some of the more important will be named and the more common uses to which they may be put mentioned.

The four essential instruments for all electrical testing of which all other instruments are but variations, are: the *battery*, the *galvanometer*, the *resistance-box*, and the *condenser*, and following will be found a concise description of the more important types of each.

BATTERIES.

These in their different forms are used as a source of current, not only for testing, but for many other purposes where smaller currents than those supplied by dynamos are required.

Batteries are of two kinds, — primary, in which the E.M.F. is generated by chemicals in the cell itself; and secondary, or storage, in which the electrical energy from some outside source is chemically stored in the battery, which becomes an independent source of current when the charging source is removed. Secondary batteries will be treated in a separate chapter.

The types of primary battery most commonly in use in America are the *gravity cell*, used mostly for telegraph and closed-circuit work; the *Lelanché cell*, used for ordinary open-circuit work, as for door bells, telephone bells and other signals; the *Fuller cell*, used for telephone and for telegraph purposes; the *chloride of silver cell*, used largely for testing-purposes, as it is small enough to enable a large number of individual cells to be grouped in a box convenient for carrying about; and the *Edison-Lalande cell*, useful in places requiring strong battery currents.

Another form of battery that has come extensively into use since about 1890 is the *dry battery*. This does not have the usual liquid solutions, but is partly filled with a substance that will hold the moisture for a considerable time. There are, therefore, no liquids to spill; and they make very handy sources of current for house bells, telephones, etc., where the users do not care to be bothered with creeping salts or any of the other troubles inherent in the common forms of liquid cells.

The Gravity Cell.

The elements are copper and zinc; the solution is sulphate of copper, or "bluestone," dissolved in water. The usual form (see Fig. 2) is a glass jar, about 8 inches high and 6 inches diameter. The copper is made of two or more layers fastened in the middle, spread out, and set on edge in the bottom of the cell, the terminal being a piece of gutta-percha insulated copper wire extending up through the solution.

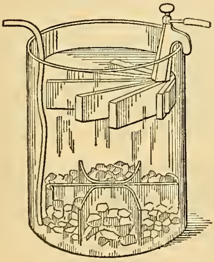


FIG. 2.

The zinc is usually cast with fingers spread out, and a hook for suspending from the top of the jar as shown, the terminal being on top of the hook. This form of zinc is commonly called "crowfoot," and the battery often goes by that name. Sometimes star-shaped zincs are suspended from a tripod across the top of the jar. The "bluestone" crystals are placed in the bottom of the jar about the copper, the jar then being filled with water to just above the "crowfoot" or zinc. A tablespoonful of sulphuric acid is added. A saturated solution of copper sulphate forms around the copper; and, after use, a zinc sulphate solution is formed around the zinc, and floats upon the copper sulphate solution. The line of separation between the two solutions is called the *blue line*. As the two solutions are kept separate because of their different specific gravities, the name "gravity cell" is employed.

This cell does not polarize, and the E.M.F. is practically constant or uniform at about 1 volt on a closed circuit. If the circuit is not closed, and the cell does not have work enough to prevent mixing of the two solutions, the copper sulphate coming in contact with the zinc will become decomposed; the oxygen forming oxide of zinc, and the copper depositing on the zinc having an appearance like black mud.

Care of the Gravity Cell. — For ordinary "local work" about three pounds of "bluestone" per cell is usually found best. When this is gone it is better to clean out the cell, and supply new solution, than to try to replenish. "Bluestone" crystals should not be smaller than a pea nor as large as an egg. In good condition the solution at the bottom should be a bright blue, changing to water-color above. A brownish color in any part denotes deterioration.

To prevent evaporation of the solution it is well to pour a layer of good mineral oil over the top when the cell is first set up. This oil should be odorless, free from naphtha or acid, and non-inflammable under 400° F. If oil is not used, dipping the top of the jar in melted paraffin for about an inch, will prevent the salts of the solution from climbing over the edge. In starting a new battery it is best to short circuit the cells for twenty-four or forty-eight hours to form zinc sulphate and lower the internal resistance. The internal resistance of the ordinary gravity cell is 2 to 3 ohms, depending on a number of conditions, such as the size of plates, the nearness together, and the nature of the solution.

Never let the temperature of gravity cells get below 65° or 70° F., as the internal resistance increases very rapidly with a decrease in temperature.

The Leclanché Cell.

This cell is one of the most commonly used outside of telegraphy, and up to the advent of the so-called dry cell was practically the only one in use for house and telephone work. The elements are zinc and carbon, with peroxide of manganese about the carbon plate for a depolarizing agent. As usually constructed — for there are many modifications of the type — the jar is of glass, about 7 inches high and 5 inches in diameter, or sometimes square. The zinc is in the form of a stick, about a half inch diameter, by 7 inches long, and is placed in one corner of the jar in a solution of sal-ammoniac. The carbon plate is placed in a porous cup within the jar, and the space around the carbon in the cup is filled with small pieces of carbon and granulated peroxide of manganese. The sal-ammoniac solution passes through the porous cup and moistens the contents. This cell will polarize if worked hard or short circuited, but recuperates quickly if left on open circuit for a while. The resistance of the Leclanché cell varies with its size and condition, but is generally less than one ohm. The initial E.M.F. is about 1.5 volt. It is desirable not to use too strong a solution of sal-ammoniac, as crystals will be deposited on the zinc; and not to let the solution get too weak, as chloride of zinc will form on the zinc; both conditions will materially increase the internal resistance of the cell, and impair its efficiency. Without knowing the dimensions of cells it is not possible to state the amount of sal-ammcniac to use; but perhaps as good a way as any is to add it to the water until no more will dissolve, then add a little water so that the solution will be weaker than saturation. Keep all parts clean, and add sal-ammoniac and water when necessary.

Chloride of Silver Cell.

The elements of this cell are a rod of chemically pure zinc, and a rod of chloride of silver in a water solution of sal-ammoniac.

As ordinarily constructed the jar is of glass, about 2½ inches long by ¾ inch diameter, with the zinc and silver rods set in as per Fig. 3. The solution is poured in, and a plug of paraffin wax hermetically seals the jar. Suitable terminals are cast in or secured to the rods. As the greatest use made of these cells is for testing purposes in connection with a galvanometer, they are usually arranged in groups in a case, with terminals so arranged as to allow the use of as many as may be necessary for any particular test. Fig. 4 shows a portable testing-battery of 50 chloride of silver cells, with attaching plugs and reversing-key. The E.M.F. of the chloride of silver cell is 1.03 volts, and the internal resistance varies with age, being about 4 ohms at first. Care should be taken not to short circuit these cells, as they are weakened thereby; and where they are much used, frequent tests of individual cells for E.M.F. should be made; they will vary considerably.

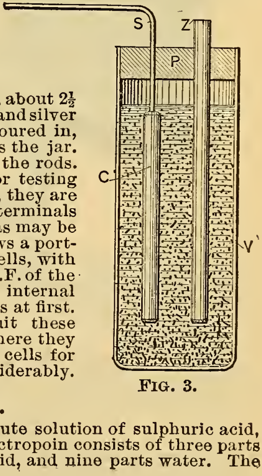


FIG. 3.

Fuller Cell.

The elements of this cell are zinc in a dilute solution of sulphuric acid, and carbon in a solution of electropoin. Electropoin consists of three parts bichromate of potash, one part sulphuric acid, and nine parts water. The

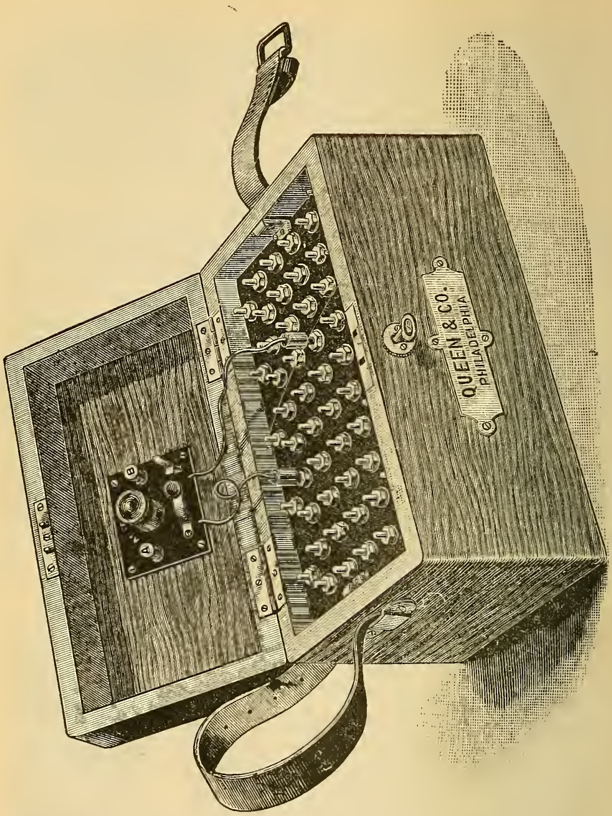


FIG. 4. Chloride of Silver Cells.

zinc plate is in the form of a cone, and is placed in the bottom of a porous cup inside a glass jar. The carbon plate is outside the porous cup.

About two ounces of mercury are placed in the porous cup with the zinc, for amalgamation, and the cup is filled with a dilute solution of sulphuric acid. The outside jar is filled with the electropoin. In this the carbon plate is immersed.

The E.M.F is 2 volts, and the internal resistance is about half an ohm. The solution is originally of an orange color. When this becomes bluish in tint, add more crystals. Should the color be normal and the cell be weak, add fresh sulphuric acid.

Edison-Lalande Cell.

The elements of this cell (see Fig. 5) are zinc, and copper oxide in a water solution of caustic potash. The plates are suspended side by side from the cover of the jar. The copper oxide, which is plated with a thin film of metallic copper to reduce the resistance when the cell is first started, is held in a frame attached to the cover. A layer of oil is poured on top of the solution to prevent creeping salts. The E.M.F. is low, starting at .78 volt, and after working for a time it decreases. The internal resistance is also low, being about .025 ohm for the largest cell. Very strong currents can be taken from this cell: for instance the cell having an E.M.F. of .75 volt and resistance of .025 ohm will produce 30 amperes on short circuit. The makers advise, in setting up the cell, that only one half of the sticks of caustic potash be placed in the jar first, and that water be then poured in up to within about an inch of the top of the jar. Then stir until the potash is dissolved, when one may add the remainder of the potash sticks, stirring as before.

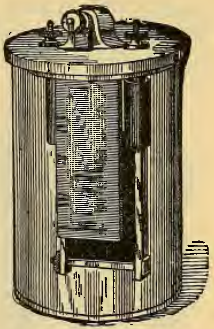


FIG 5.

Dry Batteries.

The general appearance of a cell of dry battery is shown in Fig. 6, and the construction varies slightly in the different makes. *The Burnley dry cell* is made of a zinc tube (see Fig. 6) as one element, which acts also as the containing jar, a carbon cylinder is the negative element, and an exciting solution composed of 1 part sal-ammoniac, 1 part chloride of zinc, 3 parts plaster, .87 parts flour, and 2 parts water. In constructing the cell a plunger somewhat larger than the carbon element is placed in the middle of the zinc jar, and the above solution mixture poured in around it, quickly becoming stiff, after which the plunger is withdrawn, the carbon inserted in place, and the surrounding space filled with another mixture consisting of 1 part sal-ammoniac, 1 part chloride of zinc, 1 part peroxide of manganese, 1 part granulated carbon, 3 parts plaster, 1 part flour, and 2 parts water. After the ingredients are all in place the top is sealed with bitumen or other suitable compound. A terminal is fastened to the zinc cup, and another to the carbon plate. The E.M.F. of the Burnley cell is 1.4 volt; the internal resistance about .3 ohm, and it gives practically constant E.M.F. during its life. *The Gasner dry cell*, shown in Fig. 7, consists of a zinc cup as the positive

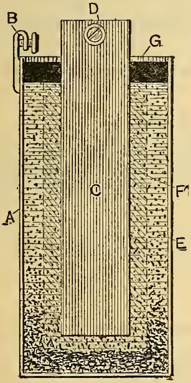


FIG. 6.

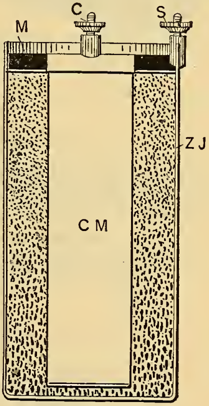


FIG. 7.

element, a cylinder composed of carbon and manganese for the negative element, and an exciting solution which becomes comparatively hard, made up of the following ingredients, viz.: 1 part by weight of oxide of zinc, 1 part sal-ammoniac, 3 parts plaster, 1 part chloride of zinc, and 2 parts water. The E.M.F. and resistance are about the same as for the cell last described.

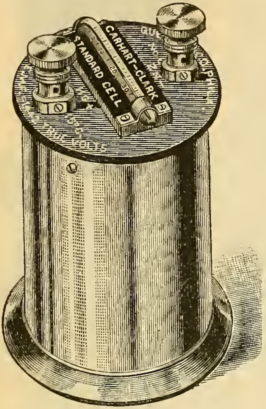


FIG. 8. Carhart Clark Standard Cell.

Standard Cells.

Clark Cell.—The form of cell called Clark, specifications for making which will be found in the chapter on units, is the one most used for a standard of E.M.F. The positive element is mercury, and the negative is amalgamated zinc, the electrolytes being saturated solutions of sulphate of zinc and mercurous sulphate.

At 15° C. the E.M.F. is 1.434 volt, and between the points 10° and 25° C., the increase of 1° C. decreases the E.M.F. .00115 volt.

Carhart-Clark Cell.—This cell has the same elements as Clark, but the solution of zinc sulphate is saturated at 0° C. The E.M.F. is 1.440 volt, and the temperature coefficient about half that of the Clark cell.

Weston Standard Cell.—The elements are mercury and cadmium amalgam in a saturated solution of cadmium sulphate. The E.M.F. is 1.019 to 1.022 volt, and the temperature coefficient 0.01 per cent per degree centigrade. These cells remain constant over long periods. Observations extending over several months showed a variation of less than 0.0001 volt.

Arrangement of Battery Cells.

Series.—When it is desired to obtain an E.M.F. greater than that of one cell, two or more are connected together in series; that is, the positive terminal of one cell is connected to the negative terminal of the next, and so on until the number of cells required to produce the E.M.F. wanted are connected. For example, the E.M.F. of one cell of Leclanché is 1.47 volt, then 10 cells connected in series as in Fig. 9 would give an E.M.F. at the extreme terminals of 14.7 volts.

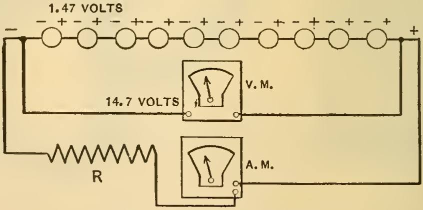


FIG. 9. Battery Cells in Series.

Multiple.—If it be desired to obtain more current strength, i.e., more amperes without change of E.M.F., then more cells must be placed along side the others, that is, in parallel with the first row; each row or series of cells producing the same E.M.F. and joined together at the ends, positive terminals to positive terminals, and negative to negative, adding their currents together at the same E.M.F. as in Fig. 10 below.

If still more current strength be needed, another series of cells may be added, and their current added to the circuit, making three times the current of one series.

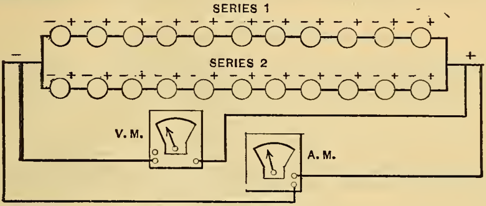


FIG. 10. Battery Cells in Multiple.

The reason for this is, that when two or more resistances are placed in parallel or multiple, the equivalent resistance is decreased, as is shown in another chapter. If the resistance of one series be 10 ohms, the resistance of two series in multiple would be one-half of ten, or 5 ohms; that of three series in parallel, one-third, or 3.33 ohms; and of four series, 2.5 ohms.

Let $E =$ E.M.F. of a single cell,
$r =$ internal resistance of one cell,
$R =$ external resistance in a circuit.

Then for n cells arranged in *series*, the current which will flow will be represented by the formula,

$$I = \frac{nE}{nr + R} = \frac{E}{r + \frac{R}{n}}.$$

If R is very small as compared with nr, then $I = \frac{E}{r}$, or the current is the same as that from one cell on short circuit.

If, as in telegraph work, nr is very small as compared with R, then $I = \frac{nE}{R}$, or the current increases in proportion to the number of cells.

The value of r is nearly inversely proportional to the area of the plates when fronting each other in the liquid, and directly as their distance apart. Therefore, if the area of the plate is increased a times, for one cell

$$I = \frac{E}{\frac{r}{a} + R} = \frac{aE}{r + aR}.$$

Let $N =$ the total number of cells in the battery,
$n_s =$ number of cells in each series,
$n_p =$ number of sets or series in parallel.

Then the internal resistance of the whole battery

$$= \frac{n_s r}{n_p}.$$

To find the best arrangement of a given number of cells (N) to obtain a maximum current (I) working through an external resistance (R), make $\frac{n_s r}{n_p} = R$, or the internal resistance of the whole battery equal to R.

In any circuit $I = \frac{\text{total E.M.F.}}{\text{total resist.}}$, and for any arrangement

$$I = \frac{n_s E}{\frac{n_s r}{n_p} + R} = \frac{n_p n_s E}{n_s r + n_p R}.$$

When arranged for maximum current through a given external resistance R,

$$n_s = \sqrt{\frac{NR}{r}} \text{ and } np = \sqrt{\frac{Nr}{R}}.$$

To find the greatest current that can be obtained from a given number of cells (N) through a given external resistance (R),

$$I = \frac{E}{2}\sqrt{\frac{N}{Rr}}.$$

To find the number of cells in series (n_s) and in parallel (n_p) required to give a current (I) through an external resistance (R) and to have an efficiency (F).

$$\text{Efficiency } F = \frac{\text{External work}}{\text{Total work}}$$

$$= \frac{I^2 R}{I^2\left(\frac{n_s r}{n_p} + R\right)} = \frac{R}{\frac{n_s r}{n_p} + R}.$$

The internal resistance of the whole battery is

$$\frac{n_s r}{n_p} = \frac{R(1-F)}{F}$$

and

$$I = \frac{n_s E F}{R}$$

$$n_s = \frac{IR}{EF}$$

$$n_p = \frac{Ir}{E(1-F)}.$$

GALVANOMETERS.

These are instruments for measuring the magnitude or direction of electric currents. The term galvanometer can also be properly applied to the many types of indicating instruments, such as voltmeters and ammeters, where a needle or pointer is under the influence of some directive force, such as the earth's field, a spring, a weight, a permanent magnet, or other means, and is deflected from zero by the passing of an electric current through its coils.

Nearly all galvanometers can be separated into two classes. The first is the *moving-needle* class. A magnetized needle of steel is suspended with its axis horizontal so as to move freely in a horizontal plane. The suspension is by means of a pivot or fiber of silk, of quartz, or of other material. The needle normally points in a north and south direction under the influence of the earth's magnetic field, or in the direction of some other field due to auxiliary magnets. Near to the needle, and frequently surrounding it, is placed a coil of wire whose axis is at right angles to the normal direction of the needle. When a current is passed through the coil the needle tends to turn into a new position, which lies between the direction of the original field and the axis of the coil.

The second class is the *moving coil* or d'Arsonval class. A small coil is suspended by means of a fine wire between the poles of a magnet. Its axis is normally at right angles with the lines of the field. Current is led into the coil by means of the suspension wire, and leaves the coil by a flexible wire attached underneath it.

The *figure of merit* of a galvanometer is (a) the current strength required to cause a deflection of one scale division; or (b) it is the resistance that must be introduced into the circuit that one volt may cause a deflection of one scale division. This expression for the delicacy of a galvanometer is insufficient unless the following quantities are also given: the resistance of the galvanometer, the distance of the scale from the mirror, the size of the scale divisions, and the time of vibration of the needle.

The *sensitiveness* of a galvanometer is the difference of potential necessary to be impressed between the galvanometer terminals in order to produce a deflection of one scale division.

Moving-Needle Galvanometers.

(*a.*) *The Tangent Galvanometer.* If the inside diameter of the coil which surrounds a needle, held at zero by the earth's field, be at least 12 times the length of the needle, then the deflections of the needle which correspond to different current strengths sent through the coils, will be such that the current strengths will vary directly as the tangents of the angles of deflection. Such an instrument is called a tangent galvanometer. It was formerly much used for the absolute measurement of current. It has, however, many correction factors, some of which are of uncertain magnitude; and, furthermore, for accuracy in the results yielded by it one must have an exact knowledge of the value of the horizontal component of the earth's magnetism. This quantity is continually changing, and is affected much by the presence of large masses of iron and the existence of heavy currents in the vicinity.

Let $r =$ the radius of a tangent galvanometer coil, in centimeters
$n =$ the number of turns in the coil,
$H =$ the horizontal intensity of the earth's magnetism,
$I =$ the current flowing in the coil in absolute units, and
$\theta =$ the deflection of the needle, then

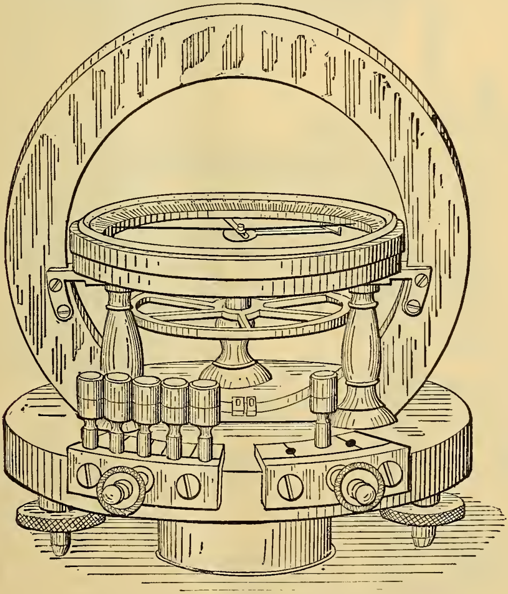


FIG. 11. Tangent Galvanometers.

$$I = \frac{r}{2\pi n} H \tan \theta.$$

For convenience the term $\frac{2\pi n}{r}$ i.e., the strength of the field produced at the center of the coil by the unit of current, is called the *constant* of the galvanometer, and is represented by G, whence

$$I = \frac{H}{G} \tan \theta$$

The current in amperes equals 10 I.

(*b.*) *Thomson Galvanometers.* The most sensitive galvanometers made are of a type due to Lord Kelvin. Fig. 12 shows one form of this instrument. The moving system consists of a slender quartz rod, to the center of which is fastened a small glass mirror. Parallel to the plane of the mirror, and at one end of the quartz tube, is fastened a complex of carefully selected minute magnetic needles. The north ends of those needles all point in the same direction. At the other end of the quartz tube is fastened a similar complex with the polarity reversed. Were the two complexes of exactly equal magnetic moment, then, when suspended in the earth's field, no directive action would be felt. In fact, this action is very small. The combination forms what is called an *astatic* system. Each magnetic complex is inclosed between two wire coils. The four coils are supplied with binding-posts, so as to permit of connection in series or in parallel. Current is sent through them in the proper direction, to produce in each case deflections the same way. Quartz fiber, which exhibits no elastic fatigue and which is very strong, is used as a suspension. An adjustable magnet is mounted on the top of the galvanometer. By means of it the directive action of the earth's field can be modified to any extent. Under weak directive force the sensitiveness increases greatly, and the period of oscillation of the needle becomes long. The limit of sensitiveness is largely influenced by the patience of the observer.

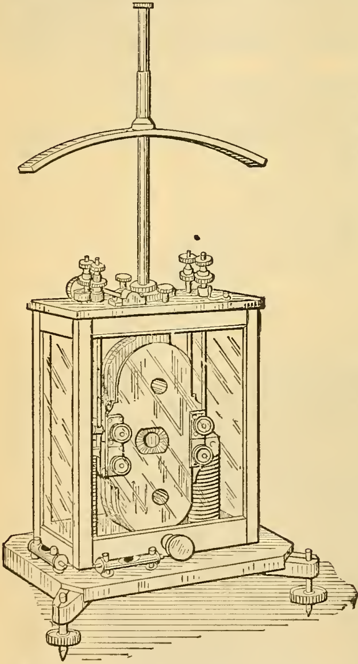


FIG. 12. — Thomson Reflecting Astatic Galvanometer with Four Coils

For very precise work the deflections of the needle are observed by means of a telescope and scale. Fig. 13 shows such an instrument. The moving mirror reflects an image of the scale into the objective of the telescope. Continuous work with the telescope is apt to injure the eyes, and is certainly tiresome. Where much galvanometer work is being done by the same person, a ray of light from a small electric, gas, or oil lamp is so directed as to be reflected from the mirror on the needle upon a divided scale. Such a lamp and scale is shown in Fig. 14. In order to bring the needle quickly to rest when under the in-

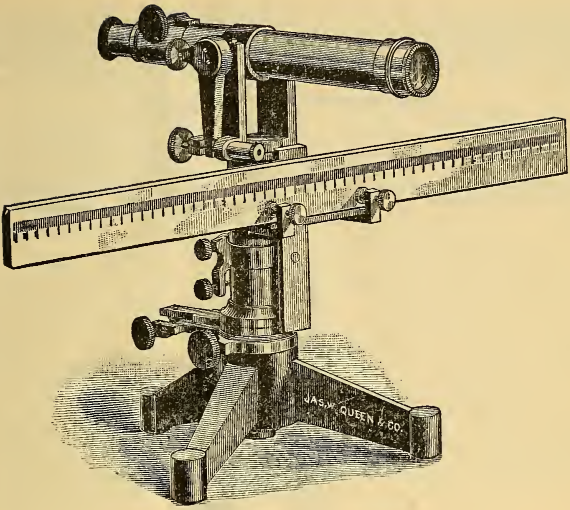


FIG. 13.

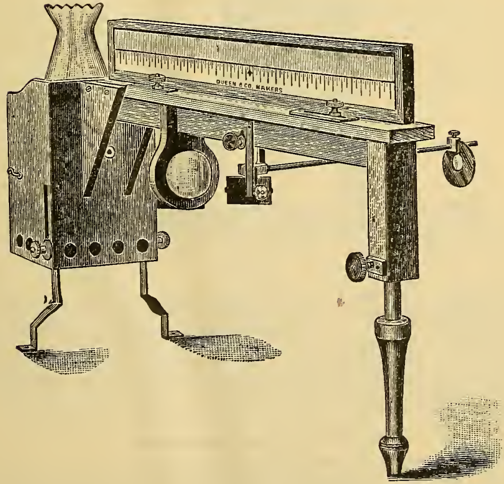


FIG. 14.

fluence of a current, some method of damping must be employed. One method is to attach a mica vane to the moving system, and allow it to swing in an inclosed chamber which contains air or oil. Sometimes the moving needle is inclosed in a hollow made in a block of copper. The eddy currents induced by the moving needle react upon it and stop its swinging.

Moving-Coil Galvanometers.

These galvanometers are to be preferred in all cases except where the utmost of delicacy is required. In the most sensitive form, with permanent magnetic field, they can be made to deflect one millimeter with a scale distance of one meter, when one microvolt is impressed between the terminals of the coil. This is sufficient for nearly all purposes. The sensitiveness can be further increased by using an electromagnetic field. The moving-coil form of galvanometer has the following good points: its readings are but slightly affected by the presence of magnetic substances in the vicinity, and are practically independent of the earth's field; the instrument can be easily made dead-beat; and many forms are not much affected by vibrations. Fig. 15 shows a form of D'Arsonval galvanometer of high sensibility. The coil (shown at the right) is inclosed in an aluminum tube. Eddy currents are induced in this tube when the coil swings. They cause damping, and, with a proper thickness of tube, the system may be made aperiodic.

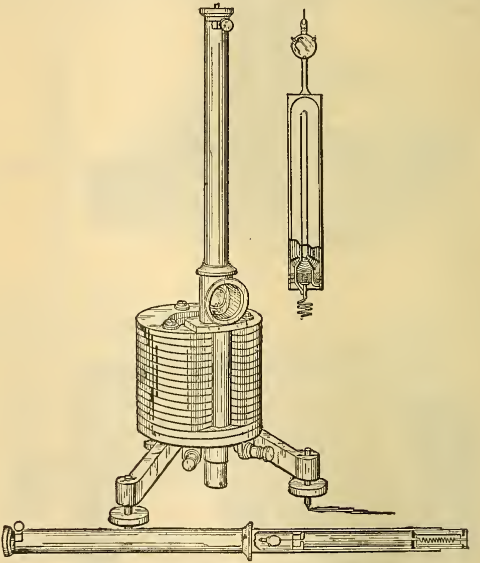


FIG. 15.

Ballistic Galvanometers.

Galvanometers are also used for measuring or comparing quantities of electricity such as flow in circuits when a condenser is discharged or magnetic flux linkages are disturbed. The time of oscillation of the needle must in such cases be long as compared with the duration of the discharge. If there be no damping of the needle the quantities of electricity are proportional to the sines of half the angle of the first throws of the needle. All galvanometers have some damping. The comparison of quantities of electricity can easily be made with galvanometers of moderate, or even strong damping. Absolute determination of quantity by means of the ballistic galvanometer requires great experimental precautions. (See the *Galvanometer*, by E. L. Nichols.)

Voltmeters.

These are indicating instruments which show the pressure impressed upon their terminals. They are in nearly all cases galvanometers of practically constant high resistance. Through them flow currents which are directly proportional to the impressed voltages. A pointer, connected to the moving element, moves over a scale which is empirically graduated to correspond with the impressed voltages. The resistances of commercial voltmeters in ohms run from 10 to 150 times the full scale readings in volts. Thus a 150-volt voltmeter may have a resistance of from 1500 to 22,500 ohms. The directive forces to bring the needle back to zero are generally obtained from springs, gravity, or magnets. Moving-coil instruments can be made so as to have high resistances and perfect damping. Moving-needle instruments are in common use for alternating current circuits. The needle is of soft iron, and is given an alternating polarity by the currents flowing because of the impressed voltages, which are being measured. Hot-wire voltmeters form a distinct class of instruments. The expansions of a wire as a result of the passage of different currents of electricity are taken up by a spring. A pointer connected with the spring moves over an empirically divided scale. These instruments have a lower resistance per volt than the other types. They are quite dead beat. They record either alternating or direct currents.

Ammeters.

The scale of a voltmeter might be graduated and marked so as to indicate the currents passing through it instead of the volts impressed upon its terminals. It would then be an ammeter. To be of value its resistance must be small. Many ammeters consist of millivoltmeters connected to the terminals of shunts through which the currents to be measured are passed. The scales are graduated so as to indicate the currents passing through the shunts. The shunt type of instrument is particularly applicable to switchboards.

Northrup's Oscillating Current Galvanometer.

From catalogue of James G. Biddle.

The working of this instrument depends upon the principle that when a metallic disk is suspended in a coil, the plane of the disk making with the plane of the coil an angle of about 45° the disk will tend to rotate, when alternating currents are sent through the coil, so as to increase this angle.

The instrument is constructed to be exceedingly sensitive, to have a minimum of self-inductance, and practically no capacity. The disk is made of pure silver, about $\frac{1}{64}''$ thick and 9 mm. in diameter. Three coils are furnished with each instrument. One coil has about 20 turns of No. 20, one about 40 turns of No. 42, and one about 100 turns of No. 36 B & S copper wire. Each coil is wound in two halves, so that the silver disk may be dropped down through the suspension tube and between the two halves of the coil. The inside diameter of the coils is about 1 mm. greater than the diameter of the disk. On either side of the hard-rubber upright piece which supports the coils are the poles of a permanent magnet. The coils are set at an angle of 45° to the line joining the two poles, and the silver disk hangs so that its plane is in this line.

The silver disk is fastened upon a light glass stem which carries a very small and thin mirror. This system is suspended upon an exceedingly fine quartz fiber. The complete period of swing of the system is about 12 seconds, and the magnet quickly dampens the oscillations to zero. For small angles the deflections are proportional to the square of the current and to its frequency. Hence as long as the frequency remains constant two currents are to each other as the square roots of the respective deflections indicating them.

This instrument replaces and is far superior to the telephone in all cases where feeble, rapidly varying currents are to be detected or compared.

The telephone fails to be of service when the frequency of the currents becomes very great; the present instrument responds to currents of any frequency, including such as are set up in a Hertzian resonator. Since the self-induction of the instrument is very minute, it can be connected in series with any circuit in which rapidly oscillating currents are passing, without appreciably changing their frequency. The instrument, therefore, serves in the performance of many Hertzian experiments.

Galvanometer Shunt Boxes.

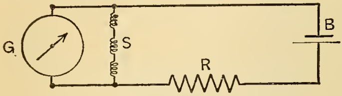


FIG. 16.

It is often desirable to use a galvanometer of high sensibility for work demanding a much lower sensibility. Again, it may be convenient to calibrate a galvanometer of low sensibility, while it would be inconvenient to calibrate a more sensitive one It is therefore useful to be able to change the sensibility in a known ratio. Convenience dictates that simple ratios be used, and those almost universally taken are 10, 100, and 1000; that is $\frac{1}{9}$, $\frac{1}{99}$, or $\frac{1}{999}$, part of the current flowing is allowed to go through the galvanometer while the remainder is diverted through a shunt. In Fig. 16 let

G = the resistance of the galvanometer, and
S = the resistance of the shunt,

then the joint resistance of the two is $\frac{G\ S}{G + S}$.

If I = the total current flowing in the circuit, and
if I_1 = the part flowing through the galvanometer,
then $\frac{I}{I_1} = \frac{G + S}{S} = \frac{G}{S} + 1 =$ the *Multiplying power* of the shunt.

The resistance of a shunt which will give a certain multiplying power, n, is equal to $\frac{G}{n - 1}$. Fig. 17 shows a form of shunt used with a galvanometer, although it is perfectly feasible to use an ordinary resistance box for the purpose. Messrs. Ayrton & Mather have developed a new shunt, which can be used with any galvanometer irrespective of its resistance: following is a diagram of it.

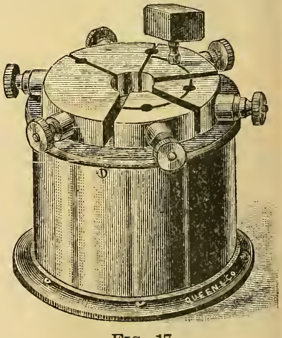


FIG. 17.

A and B are terminals for the galvanometer connections. B and C are the ingoing and outgoing terminals for battery circuit. To short circuit G, place plugs in j and f. To throw all the current through G, put a plug in f only. To use the shunts, place a plug in h, and leave it there until through using. In this method it is not necessary to know the resistance of either G or r. The shunt box can therefore be used with any galvanometer. Temperature variations make no difference, provided they do not take place during one set of tests. The resistance r may be any number of ohms, but in order not to decrease the sensibility too much r should be at least as large as G. The resistance r is divided for use as follows: permanent attachments to the various blocks are made at points in the coil corresponding with $\frac{r}{1000}$, $\frac{r}{100}$, $\frac{r}{10}$ ohms.

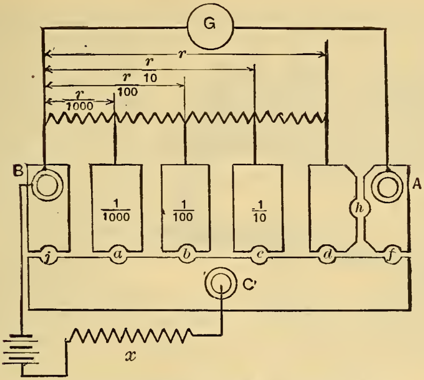


FIG. 18. Ayrton & Mather's Universal Shunt.

RESISTANCES.

The unit of resistance, the international ohm, is represented by the resistance of a uniform column of mercury 106.3 cm. long and 14.4521 grammes in mass, at 0° C; but in practice it is not convenient to compare resistances with such a standard, and therefore secondary standards (Fig. 19) of resistance are made up, and standardized with a great degree of precision. These secondary standards are made of wire. The material must possess permanency of constitution and of resistivity, must have a small temperature coefficient of resistivity, must have a small thermo-electric power when compared with copper, and should have a fairly high resistivity. Manganin when properly treated possesses all of these qualities. Platinoid is also frequently used. An assemblage of standards of various convenient magnitudes in a single case is called a resistance box, or rheostat.

The form of resistance box most frequently met with is some type of "Wheatstone's bridge," the theory of which is described elsewhere.

The coils are usually of silk insulated wire wound non-inductively on spools, with the ends attached to brass blocks, so arranged that brass plugs can be inserted in a hole between two blocks, thus short circuiting the resistance of the particular bobbin over which the plug is placed. By non-inductive winding is meant that the wire is first doubled, then the closed end is placed on the bobbin and the wire wound double about the bobbin. By this method any electromagnetic action in one wire is neutralized by an equivalent action in the other, and there is no inductive effect when the circuit is opened or closed.

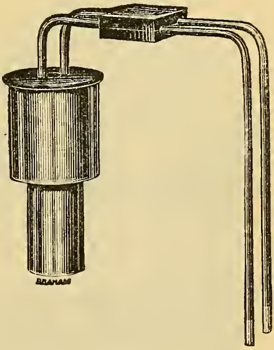


FIG. 19.

The Post-office bridge, Figs. 20 and 21, is one of the most convenient forms. One arm of the bridge has separate resistances of the following values: 1, 2, 3, 4, 10, 20, 30, 40, 100, 200, 300, 400, 1000, 2000, 3000, and 4000 ohms.

Another arm is left open for the unknown resistance, x, which is to be measured. The remaining two arms each have three resistance coils of 10, 100, and 1000 ohms respectively. Two keys are supplied with the P.O. bridge, one for closing the battery circuit, and the other for closing the galvanometer circuit. The battery key should be closed first; and in some instruments the two keys are arranged with the battery key on top of the galvanometer key, so that but one finger and one pressure are necessary.

Prof. Anthony has devised a resistance box in which there are ten one ohm coils, 10 tens, 10 hundreds, and 10 thousands. Any number of any group can be connected either in series or in multiple. The means of accomplishing this are seen clearly in the cut.

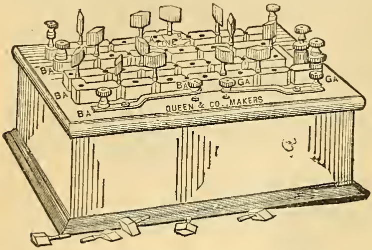


FIG. 20. Standard Resistance Coils with Wheatstone Bridge (Post Office Pattern).

Standard Low Resistances.

Resistances of the ordinary form, which are smaller than $\frac{1}{10}$ ohm, are very difficult to measure with great accuracy, owing to the uncertainty of the magnitude of the resistance of the leads and contact devices. Fortunately it is seldom that such a form of resistance is used. Instead, the resistance between two potential points on a properly shaped conductor is used. Such standard resistances of $\frac{1}{10000}$, $\frac{1}{1000}$, $\frac{1}{100}$, etc., ohms are now on the market, and are known as the Reichsanstalt form. They are made to carry very heavy currents. Fig. 23 shows such a resistance supplied with heavy contact terminals and a cooling coil. When this resistance is carrying a current, the drop between the two small terminals is such as would result from passing the same current through $\frac{1}{10000}$ ohm.

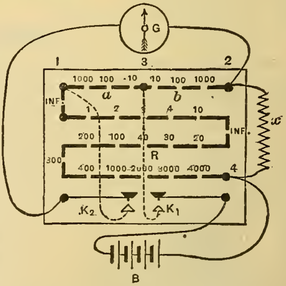


FIG. 21.

CONDENSERS.

If one terminal of a source of E.M.F. be connected to a conductor, and the other terminal be connected to another conductor adjacent to the first but insulated from it, it will be found that the two conductors exhibit a capacity for absorbing a charge of electricity that is somewhat analogous to the filling of a pipe with water before a pressure can be exerted. The charge will remain in the conductors after the removal of the source of supply. This capacity of the conductors to hold under a given E.M.F. a

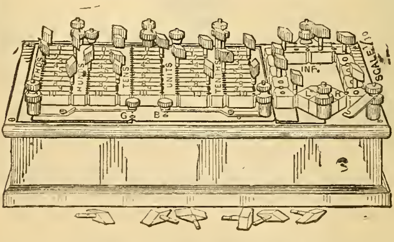


FIG. 22 Standard Resistance Coils with Wheatstone Bridge (Anthony Form).

charge of electricity is governed by the amount of surface exposed, by the nearness of the surfaces to each other, by the quality of the insulating material, and by the degree of insulation from each other. If the terminals of a battery be connected, through a battery and sensitive galvanometer, to a long submarine cable conductor and to the earth, it will be found that a very considerable time will elapse before the needle will settle down to a steady point. This shows that the cable insulation has been *filled* with electricity; and it is common in so measuring the insulation resistance of a cable to assume a standard length of time, generally three minutes, during which time such electrification shall take place.

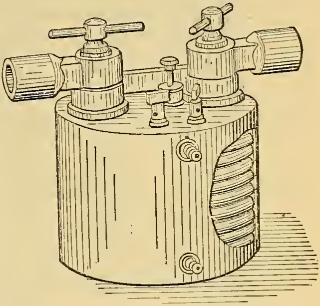
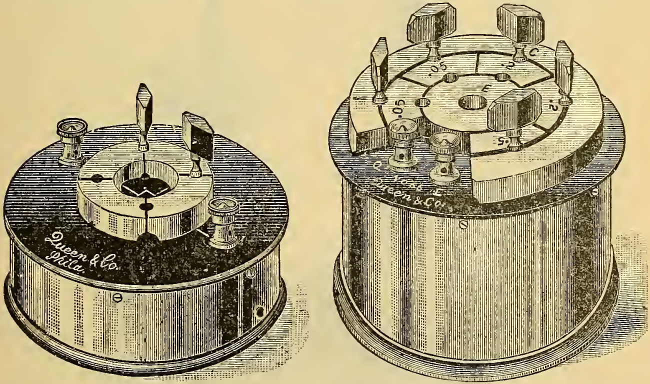


FIG. 23.

A *condenser* is an arrangement of metallic plates and insulation so made up that it will take a standard charge of electricity at a certain pressure. The energy represented by the charge seems to be stored up in the insulation between the conducting plates in the form of a stress. This property of insulating materials to take on a charge of static electricity is known as *inductive capacity*, and a table in the section on the testing of capacity shows the specific inductive capacities of different substances.

The unit of *capacity* is the international *farad*, which is defined as the capacity of a condenser which requires one coulomb (1 ampere for 1 second) to raise its potential from zero to one volt.



FIGS. 24 and 25. Queen Standard Condensers.

As the *farad* is far larger than ever is met in practice, the practical unit is taken as one-millionth farad or the micro-farad.

The commercial standard most in use is the $\frac{1}{3}$ micro-farad, although adjustable condensers are often used, arranged so as to combine into many micro-farads or fractions of the same. Fig. 24 shows the ordinary $\frac{1}{3}$ micro-farad condenser, and Fig. 25 one that is adjustable for different values. Diagram 26 shows an outline of the connections inside an adjustable condenser. The ordinary commercial condenser is most usually made up of

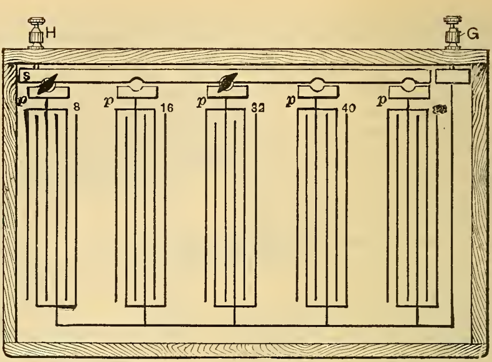


FIG. 26.

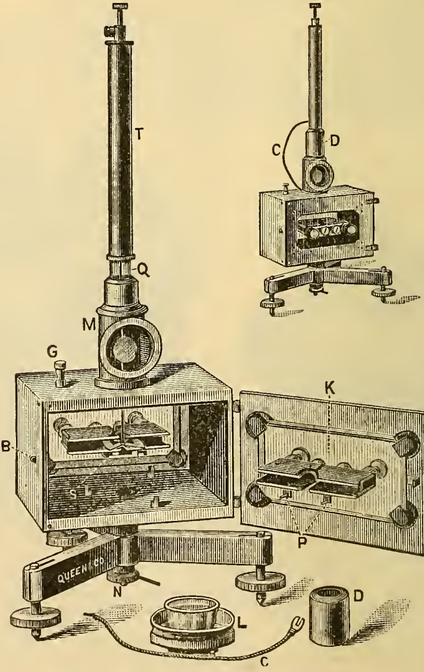


FIG. 27. Modified Mascart Electrometer.

sheets of tin foil separated from each other by some insulator such as paraffined paper or mica. Every alternate sheet of foil is connected to a common terminal. As the capacity of a condenser depends upon the nearness of the conductors to each other, and upon the area of the same, the insulating material is made as thin as possible, and still be safe from leakage or puncture. Many sheets of foil are joined together as described to make up the area. In adjustable condensers, the sheets are separated into bundles, and arranged so that any of them can be plugged in or out to add to or lessen the total capacity. If connected in multiple as shown, or if the positive side of one condenser be connected to the negative side of another, or a number of them are thus added together, then the condensers are said to be arranged in "cascade" or in series. This is seldom done unless it be to obtain greater variation in capacity.

Electrometer. — Another instrument used somewhat in cable work, or where the measurement of electrostatic capacities or potentials is common, is the *electrometer*. A type of electrometer commonly used is the quadrant electrometer, for which we are indebted to Lord Kelvin. The needle is a thin, flat piece of aluminium suspended in a horizontal position by a thin metallic wire, in close proximity to four quadrants of thin sheet brass, that are supported on insulators without touching each other. Opposite quadrants are connected by fine wires. A charge of electricity is given the needle by connecting the suspension filament with a Leyden jar or other condenser.

If the needle be charged positively it will be attracted by a negative charge and repelled by a positive charge. If, therefore, there be a difference of potential between the pairs of quadrants, the needle will be deflected from zero. The usual mirror, scale, and lamp are used with this instrument, as in the case of the reflecting galvanometer. A form is shown in Fig. 27.

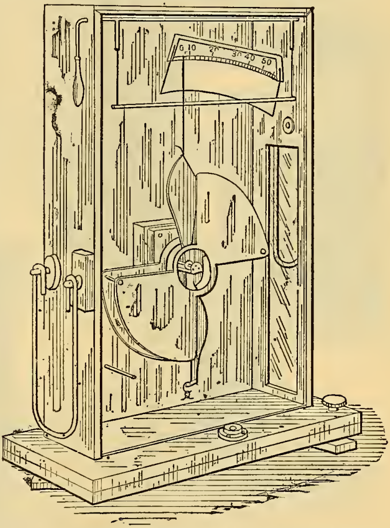


FIG. 28. Kelvin's Electrostatic Voltmeter.

Electrostatic Voltmeter.

A modification of the electrometer, used for indicating high, and in some cases low, alternating current potentials is the electrostatic voltmeter of Lord Kelvin. It is constructed on the principle of an air condenser.

In the high potential instrument, Fig. 28, the needle is made of a thin aluminium plate suspended vertically on delicate knife-edges, with a pointer extending from the upper part to a scale.

On either side of the needle, and parallel to its face, are placed two quadrant plates metallically connected and serving as one terminal of the circuit to be measured, while the needle serves as the other and opposite terminal. Any electrical potential difference between the needle and the plates will deflect the needle out of its neutral position. Calibrated weights can be hung on the bottom of the needle to change the value of the scale indications.

In the multicellular voltmeter, see Fig. 29, the needle consists of a number of thin plates, suspended horizontally and between corresponding quad-

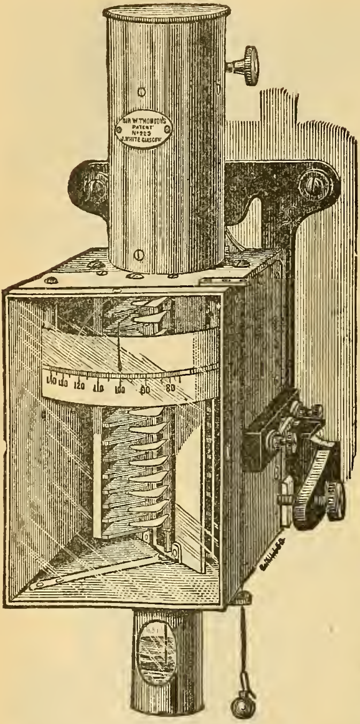


FIG. 29. Another Form of Lord Kelvin's Electrostatic Voltmeter.

rant plates, thus multiplying the force tending to deflect the needles, and serving to indicate lower potential differences than the form described above is capable of.

THE ELECTRO-DYNAMOMETER.

If currents be sent through two coils of wire, which are capable of movement as regards each other, they will tend to place themselves in such a position as to bring the lines of force of their magnetic fields parallel to each other and in the same direction. The Siemen's electrodynamometer acts according to this principle.

Fig. 30 below shows the form most used in the United States. It consists of a fixed coil usually having two divisions, — one of a few turns of heavy wire for heavy currents, and another of many turns of finer wire for smaller currents. Outside of this fixed coil, and at right angles thereto, is suspended a movable coil of few turns. A carefully wound helical spring joins the movable coil to a torsion screw above the dial. A pointer on this torsion screw shows on the dial the degrees of angle through which it may be twisted. The lower ends of the movable coil dip into mercury cups to make connection with the fixed coil. If current flows through the two coils in series, the movable coil is turned from its position at right angles with the fixed coil, and tries to arrange itself in the same plane as the latter, according to law above.

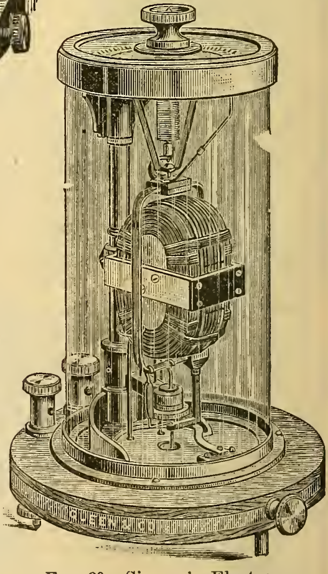


FIG. 30. Siemen's Electro-Dynamometer.

The torsion screw is then turned in the opposite direction until the force of the spring overcomes the electrodynamic action of the coils, and the movable coil is brought to zero.

If A be a constant depending upon the character of the torsion spring, I be the current, and d be the angle of deflection of the torsion screw to return the movable coil to zero, then

$$I = A\sqrt{d}.$$

The electro-dynamometer is suited to measure alternating currents of ordinary frequencies.

Wattmeter.—If the movable coil be of very fine wire, and have a coil of very high and non-inductive resistance in series with it, and if the fixed coil be of heavy wire, then the instrument may be used for measuring the work of a circuit in watts, by connecting the fixed coil in series with the circuit under test, and the movable coil across the terminals of the circuit. In this case, if the voltage current be i_1, and the series current in the movable coil be i_2, then the power equals $K\, i_1 i_2$, where K is a constant of the instrument. The two currents are supposed to be in phase with each other. If the movable coil be not brought back to zero, but a pointer connected with it be permitted to move over a graduated scale, the scale can be calibrated directly in watts.

Weston's well-known wattmeter is constructed substantially on this principle.

In order that a wattmeter (electro-dynamometer) may be reliable for measuring alternate-current power, it is needful that the fine-wire circuit, which is to be connected as a shunt to the apparatus under measurement, should have as little self-induction as possible in proportion to its resistance. The latter may be increased by adding auxiliary non-inductive resistances. The instrument must itself be so constructed that there shall not be any eddy currents set up by either circuit in the frames, supports, or case; otherwise the indications will be false.

Kelvin's Composite Electric Balance.

This instrument is employed much as a standard for comparison of instruments used in all practical work for both continuous and alternating currents. It can be used as a voltmeter, ampere-meter, or wattmeter. The principle of its action is similar to that of the electro-dynamometer. The attraction and repulsion between movable and stationary coils is balanced by the attraction of gravity on a sliding weight connected with the movable coils.

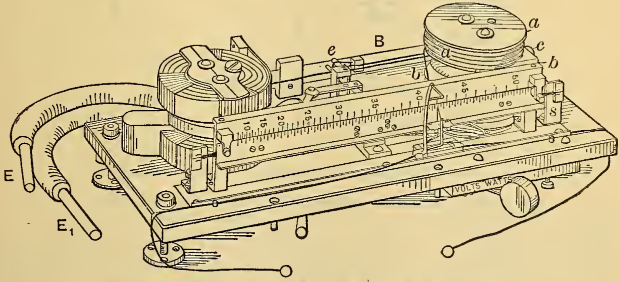


FIG. 31. Kelvin's Standard Composite Balance.

Above is a cut of the instrument in its latest form, and the diagram following shows the theory on which the instrument works.

In both cut and diagram the same letters indicate the same parts. a and b are two coils of silk-covered copper wire placed one above the other as shown, with their planes horizontal, and the whole being mounted on a slab of slate which is supported on leveling screws.

Two coils *c* and *d*, of similar wire are made in rings that are secured to the ends of a balance beam *B*, which is suspended at its center by two flat ligaments of fine copper wire.

When for use with continuous currents two other coils, *g* and *h*, made of strip copper, and of cross-section heavy enough to carry large currents, say 500 amperes, are secured to the base plate at the left in the same relative position as are the coils *a* and *b* at the right. When the instrument is to be used in the measurement of alternating currents, the coils *g* and *h* are made of two or three turns of a stranded copper conductor, each wire of which is insulated ; and, to as far as possible annul the effects of induction, the strand is given one turn or twist for each turn around the coil.

The coils *c* and *d* of the balance are suspended equidistant between the right and left pairs of coils, with planes parallel to their planes, and centers coinciding with their centers.

To Set the Balance.—Level the instrument with the adjustable legs, turn the stop screws back out of contact with the cross trunnions and front plate of the beam, leaving it free.

To Use as Voltmeter or Centi-ampere Meter.—Connect the instrument to the circuit or source of E.M.F. through a non-inductive resistance *R*, as shown in the preceding diagram, the resistance terminal to *T* and the other terminal to T_1 ; throw the switch *H* to the right to the "volt" contact.

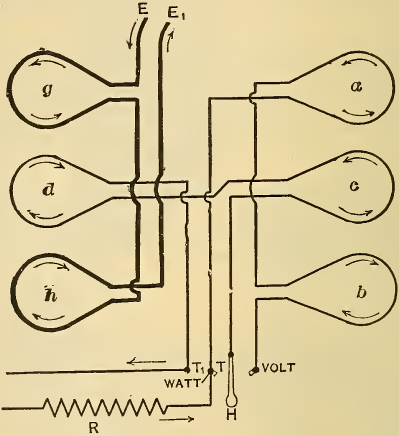


FIG. 32. Diagram of the Kelvin Composite Balance.

One of the weights $v\,w_1$, $v\,w_2$, $v\,w_3$, is then used on the scale beam, and a is balance obtained. The current flowing in the instrument is then calculated by a comparison of the scale-reading with the certificate accompanying the instrument. The volts E.M.F. at the terminals are calculated from the current flowing and the resistance in circuit, including the non-inductive resistance used, by Ohm's law, $v = IR$.

To Use as Hekto-ampere Meter.— Turn the switch *H* to "watts," insert the thick wire coils in circuit with the current in such a way that the right-hand end of the beam rises. Use the "sledge" alone or the weight marked *w.w.*

Terminals *E* and E^1 are then introduced into the circuit, and a measured current passed through the suspended coils *g* and *h* ; and the constants given in the certificate for the balance used in this way are calculated on the assumption that this current is .25 ampere. Any other current may be used, say *I* ampere, then the constant becomes $I \div .25$ or 4 *I*.

The current flowing in the suspended coils g and h may be measured by the instrument itself, arranged for the measurement of volts. To do this, first measure the current produced by the applied E.M.F. through the coils of the instrument and the external resistance, then turn the switch H to "watt," and introduce into the circuit a resistance equal to that of the fixed coils.

To Use as a Wattmeter. — Insert the thick wire coils in the main circuit; then join one end of the non-inductive resistance R to one terminal of the fine wire coils, and the other end of R to one of the leads; the other terminal of the fine wire coils is connected to the other lead. The current flowing and the E.M.F. may now be determined by the methods described above. The watts can then be calculated from the E.M.F. of the leads, and the current flowing in the thick wire coils by the formula,

$$P_w = VI = i\,IR,$$

Where i = current in the suspended coil circuit.
I = current in the thick wire coils.
R = resistance in the circuit.

When working with alternating currents the non-inductive resistance R must be large enough to prevent any difference of phase of the current flowing in the fine wire coils and the E.M.F. of the circuit.

Table of Doubled Square Roots for Lord Kelvin's Standard Electric Balances.

	0	100	200	300	400	500	600	700	800	900	
0	0.000	20.00	28.28	34.64	40.00	44.72	48.99	52.92	56.57	60.00	0
1	2.000	20.10	28.35	34.70	40.05	44.77	49.03	52.95	56.60	60.03	1
2	2.828	20.20	28.43	34.76	40.10	44.81	49.07	52.99	56.64	60.07	2
3	3.464	20.30	28.50	34.81	40.15	44.86	49.11	53.03	56.67	60.10	3
4	4.000	20.40	28.57	34.87	40.20	44.90	49.15	53.07	56.71	60.13	4
5	4.472	20.49	28.64	34.93	40.25	44.94	49.19	53.10	56.75	60.17	5
6	4.899	20.59	28.71	34.99	40.30	44.99	49.23	53.14	56.78	60.20	6
7	5.292	20.69	28.77	35.04	40.35	45.03	49.27	53.18	56.82	60.23	7
8	5.657	20.78	28.84	35.10	40.40	45.08	49.32	53.22	56.85	60.27	8
9	6.000	20.88	28.91	35.16	40.45	45.12	49.36	53.25	56.89	60.30	9
10	6.325	20.98	28.98	35.21	40.50	45.17	49.40	53.29	56.92	60.33	10
11	6.633	21.07	29.05	35.27	40.55	45.21	49.44	53.33	56.96	60.37	11
12	6.928	21.17	29.12	35.33	40.60	45.25	49.48	53.37	56.99	60.40	12
13	7.211	21.26	29.19	35.38	40.64	45.30	49.52	53.40	57.03	60.43	13
14	7.483	21.35	29.26	35.44	40.69	45.34	49.56	53.44	57.06	60.46	14
15	7.746	21.45	29.33	35.50	40.74	45.39	49.60	53.48	57.10	60.50	15
16	8.000	21.54	29.39	35.55	40.79	45.43	49.64	53.52	57.13	60.53	16
17	8.246	21.63	29.46	35.61	40.84	45.48	49.68	53.55	57.17	60.56	17
18	8.485	21.73	29.53	35.67	40.89	45.52	49.72	53.59	57.20	60.60	18
19	8.718	21.82	29.60	35.72	40.94	45.56	49.76	53.63	57.24	60.63	19
20	8.944	21.91	29.66	35.78	40.99	45.61	49.80	53.67	57.27	60.66	20
21	9.165	22.00	29.73	35.83	41.04	45.65	49.84	53.70	57.31	60.70	21
22	9.381	22.09	29.80	35.89	41.09	45.69	49.88	53.74	57.34	60.73	22
23	9.592	22.18	29.87	35.94	41.13	45.74	49.92	53.78	57.38	60.76	23
24	9.798	22.27	29.93	36.00	41.18	45.78	49.96	53.81	57.41	60.79	24
25	10.000	22.36	30.00	36.06	41.23	45.83	50.00	53.85	57.45	60.83	25
26	10.198	22.45	30.07	36.11	41.28	45.87	50.04	53.89	57.48	60.86	26
27	10.392	22.54	30.13	36.17	41.33	45.91	50.08	53.93	57.52	60.89	27
28	10.583	22.63	30.20	36.22	41.38	45.96	50.12	53.96	57.55	60.93	28
29	10.770	22.72	30.27	36.28	41.42	46.00	50.16	54.00	57.58	60.96	29
30	10.954	22.80	30.33	36.33	41.47	46.04	50.20	54.04	57.62	60.99	30
31	11.136	22.89	30.40	36.39	41.52	46.09	50.24	54.07	57.65	61.02	31
32	11.314	22.98	30.46	36.44	41.57	46.13	50.28	54.11	57.69	61.06	32
33	11.489	23.07	30.53	36.50	41.62	46.17	50.32	54.15	57.72	61.09	33
34	11.662	23.15	30.59	36.55	41.67	46.22	50.36	54.18	57.76	61.12	34
35	11.832	23.24	30.66	36.61	41.71	46.26	50.40	54.22	57.79	61.16	35
36	12.000	23.32	30.72	36.66	41.76	46.30	50.44	54.26	57.83	61.19	36
37	12.166	23.41	30.79	36.72	41.81	46.35	50.48	54.30	57.86	61.22	37
38	12.329	23.49	30.85	36.77	41.86	46.39	50.52	54.33	57.90	61.25	38
39	12.490	23.58	30.92	36.82	41.90	46.43	50.56	54.37	57.93	61.29	39
40	12.649	23.66	30.98	36.88	41.95	46.48	50.60	54.41	57.97	61.32	40
41	12.806	23.75	31.05	36.93	42.00	46.52	50.64	54.44	58.00	61.35	41
42	12.961	23.83	31.11	36.99	42.05	46.56	50.68	54.48	58.03	61.38	42
43	13.115	23.92	31.18	37.04	42.10	46.60	50.71	54.52	58.07	61.42	43
44	13.266	24.00	31.24	37.09	42.14	46.65	50.75	54.55	58.10	61.45	44
45	13.416	24.08	31.30	37.15	42.19	46.69	50.79	54.59	58.14	61.48	45
46	13.565	24.17	31.37	37.20	42.24	46.73	50.83	54.63	58.17	61.51	46
47	13.711	24.25	31.43	37.26	42.28	46.78	50.87	54.66	58.21	61.55	47
48	13.856	24.33	31.50	37.31	42.33	46.82	50.91	54.70	58.24	61.58	48
49	14.000	24.41	31.56	37.36	42.38	46.86	50.95	54.74	58.28	61.61	49
50	14.142	24.49	31.62	37.42	42.43	46.90	50.99	54.77	58.31	61.64	50

	0	100	200	300	400	500	600	700	800	900	
51	14.283	24.58	31.69	37.47	42.47	46.95	51.03	54.81	58.34	61.68	51
52	14.422	24.66	31.75	37.52	42.52	46.99	51.07	54.85	58.38	61.71	52
53	14.560	24.74	31.81	37.58	42.57	47.03	51.11	54.88	58.41	61.74	53
54	14.697	24.82	31.87	37.63	42.61	47.07	51.15	54.92	58.45	61.77	54
55	14.832	24.90	31.94	37.68	42.66	47.12	51.19	54.95	58.48	61.81	55
56	14.967	24.98	32.00	37.74	42.71	47.16	51.22	54.99	58.51	61.84	56
57	15.100	25.06	32.06	37.79	42.76	47.20	51.26	55.03	58.55	61.87	57
58	15.232	25.14	32.12	37.84	42.80	47.24	51.30	55.06	58.58	61.90	58
59	15.362	25.22	32.19	37.89	42.85	47.29	51.34	55.10	58.62	61.94	59
60	15.492	25.30	32.25	37.95	42.90	47.33	51.38	55.14	58.65	61.97	60
61	15.620	25.38	32.31	38.00	42.94	47.37	51.42	55.17	58.69	62.00	61
62	15.748	25.46	32.37	38.05	42.99	47.41	51.46	55.21	58.72	62.03	62
63	15.875	25.53	32.43	38.11	43.03	47.46	51.50	55.24	58.75	62.06	63
64	16.000	25.61	32.50	38.16	43.08	47.50	51.54	55.28	58.79	62.10	64
65	16.125	25.69	32.56	38.21	43.13	47.54	51.58	55.32	58.82	62.13	65
66	16.248	25.77	32.62	38.26	43.17	47.58	51.61	55.35	58.86	62.16	66
67	16.371	25.85	32.68	38.31	43.22	47.62	51.65	55.39	58.89	62.19	67
68	16.492	25.92	32.74	38.37	43.27	47.67	51.69	55.43	58.92	62.23	68
69	16.613	26.00	32.80	38.42	43.31	47.71	51.73	55.46	58.96	62.26	69
70	16.733	26.08	32.86	38.47	43.36	47.75	51.77	55.50	58.99	62.29	70
71	16.852	26.15	32.92	38.52	43.41	47.79	51.81	55.53	59.03	62.32	71
72	16.971	26.23	32.98	38.57	43.45	47.83	51.85	55.57	59.06	62.35	72
73	17.088	26.31	33.05	38.63	43.50	47.87	51.88	55.61	59.09	62.39	73
74	17.205	26.38	33.11	38.68	43.54	47.92	51.92	55.64	59.13	62.42	74
75	17.321	26.46	33.17	38.73	43.59	47.96	51.96	55.68	59.16	62.45	75
76	17.436	26.53	33.23	38.78	43.63	48.00	52.00	55.71	59.19	62.48	76
77	17.550	26.61	33.29	38.83	43.68	48.04	52.04	55.75	59.23	62.51	77
78	17.664	26.68	33.35	38.88	43.73	48.08	52.08	55.79	59.26	62.55	78
79	17.776	26.76	33.41	38.94	43.77	48.12	52.12	55.82	59.30	62.58	79
80	17.889	26.83	33.47	38.99	43.82	48.17	52.15	55.86	59.33	62.61	80
81	18.000	26.91	33.53	39.04	43.86	48.21	52.19	55.89	59.36	62.64	81
82	18.111	26.98	33.59	39.09	43.91	48.25	52.23	55.93	59.40	62.67	82
83	18.221	27.06	33.65	39.14	43.95	48.29	52.27	55.96	59.43	62.71	83
84	18.330	27.13	33.70	39.19	44.00	48.33	52.31	56.00	59.46	62.74	84
85	18.439	27.20	33.76	39.24	44.05	48.37	52.35	56.04	59.50	62.77	85
86	18.547	27.28	33.82	39.29	44.09	48.41	52.38	56.07	59.53	62.80	86
87	18.655	27.35	33.88	39.34	44.14	48.46	52.42	56.11	59.57	62.83	87
88	18.762	27.42	33.94	39.40	44.18	48.50	52.46	56.14	59.60	62.86	88
89	18.868	27.50	34.00	39.45	44.23	48.54	52.50	56.18	59.63	62.90	89
90	18.974	27.57	34.06	39.50	44.27	48.58	52.54	56.21	59.67	62.93	90
91	19.079	27.64	34.12	39.55	44.32	48.62	52.57	56.25	59.70	62.96	91
92	19.183	27.71	34.18	39.60	44.36	48.66	52.61	56.28	59.73	62.99	92
93	19.287	27.78	34.23	39.65	44.41	48.70	52.65	56.32	59.77	63.02	93
94	19.391	27.86	34.29	39.70	44.45	48.74	52.69	56.36	59.80	63.06	94
95	19.494	27.93	34.35	39.75	44.50	48.79	52.73	56.39	59.83	63.09	95
96	19.596	28.00	34.41	39.80	44.54	48.83	52.76	56.43	59.87	63.12	96
97	19.698	28.07	34.47	39.85	44.59	48.87	52.80	56.46	59.90	63.15	97
98	19.799	28.14	34.53	39.90	44.63	48.91	52.84	56.50	59.93	63.18	98
99	19.900	28.21	34.58	39.95	44.68	48.95	52.88	56.53	59.97	63.21	99
100	20.000	28.28	34.64	40.00	44.72	48.99	52.92	56.57	60.00	63.25	100

MEASUREMENTS.

RESISTANCE MEASUREMENTS.

Ohm's Law is the foundation of all electrical testing, and is written in the following forms :—

$$I = \frac{E}{R};$$
$$E = IR;$$
$$R = \frac{E}{I}.$$

where $I =$ the current strength in amperes,
$R =$ the resistance in ohms,
and $E =$ the electromotive force in volts.

The Resistance of Multiple Circuits equals the reciprocal of the sum of the reciprocals of the resistances of each circuit individually.

In the figure the joint resistance R_1 of the two circuits r and r_1, between a and b.

$R_1 = \frac{r \times r_1}{r + r_1}$ and the resistance required to be joined in parallel with r to give R_1 is

$$r_1 = \frac{r \times R_1}{r - R_1}$$

and the total resistance of the figure, neglecting that of the battery and connections,

$$= R + \frac{r \times r_1}{r + r_1}.$$

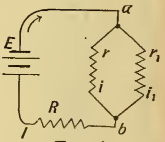


FIG. 1.

The joint resistance of any number of resistances in parallel, as, a, b, c, d, e, etc., will be

$$\frac{1}{\frac{1}{a} + \frac{1}{b} + \frac{1}{c} + \frac{1}{d} \text{ etc.}}$$

Joint Insulation Resistance.—If $n =$ total insulation resistance of the figure, and $y =$ insulation resistance of the section from a to c, then the insulation resistance x of the section from b to c will be

$$x = \frac{y \times n}{y - n}.$$

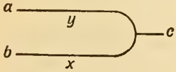


FIG. 2.

The Current Strengths in Parallel or Multiple Circuits are in proportion to the conductivities of the separate branches, or inversely proportional to their respective resistances.

In the figure, total current flowing in R,

$$I = E\frac{r + r_1}{Rr + Rr_1 + rr_1},$$
$$i = E\frac{r_1}{Rr + Rr_1 + rr_1},$$
$$i_1 = E\frac{r}{Rr + Rr_1 + rr_1},$$

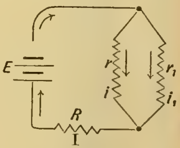


FIG. 3.

Wheatstone's Bridge.—For accurate measurement of resistance the Wheatstone's bridge method is more generally used than any other.

The diagram Fig. 4 shows the theoretical connections of the bridge.

In the diagrams Fig. 4 and Fig. 6 a, b, and R are known resistances, and x the unknown resistance to be measured. G is the galvanometer; B is a battery of several cells, the number being varied according to the resistance of x. a and b are adjustable, but may be left equal to each other; when R may be adjusted until there is no deflection of the galvanometer needle.

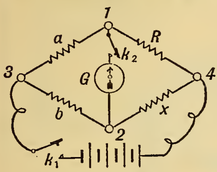


FIG. 4.

Then $a : b :: R : x$

and $ax = bR$

and $x = \dfrac{bR}{a}$.

NOTE.—Always close the battery key before closing the galvanometer key, to avoid an instantaneous deflection of the galvanometer, which may be due to inductance in one of the arms of the bridge. This deflection might occur even though the resistances be properly balanced.

If $a = b$ the value of x is the same as R. Should x be higher than the capacity of R, or lower than its smallest unit, then a and b can be arranged to multiply or divide the resistance value of R, and the equation still remains

$$a : b :: R : x.$$

For example,

let
$$a = 10$$
$$b = 1000$$
$$R = 200;$$

then
$$10 : 1000 :: 200 : x$$
$$10x = 200{,}000$$
$$x = 20{,}000;$$

and in practice the ratio $a : b = 100$, and any reading as R would be *multiplied* by 100.

Again, let
$$a = 1000$$
$$b = 10$$
$$R = 200$$
$$1000 : 10 :: 200 : x$$
$$1000x = 2000$$
$$x = 2;$$

and the ratio $a : b = \frac{1}{100}$, and any reading as R would be *divided* by 100.

Post-Office Bridge.—A very convenient form of Wheatstone's bridge is shown in Fig. 5, of which the connections are shown in diagram 6. The letters and figures are the same as in the former diagrams, and will need no further explanation.

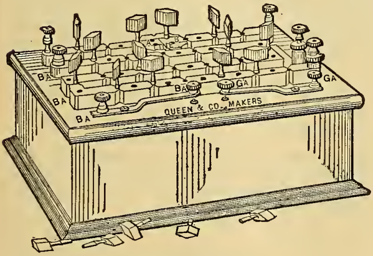


FIG. 5.

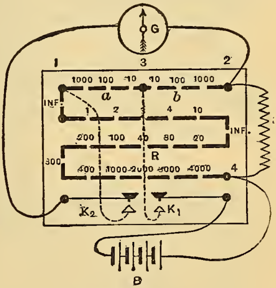


FIG. 6.

Fig. 7 is a form of bridge designed by Prof. Anthony which employs a smaller number of plugs than are used in ordinary forms of bridges, and thereby dispenses with much of the accompanying contact resistance.

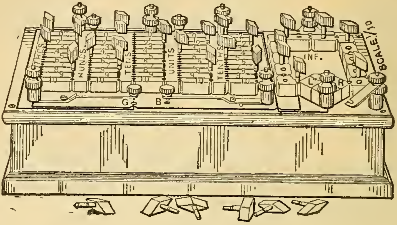


FIG. 7.

Slide-wire Bridge.—A very convenient form of bridge for ordinary use where extreme accuracy is not demanded is the slide-wire bridge, shown in Fig. 8. It consists of a wire one meter long and about 1.5 mm. diameter stretched parallel with a meter scale divided into millimeters. A contact key is so arranged as to be moved along the wire so that contact with it can be made at any point.

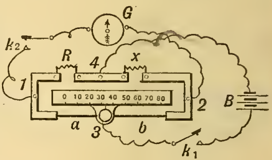


FIG. 8.

A known resistance R is connected as shown; x is the unknown resistance; the galvanometer and the battery are joined up as shown in the figure; after closing the key k_1 the contact 3 is then moved along the wire until the galvanometer needle returns to zero; then again;

$$a : b :: R : x,$$

and

$$x = \frac{bR}{a}.$$

The Cary-Foster Method.—For the very precise comparison of nearly equal resistances of from 1 to 100 ohms this method yields exquisite results. In Fig. 9, S_1 and S_2 represent the two nearly equal resistances to be compared, and R_1, R_2 represent nearly equal resistances, which, for best results, should not differ much in magnitude from S_1 and S_2. S_1 and S_2 are connected by a slide-wire whose resistance per unit length ρ is known. The battery and galvanometer are connected as in the diagram. A balance is obtained by moving the contact c along the stretched wire. Suppose the length of the wire on the left-hand side to the point of contact to be a units. Then exchange S_1 and S_2 for each other without altering any other connections in the circuit. Upon producing a new balance, let a_1 be the length of wire to the left of the contact.

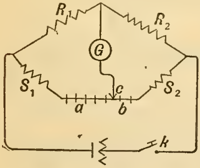


FIG. 9. Cary-Foster Bridge.

Then

$$S_1 = S_2 + (a - a_1)\,\rho.$$

Special commutators are upon the market which have for their purpose the easy exchange of S_1 and S_2.

To avoid thermal effects, which are quite considerable with resistances made of some materials, the battery should be commutated for each position of the resistances to be compared. The readings for the two balances accompanying the battery commutation should be averaged.

Thomson's Double Bridge.—If the resistances in a Wheatstone's bridge be much less than one ohm in magnitude, the accuracy of the results obtained is inferior. Samples of copper or other wires of moderate lengths and diameters have such small resistances that the resistivities of the materials of which they are constructed cannot be determined satisfactorily by this method. Thomson designed a modified form of bridge which gives very satisfactory results. Its construction is represented diagrammatically in Fig. 10, where the unknown low resistance x is compared with a standard low resistance R. R and x represent the resistances of measured lengths of standard wire and test wire respectively. These two wires are firmly joined at y. The uncertainty of the exact point of separation between them would make it difficult to connect the galvanometer so as to yield a reliable balance. By the insertion of two auxiliary resistances n and o of such magnitudes that $n : o = R : x = a : b$, and by connecting the galvanometer through the key k_1 to a point between n and o, results of very good accuracy may be obtained.

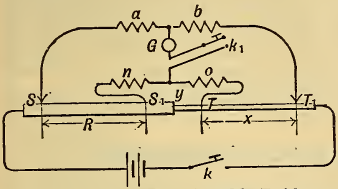


Fig. 10. Thomson's Double Bridge.

Precise Comparison of Very Small Resistances.—For comparing the low resistances of ammeter shunts, etc., with standard side terminal resistances of the Reichsanstalt form, the method of Sheldon yields very accurate results. The unknown resistance x, Fig. 11, which may be assumed to be supplied with branch potential points a b, is connected by heavy conductors in series with a standard resistance R, having potential points c d. From the two free terminals T T^1 of these resistances are shunted two 10,000 ohm resistance boxes S P, adjusted to the same normal temperature, and wound with wire of the same or negligable temperature coefficient, and connected in series. From the point of connection e, between the two boxes, connection is made to one terminal of the galvanometer g, the other terminal being connected successively with the potential points a, b, c, and d. At the outset all the plugs are removed from the box S, and all are in place in the box P. After connecting T and T^1 with a source of heavy current, plugs are transferred from one box to the corresponding holes in the other box (this keeps the total resistance in the two boxes constant) until no deflection is observed in the galvanometer. This operation is repeated for each of the potential points a, b, c, and d. Representing the resistances in the box S on the occasion of each of these balances by S_a, S_b, S_c, and S_d respectively, we have the following expression for the value of the unknown resistance: —

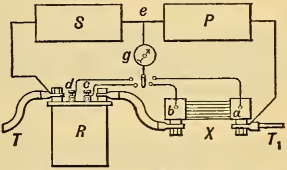


Fig. 11. Precise Measurement.

$$x = \frac{S_a - S_b}{S_c - S_d} R.$$

Differential Galvanometer Method.—In galvanometers having two coils wound side by side, when two separate and equal currents are sent through the coils, but in opposite directions, the needle will not move. If the currents are unequal the needle will be deflected in proportion to the difference of current strength; and, as the current can be varied by varying the resistance, this instrument will serve for comparing an unknown resistance with a known resistance.

To determine if the coils have equal effect on the needle, connect them in series opposition, and pass a current through them; if there be any deflection of the needle one of the coils will have to be moved until the needle stands at zero; or with the coils in multiple a resistance can be placed in series with the coil taking the most current.

RESISTANCE OF WIRES.

By Simple Substitution.—Place the resistance to be measured in series with a galvanometer and battery or other source of steady current, and note the deflection of the needle. Replace the unknown resistance with a known adjustable resistance, and change the latter resistance until the same deflection of the galvanometer needle is obtained as with the unknown resistance; then the unknown resistance equals the value of the known resistance that is necessary to produce the same deflection.

Other methods and applications are shown in the section on voltmeter tests.

RESISTANCE OF GALVANOMETERS.

When a second galvanometer is available, by far the most simple and satisfactory method is to measure the resistance of the galvanometer by any of the ordinary Wheatstone's bridge methods. Take the temperature at the same time, and, if the instrument has a delicate system, remove the needle and suspension.

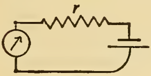


FIG. 12.

Half Deflection Method.—Connect the galvanometer in series with a resistance r and battery as in the following figure. Note the deflection d; then increase r so that the new deflection d_1 will be one-half the first, or $\frac{d}{2} = d_1$; call the new resistance r_1; then

Resistance of Galvanometer $= r_1 - 2r$.

If the instrument be a tangent galvanometer, then d and d_1 should represent the tangents of the deflections.

Thomson's Method.—Connect the galvanometer, as x in a Wheatstone's bridge, as in Fig. 13. Adjust r until the deflection of G is the same, whether the key is closed or open.

$$G = r\frac{b}{a}.$$

The result is independent of the resistance of the battery. The battery should be connected from the junction of the two highest resistances to that of the two lowest.

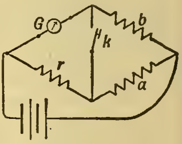


FIG. 13.

RESISTANCE OF BATTERIES.

Condenser Method.—For this test is needed a condenser C, a ballistic galvanometer G, a double contact key k_1, a resistance R, of about the same magnitude as the supposed resistance of the battery B, and a single contact key k_2. Connect as in the following figure. With the key k_2 open, press the key k_1, and observe the throw θ_1 in the galvanometer. Then, after the needle has come to rest, with key k_2 closed, repeat the operation observing the throw θ_2. Then the resistance of the battery

$$x = R\frac{\theta_1 - \theta_2}{\theta_2}.$$

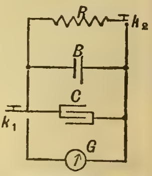


FIG. 14.

Reduced Deflection Method.—Connect the battery B in circuit with a galvanometer G and a resistance r as in Fig. 15. Note the deflection d, and then increase r to r_1 and note the smaller deflection d_1; then, if the deflections of the galvanometer be proportional to the currents,

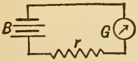


FIG. 15.

$$B = \frac{r_1 d_1 - rd}{d - d_1} - G.$$

If r_1 is such that $d_1 = \frac{d}{2}$,

then $B = r_1 - (2r + G)$.

The E.M.F. of the battery is supposed to remain unaltered during the measurement.

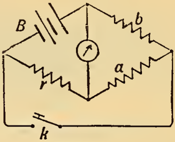


FIG. 16.

Mance's Method.—Connect the battery as x in Wheatstone's bridge as in Fig. 16. Adjust r until the deflection of G is the same whether the key be closed or open.

Then $$B = r\frac{b}{a}.$$

The galvanometer should be placed between the junction of the two highest resistances and that of the two lowest.

Resistance of Battery while Working.—Connect the battery B with a resistance r, and also in parallel with a condenser C, galvanometer G, and key k; shunt the battery through s with key k_1, as in Fig. 17.

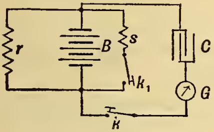


FIG. 17.

Close the key k, and note the deflection d of the galvanometer, keeping k closed, close k_1 and note d_1, the deflection in the opposite direction. Then the battery resistance

$$B = s\frac{d_1}{d - d_1 - \frac{d_1 s}{r}}.$$

If r be large, the term $\frac{d_1 s}{r}$ is negligible, and

$$B = s\frac{d_1}{d - d_1},$$

s being the multiplying power of the shunt.

Workshop Method, Applicable as well to Dynamos.—With dynamo or battery on open circuit, take the voltage across the terminals with a voltmeter, and call it d; take another reading d_1 at the same points with the battery or dynamo working on a known resistance r: then the internal resistance $$R = \frac{d - d_1}{d_1}r.$$

In the case of storage batteries, if the current I be read from an inserted ammeter when charging, the resistance of the battery is

$$B = \frac{d_1 - d}{I},$$

and when discharging $$B = \frac{d - d_1}{I}.$$

RESISTANCE OF AËRIAL LINES OR HOUSE CIRCUITS.

Conductor Resistance.—When the circuit has metallic return, it is easily measured by any of the Wheatstone's bridge methods, or, if the circuit conductor can be supplied with current through an ammeter, then the fall of potential across the ends of the conductor will give a measure of the resistance by ohms law, viz.,

$$\text{Resistance} = \frac{\text{drop in volts}}{\text{current}}.$$

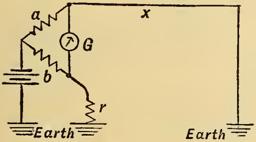


FIG. 18.

If the circuit has earth return as in telegraph and some telephone circuits, then place far end of the line to earth, and connect with bridge as in Fig. 18.

Then the total resistance x of the line and earth, is $$x = r\frac{b}{a}.$$

If a second line be available, the resistance of the first line can be determined separated from that of earth, as well as the resistance of earth.

Let $r =$ resistance of first line
$r_{\prime} =$ resistance of second line
$r_{\prime\prime} =$ resistance of earth.

First connect the far end of r and $r_{\prime}$ together, and get the total resistance R; connect r and $r_{\prime\prime}$, and measure the resistance $R_{\prime}$; connect $r_{\prime}$ and $r_{\prime\prime}$, and get total resistance $R_{\prime\prime}$. Then if

$$T = \frac{R + R_{\prime} + R_{\prime\prime}}{2}$$

$$r = T - R_{\prime\prime}$$
$$r_{\prime} = T - R_{\prime}$$
$$r_{\prime\prime} = T - R.$$

This test is particularly applicable to finding the resistance of trolley wires, feeders, and track.

INSULATION RESISTANCE OF ELECTRIC CIRCUITS IN BUILDINGS.

In the United States it is quite common to specify that the entire installation when connected up shall have an insulation resistance from earth of at least one megohm.

The National Code gives the following: —

The wiring of any building must test free from grounds; i.e., each main supply line and every branch circuit should have an insulation resistance of at least 100,000 ohms, and the whole installation should have an insulation resistance between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.) of not less than the following: —

Up to 5 amperes . .	4,000,000.
Up to 10 amperes . .	2,000,000.
Up to 25 amperes . .	800,000.
Up to 50 amperes . .	400,000.
Up to 100 amperes . .	200,000.
Up to 200 amperes . .	100,000.
Up to 400 amperes . .	50,000.
Up to 800 amperes . .	25,000.
Up to 1,600 amperes . .	12,500.

All cut-outs and safety devices in place in the above.

Where lamp-sockets, receptacles, and electroliers, etc., are connected, one-half of the above will be required.

Professor Jamison's rule is: —

$$\text{Resistance from earth} = 100{,}000 \times \frac{\text{E.M.F.}}{\text{number of lamps}}.$$

Kempe's rule is: —

$$\text{Resistance in megohms} = \frac{75}{\text{number of lamps}}.$$

A rule for use in the U. S. Navy is: —

$$\text{Resistance} = 300{,}000 \times \frac{\text{E.M.F.}}{\text{number of outlets}}.$$

Institution of Electrical Engineers' rule is: —

$$R = \frac{7900 \times \text{E.M.F.}}{\text{number of lamps}}.$$

Phœnix Fire Office rule for circuits of 200 volts is that

$$\text{The least } R = \frac{12.5 \text{ megohms}}{\text{number of lamps}}.$$

Twenty-five English insurance companies have a rule that the leakage from a circuit shall not exceed $\frac{1}{200000}$ part of the total working current.

Below is a table giving the approximate insulation allowable for circuits having different loads of lamps.

For a circuit having—

25 lamps, insulation should exceed . .	500,000 ohms.
50 lamps, insulation should exceed . .	250,000 ohms.
100 lamps, insulation should exceed . .	125,000 ohms.
500 lamps, insulation should exceed . .	25,000 ohms.
1000 lamps, insulation should exceed . .	12,000 ohms.

All insulation tests of lighting circuits should be made with the working current. (See page 58, voltmeter test.)

In the following table Uppenborn shows the importance of testing with the working voltage.

Table I. shows the resistance between the terminals of a slate cut out.

Table II. shows the resistance between two cotton-covered wires twisted.

I.		II.	
VOLTS.	MEGOHMS.	VOLTS.	MEGOHMS.
5	68	5	281
10	53	10	188
13.6	45	16.9	184
27.2	24	27.2	121

MEASUREMENT OF ELECTROMOTIVE FORCE.

Of Batteries.—This can usually be measured near enough for all practical purposes by Weston or other high-class low-reading voltmeters (see voltmeter tests); but if greater accuracy be wanted, it can be obtained by comparing with a standard cell by the following method:—

Lord Rayleigh's Compensation Method.—In the following diagram let R and R_1 be two 10,000-ohm rheostats, B be the battery of larger E.M.F. than either of the cells to be compared, B_1 be one of the cells under test, G be a sensitive galvanometer, HR be a high resistance to protect the standard cell, and k be a key. Obtain a balance, so that the galvanometer shows no deflection on closing the key k, by transferring resistance from one box to the other, being careful to keep the sum of the resistances in the boxes equal to 10,000 ohms. Observe the resistance in R and call it R_1. Repeat with the other cell B_2, and call the resistance R_2. Then the E.M.F.'s of the two cells

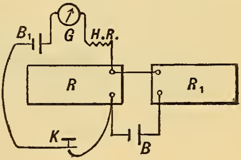


FIG. 19.

$$E_1 : E_2 = R_1 : R_2.$$

Electrometer Method.—Connect the cell whose E.M.F. it is desired to measure to the terminals of a quadrant electrometer, and note the deflection d. Then substitute the standard cell for the first cell, and note the deflection d_1.

Then, if $e =$ the E.M.F. of the cell to be measured,
and $e_1 =$ the E.M.F. of the standard,

$$d_1 : d :: e_1 : e,$$

and

$$e = \frac{de_1}{d_1}.$$

Wheatstone's Method.—Connect the cell or battery to be compared in circuit with a galvanometer and high resistance r, and note the deflection d; then add another high resistance r_1 (about equal to r), and note the deflection d_1. Next, connect the cell with which the first is to be compared in circuit with the galvanometer, and connect in resistance until the galvanometer deflection is the same as d; then add further resistance until the galvanometer deflection is the same as d_1; then, if $e =$ the E.M.F. of the first cell, and $E =$ the E.M.F. of the cell with which it is compared,

$$r_1 : R :: e : E,$$

and

$$E = \frac{R_1 e}{r_1}.$$

MEASURING CAPACITY.

Arrangement of Condensers. In Parallel.—Join like poles of the several condensers together as in the figure; then, the joint capacity of the set is equal to the sum of the several capacities.

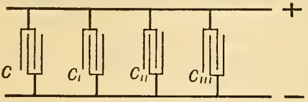


FIG. 20.

Total capacity $= c + c_{/} + c_{//} + c_{///}$.

Condensers in Series.—Join the unlike poles as if connecting up battery cells in series as in Fig. 21, then the joint capacity of all is the reciprocal of the sum of the reciprocals of the several capacities.

$$\text{Capacity } C = \frac{1}{\frac{1}{c} + \frac{1}{c_{/}} + \frac{1}{c_{//}} + \frac{1}{c_{///}}}.$$

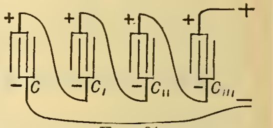


FIG. 21.

Capacity by Direct Discharge.—Charge a standard condenser, Fig. 22, C_s by a battery E for a certain time, say 30 seconds; then discharge it through a ballistic galvanometer G; note the throw d.

Next charge the condenser to be measured, C_1, by the same battery and for the same length of time, and discharge this through the same galvanometer noting the throw d_1;

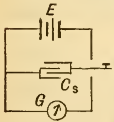


FIG. 22.

Then $$C_s : C_1 :: d : d_1.$$

and $$C_1 = C\frac{d_1}{d}.$$

Thomson's Method.—This method is that most generally used for comparing capacities of condensers, cables, etc.

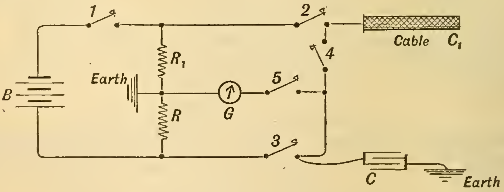


FIG. 23.

$B =$ battery, say 10 chloride of silver cells.
$R =$ variable resistance.
$R_1 =$ fixed resistance.
$G =$ galvanometer.
$C =$ standard condenser.
$C_1 =$ cable or condenser to be measured.
1, 2, 3, 4, 5 $=$ keys.

Test.—Close key 1, thus joining the two resistances R and R_1 to earth. Then if V and V_1 = the potentials at the junctions of the battery with the resistances R and R_1,

$$V : V_1 :: R : R_1.$$

Close keys 2 and 3 simultaneously for a certain length of time, and charge the condenser C and cable C_1 to potentials V and V_1 respectively.

If C and C_1 be the respective capacities (in microfarads) of the condenser and cable, and Q and Q_1 the charges given to them,

$$Q : Q_1 :: VC : V_1C_1.$$

Release keys 2 and 3, then close key 4 for a fixed time, to allow the charges of condenser and cable to mix, then if Q is not = Q_1 when the key 5 is closed cutting in the galvanometer, there is a deflection. Change the ratio of R to R_1 until on trial there is no deflection.

Then $\qquad VC = V_1C_1$

or $\qquad V_1 : V :: C : C_1$

but we found $\qquad V_1 : V :: R_1 : R$

or $\qquad R_1 : R :: C : C_1$

and $\qquad C_1 = \dfrac{R}{R_1} C$ microfarads.

Bridge Method.—For comparing the capacities of two condensers, C_s and C, which are approximately the same, connect as in Fig. 24 through two rather high inductionless resistances R_1 and R_2 to the key k which makes and breaks contacts at each end. E is a battery. A galvanometer is inserted between the ends of the condensers where they join the resistances. Adjust the resistances so that no deflection results when the key is manipulated.

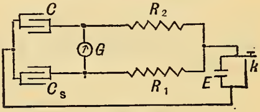


FIG. 24.

Then $\qquad C = C_s \dfrac{R_1}{R_2}.$

Intermittent Current Method.—If a tuning fork, making n complete vibrations per second, and provided with a stylus, be connected as in Fig. 25, it will charge the condenser to the voltage of the battery E, and then discharge it through the galvanometer G, n times per second. The effect on the galvanometer will be the same as though a constant current of strength, nEC, were flowing through it, where C is the capacity of the condenser. To determine the value of this current, connect the battery directly to the galvanometer through a total resistance R, so adjusted as to give the same deflection as before.

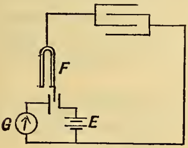


FIG. 25.

Then $\qquad nEC = \dfrac{E}{R}. \qquad \therefore C = \dfrac{1}{nR}.$

Coefficient of Self-Induction L of a Coil or Circuit.—The coefficient of self-induction of a coil or circuit is the equivalent in volts that would be produced in that coil or circuit by a rate of change of current equivalent to a uniform change of one ampere of current per second. It is numerically equal to the number of lines of force linked with the circuit per unit current in it.

For example, if we have a coil of 150 turns of wire carrying 2 amperes and producing 200,000 lines of force, or 200 kilogausses, then one ampere would produce 100,000 lines; and if it took the current one second to die out when the circuit was opened, then each turn would cut 100,000 lines in that time, and 150 turns would be equivalent to 1 turn cutting 15,000,000 lines. 1 volt = 10^8 lines cut by one coil; therefore

$$\frac{15{,}000{,}000}{100{,}000{,}000} = .15 \text{ volts, or } .15 \text{ henry} = L.$$

MEASUREMENTS OF COEFFICIENTS OF INDUCTION.

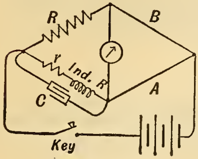


FIG. 26.

Determination of the coefficients of inductance may be made with a Wheatstone's bridge, condenser, and variable non-inductive resistance; connect up as follows: —

In the cut let A and B be equal constant arms of the bridge; R, the variable arm; r, a variable non-inductive resistance in series with the inductive resistance, Ind. R, to be measured, and the ohmic resistance of which is R_1, C being a condenser placed as a shunt around the two resistances. The resistance r is employed to enable one to use a condenser C of practicable size. Adjust C, r, and R, until there is no deflection of the galvanometer when the battery circuit is opened; then

$$L = C\,(r + R_1)^2.$$

Another Method: —

Let $r =$ resistance of article to be measured,
$L =$ coefficient of self-induction of article,
$R =$ resistance $=$ to r,
$C =$ capacity of a condenser in microfarads.

Then proceed as follows: —

1st. Balance for constant currents by adjusting r_1, both k and k_1 being closed.

2d. After closing the galvanometer key k_1, close key k, and note the throw θ_1 in the ballistic galvanometer.

3d. Substitute in the bridge, for the article whose inductance is being measured, the condenser C shunted by the resistance $R = r$.

4th. Repeat the operation 2, and note the galvanometer throw θ_2.

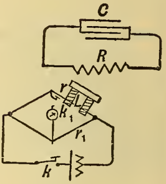


FIG. 27.

Then
$$L = Cr^2\,\frac{\theta_1}{\theta_2} \div 1{,}000{,}000 \text{ henrys.}$$

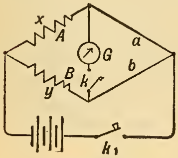


FIG. 28.

To Compare Two Coefficients of Self-Induction. — Let the connections be made as in the cut, the two coefficients of self-induction being x and y in the arms A and B.

Balance the bridge so there is no movement of the galvanometer needle, the key k being closed, when k_1 is opened or closed suddenly.

Then, if the total resistance of the arm A, including the coil x be A, and the resistance of the arm B is B, including the coil y, the coefficient of the coil x and that of the coil y are such that

we have
$$\frac{x}{y} = \frac{a}{b} = \frac{A}{B}.$$

MEASUREMENT OF SELF-INDUCTANCE WITH AN ALTERNATING CURRENT OF KNOWN FREQUENCY.

For this test is needed a high resistance or electrostatic alternating current voltmeter, a direct current ammeter, and a non-inductive resistance.

Connect as in Fig. 29, where R_1 is an inductive resistance to be measured, and S a switch for short-circuiting the ammeter; the $A.\ C.$ dynamo of frequency n is so arranged that its terminals may be disconnected, and a battery be substituted therefore.

With the connections as in Fig. 29, close the switch S, and take the drop with the voltmeter from a to b and the drop from a to C; then disconnect the A. C. dynamo, and connect the battery B; open the switch s, and vary the continuous current until the drop from a to C is the same as with the alternating current, both measurements being made with the same voltmeter; then note the current shown by the ammeter, and measure the drop from a to b with the voltmeter. Call the drop across R_1 from a to b, with alternating current, E, and the same with continuous current, E_1, and the reading of the ammeter with the latter, I.

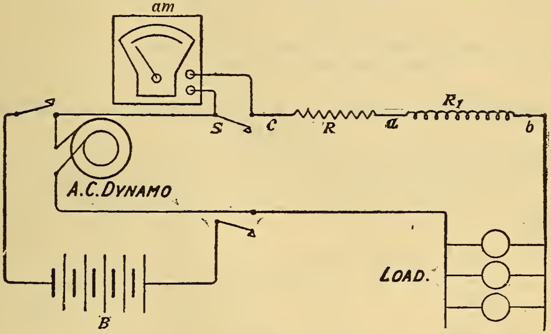


FIG. 29.

Then $$L = \frac{\sqrt{E^2 - E_1^2}}{2\pi n I}.$$

If the resistance R_1 be known, and the ammeter be suitable for use with alternating currents, the switch and non-inductive resistance may be dispensed with. We then have $L = \dfrac{\dfrac{E^2}{I_1^2} - R_1}{2\pi n}$, where I_1 is the value of the alternating current.

NOTE. — The resistance of the voltmeter must be high enough to render its current negligible as compared with that through the resistance R_1.

MEASUREMENT OF MUTUAL INDUCTANCE.

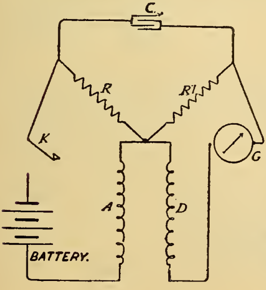


FIG. 30.

Let M = the mutual inductance between two coils,
Let L = the self-inductance of one coil,
Let $L_{\prime}$ = the self-inductance of the other coil,
Let $L_{\prime\prime}$ = the self-inductance of both coils connected in series,
Let $L_{\prime\prime\prime}$ = the self-inductance of both coils connected in opposition to each other.

Then, since $L_{\prime\prime} = L + L_1 + 2M$
and $L_{\prime\prime\prime} = L + L_{\prime} - 2M$

$$M = \frac{L_{\prime\prime} - L_{\prime\prime\prime}}{4}.$$

Another Method with battery is as follows: connect as in Fig. 30 where A and D are the two coils whose mutual inductance, M_1, is required. R and R_1 are two non-inductive resistances, and C is a condenser placed in shunt to $R + R_1$. Closing and opening the key k produces deflections of the galvanometer G by the mutual induction of the coils and proportional to $M - CRR_1$. Varying C gives different deflections in which, d being the first deflection and d_1 a second deflection,

$$\frac{M - CRR_1}{d} = \frac{M - C_1RR_1}{d_1}.$$

C_1 being the second value of the capacity of the condenser.

Then $M = CRR_1$ when d is reduced to zero.

MEASURING THE INDUCTANCE OF AËRIAL LINES.

In the following figure a line is shown with a load of lamps or other translating devices, although for the purpose of getting the line inductance alone, it would most likely be closed on itself.

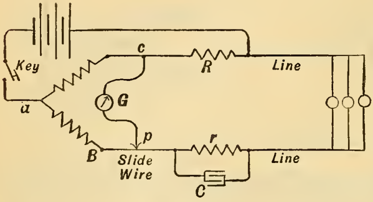


FIG. 31.

Connect up for a Wheatstone's bridge method as shown in the cut; close the key, and manipulate the slider p until a balance is obtained; then vary the capacity of the condenser C until there is no movement of the needle when the battery circuit is broken with the key.

Then, disregarding line capacity, the inductance is

$$L = cr^2,$$

and, if C = capacity of the line, and R be the resistance of the same, then

$$L = cr^2 + \tfrac{1}{3}CR^2.$$

MEASUREMENT OF MUTUAL INDUCTANCE OF AËRIAL LINES.

To measure the mutual inductance of a pair of parallel lines, connect up as in the cut below. Earth both ends of each line separately, and, to avoid trouble from earth currents, put a small battery in secondary line with adjustable shunt as shown. Adjust R and C until there is no movement of the galvanometer needle, when the circuit of the battery is opened with the key; then, if

R = the resistance of the rheostat R as finally arranged,
R_1 = the resistance of secondary line,
C = the capacity of the condenser as finally arranged,
and M = mutual inductance,
$M = CRR_1$.

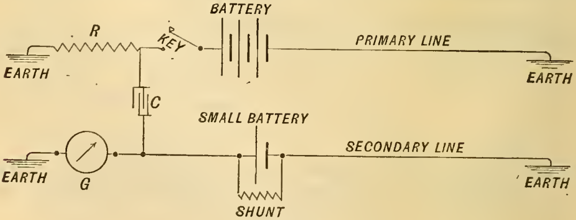


FIG. 32.

MEASUREMENT OF POWER IN ALTERNATING CURRENT CIRCUITS.

In circuits carrying alternating currents, and having an inductance in some part of their length, either in the shape of motors or other inductive load, as unloaded transformers, and the self-induction of the wires themselves, the ordinary methods of measurement of the power or watts conveyed are not available, as the current is seldom exactly in phase with the E.M.F., and therefore the value of the current multiplied by the E.M.F. will not be the true watts of the circuit.

In all alternating circuits the power, at any instant of time, is equal to the product of the instantaneous values of the current and voltage at that time. If the current be in phase with the voltage, each will have zero values at the same instant of time, and will have maximum positive and maximum negative values simultaneously. Inasmuch as the product of two negative quantities is a positive quantity, the power of the circuit, with no phase difference, is made up of positive pulsations varying in magnitude from 0 to a maximum. The latter is equal to the product of the maximum values of the current and E.M.F. If, however, the current differ by 90° in phase from the voltage, i.e., each having 0 value when the other has a maximum value, the power will consist of a series of pulsations, first positive and then negative, and the algebraic value of the work done, i.e., power times its duration, would be equal to zero. The result is that no permanent work is done, and the circuit is said to have a "Power Factor" of 0. The current which flows is called a wattless current. If the phase difference be less than 90° and more than 0°, at some instants of time the product of the volts and amperes will be negative, but oftener will be positive. The fractional part of the whole which is positive is called the power factor. It can be shown that the power factor is equal to the cosine of the angle of phase difference.

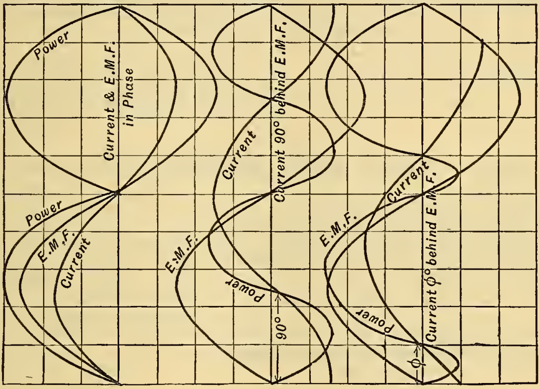


FIG. 33

Inasmuch as an ampere of alternating current is one whose maximum value is 1.41 amperes ($\sqrt{2}$), and a volt of alternating current is one whose maximum value is 1.41 volts, the following relations hold true:—

If $f =$ maximum value of E.M.F.,
$d =$ maximum value of current,
and $\theta =$ angle of lag of current behind the E.M.F.,

then True Watts $= \frac{f \times d}{2} \times \text{Cos}\ \theta$.

If $E =$ E.M.F. by voltmeter : $\sqrt{\text{mean}^2}$,

$I =$ current by ammeter : $\sqrt{\text{mean}^2}$,

$\theta =$ angle of lag,

$W =$ watts measured by watt meter,

then $$\frac{W}{E \times I} = \text{Cos } \theta = \text{Power factor},$$

or the power factor is the value by which the observed volt-amperes must be multiplied to give the true watts.

If a wattmeter be without self-induction in its fine wire coils, and the supporting part be not subject to eddy currents, then it may be used for measuring the value of power in A. C. circuits; in fact, in all full tests of alternating-current work it is necessary to have wattmeter, ammeter, and voltmeter readings.

Three Voltmeter Method. Ayrton & Sumpner.

This method is good where the voltage can be regulated to suit the load.

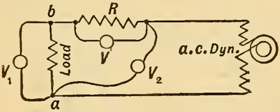


FIG. 34.

In figure 34 let the non-inductive resistance R be placed in series with the load $a\ b$; take the voltage V across the terminals of R; V_1 across the load $a\ b$, and V_2 across both, or from a to c.

Then the $$\text{True watts} = \frac{V_2^2 - V_1^2 - V^2}{2R}.$$

The best conditions are when $V = V_1$, and, if $R = \frac{1}{2}$ ohm,

then $$W = V_2^2 - V_1^2 - V^2.$$

Three Ampere Meter Method (*not recommended*).

This method, due to Fleming, can be used when it is not convenient to regulate the potential of load $a\ b$.

In Fig. 35 R is a non-inductive resistance connected in shunt to the inductive load $a\ b$, with the three ammeters connected as shown,

Then $$\text{True watts} = \frac{R}{2}(A_2^2 - A^2 - A_1^2).$$

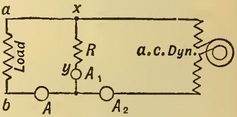


FIG. 35.

Combined Voltmeter and Ammeter Method.

This method, devised also by Fleming, is quite accurate, and enables the accuracy of instruments in use to be checked. In Fig. 36 R is a non-inductive resistance connected in shunt to the inductive load $a\ b$, and the voltmeter V measures the $p.\ d.$ across $x\ y$. A and A_1 are ammeters connected as shown; then

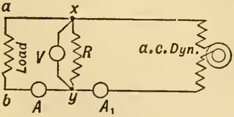


FIG. 36.

$$\text{True watts} = \frac{R}{2}\left(A_1^2 - A^2 - \left(\frac{V}{R}\right)^2\right).$$

If the voltmeter V takes an appreciable amount of current, it may be tested as follows: disconnect R and V at y, and see that A and A_1 are alike; then connect R and V at y again, and disconnect the load $a\ b$. Then $A_1 =$ current taken by R and V in multiple.

As regards all the above mentioned tests with 3 voltmeters, ammeters, etc., it may be said that they were developed at a time when no good alternating current instruments were available. Since then a number of good A. C. voltmeters have been developed, and more recently the inclined coil instruments of the General Electric Co., and Schallenberger instruments of the Westinghauss Co., have placed instruments in our hands that make alternating-current testing nearly as easy as d. c. testing.

TESTS WITH VOLTMETER.

The following are a few of the more important tests for which a voltmeter is especially adapted, and have mostly been condensed from a very fine article by H. Maschke, Ph.D. published in the *Electrical World* in April, 1892.

The scales of the better known portable instruments of to-day read in general from 0 to 150 volts, or from 0 to 750 volts, and in special instruments the two scales are combined, so that by connecting one wire to one or the other of two binding posts either scale is available. Instruments for battery use read from 0 to 15 volts with a second scale reading as low as $\frac{1}{10}$, or 1.5 volts. Millivoltmeters reading from 0 to $\frac{1}{10}$, or 0 to $\frac{1}{100}$, etc., with divisions capable of being read as low as $\frac{1}{100000}$ volt, are also obtainable.

None of the refined laboratory methods will be given here, as the reader is referred to the text-books for such tests.

ELECTROMOTIVE FORCE OF BATTERIES.

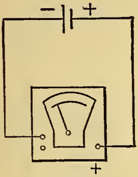


FIG. 37.

The positive post of voltmeters is usually at the right, and marked +. In a battery the zinc is commonly negative, and should therefore be connected to the left or negative binding post.

For single cells or a small number, a low-reading voltmeter, say one reading to 15 volts, will be used, the connections being as per diagrams.

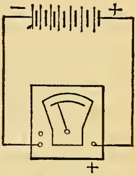


FIG. 38.

ELECTROMOTIVE FORCE OF DYNAMOS.

For voltage within range of the instrument available for the purpose, it is only necessary to connect one terminal of the voltmeter to a brush of one polarity, and the other terminal to a brush of the opposite polarity, and read direct from the scale of the instrument. As continuous current voltmeters usually deflect forward or back according to which pole is connected, it is necessary sometimes to reverse the lead wires, in which case the polarity of the dynamo is also determined. Of course the voltage across any circuit may be taken in the same way, or the dynamo voltage may be taken at the switchboard, in which case the drop in the leads sometimes enters into the calculations. Following are diagrams of the connections to bipolar and multipolar dynamos:—

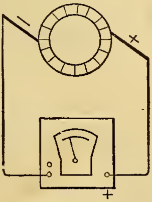


FIG. 39.

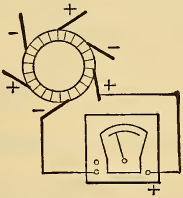


FIG. 40.

In the case of arc dynamos or other machines giving high voltage, it is necessary to provide a multiplier in order to make use of the ordinary instrument; and the following is the rule for determining the resistance which, when placed in series with the voltmeter, will provide the necessary multiplying power.

Let $e =$ upper limit of instrument scale, for example 150 volts,
$E =$ upper limit of scale required, for example 750 volts,
$R =$ resistance of the voltmeter, for example 18,000 ohms,
$r =$ additional resistance required, in ohms.

Then $r = R\,\dfrac{E - e}{e}$ or $r = 18{,}000\,\dfrac{750 - 150}{150} = 72{,}000$ ohms.

$$\text{The multiplying power} = \frac{E}{e} \text{ or } \frac{750}{150} = 5.$$

Should the exact resistance not be available, then with any available resistance r_1 the regular scale readings must be multiplied by $\left(\dfrac{r_1}{R} + 1\right)$.

IMPORTANCE OF HIGH RESISTANCE FOR VOLTMETERS.

It is highly important, as reducing the error in measurement, that the internal resistance of a voltmeter be as high as practicable, as is shown in the following example: —

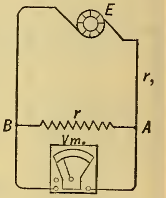


FIG. 41.

Let E in the figure be a dynamo, battery, or other source of electric energy, sending current through the resistance r; and *vm.* be a voltmeter indicating the pressure in volts between the terminals A and B. Before the *vm.* is connected to the terminals A and B there will be a certain difference of potential, which will be less when the voltmeter is connected, owing to the lessening of the total resistance between the two points; if the resistance of the *vm.* be high, this difference will be very small, and the higher it is the less the error. Following are the formulas and computations for determining the error.

In the above figure let E be the E.M.F. of the dynamo, r the resistance of the circuit as shown between A and B, and r_1 be the resistance of the leads A and B plus that of the dynamo, and let R be the resistance of the voltmeter; then before the *vm.* is connected the difference between A and B will be

$$e = \frac{r}{r + r_1} \times E,$$

and after connecting the voltmeter it will be

$$e_1 = \frac{R \times r}{R \times r + r \times r_1 + r_1 \times R} \times E.$$

The difference between the two results e and e_1 is then

$$e - e_1 = \frac{1}{R} \times \frac{r \times r_1}{r + r_1} \times e_1,$$

and this difference will be smaller the greater the resistance R of the *vm.* is.

Example: —

Let
$E = 10$ volts
$r = 10$ ohms
$r_1 = 2$ ohms
$R = 500$ ohms

then $$e_1 = \frac{500 \times 10}{500 \times 10 + 10 \times 2 + 2 \times 500} \times 10 = 8.3056,$$

and $$e - e_1 = \frac{1}{500} \times \frac{10 \times 2}{10 + 2} \times 10 = .0333.$$

If R be made 1000 ohms, then

$$e_1 = \frac{1000 \times 10}{1000 \times 10 + 10 \times 2 + 2 \times 1000} \times 10 = 8.32,$$

and $$e - e_1 = \frac{1}{1000} \times \frac{10 \times 2}{10 + 2} \times 10 = .0166.$$

or just one half of the error; it may be said that the error is therefore in inverse proportion to the resistance of the *vm.*

If the error of measurement is not to exceed a stated per cent p, then r and r_1 must be such that $\frac{r \times r_1}{r + r_1}$ is smaller than $\frac{p \times R}{100}$ ohms.

If the circuit is not closed by a resistance r, then with *vm.* connected between A and B

$$e_1 = \frac{R}{R + r_1} \times E,$$

and the error between the true value and that shown on the *vm.* is

$$E - e_1 = \frac{r_1}{R} \times e_1$$

and this error decreases in inverse proportion to the increase of the ratio between R and the internal resistance of the current generator r_1.

If the error is not to exceed p per cent, then the internal resistance r_1 must be less than $\frac{p \times R}{100}$ ohms.

The E.M.F. of high-resistance cells cannot be correctly measured by the above method, even with voltmeters of relatively high resistance, but it is better done by one of the methods mentioned below.

COMPARISON OF E.M.F. OF BATTERIES.

Wheatstone's Method.—To compare E.M.F. of two batteries A and X, with low-reading voltmeters, let E be the E.M.F. of A; and E_1 the E.M.F. of X.

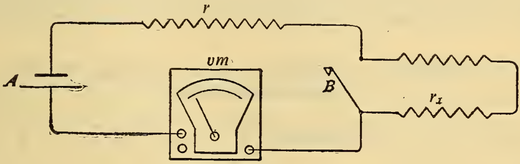


FIG. 42.

First connect battery A in series with the voltmeter and a resistance r, switch B being closed, and note the deflection V; then open the switch B, and throw in the resistance r_1, and note the deflection V_1. Now connect battery X in place of A, and close the switch B, and vary the resistance r until the same deflection V of voltmeter is obtained and call the new resistance r_2; next open the switch B, or otherwise add to the resistance r_2 until the deflection V_1 of the voltmeter is produced; call this added resistance r_3, then

$$E : E_1 :: r_1 : r_3.$$

If E be smaller than E_1, the voltmeter resistance R may be taken as r, and it is better to have r_1 about twice as large as the combined resistance of r and the resistance of A.

It is not necessary that the internal resistance of the cells be small as compared with R.

Poggendorff's Method Modified by Clark.

To Compare the E.M.F. of a battery cell or element with a standard cell.

Let S be a standard cell,
T be a cell for comparison with the standard,
B be a battery of higher E.M.F. than either of the above elements.

A resistance r is joined in series with the battery B and a slide wire $A\,D$. A millivoltmeter is connected as shown, both its terminals being connected to the like poles of the battery B and the Standard S.

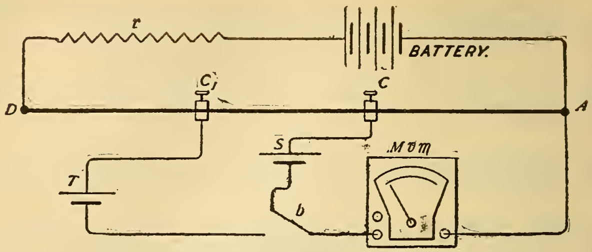


FIG. 43.

Move the contact C along the wire until the pointer of the instrument stands at zero, and let r_1 be the resistance of $A\ C$.

Throw the switch b so as to cut out the standard S, and cut in the cell T; now slide the contact C_1 along the wire until the pointer again stands at zero, and call the resistance of $A\ C_1\ r_2$,

Then the E.M.Fs. of the two cells

$$T : S :: r_2 : r_1.$$

If a meter bridge or other scaled wire be used in place of $A\ D$, the results may be read directly in volts by arranging the resistance r so that with the pointer at zero the contact C is at the point 144 on the wire scale, or at 100 times the E.M.F. of the standard S, which may be supposed to be a Clark cell. All other readings will in this case be in hundredths of volts; and should the location of C_1 be at 175 on the scale when the pointer is at zero on the voltmeter, then the E.M.F. of the cell, being compared, will be 1.75 volts.

MEASURING CURRENT STRENGTH WITH A VOLTMETER.

If the resistance of a part of an electric circuit be known, taking the drop in potential around such resistance will determine the current flowing by ohms law viz., $I = \frac{E}{R}$.

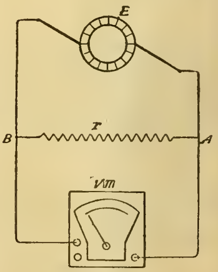


FIG. 44.

In the figure let r be a known resistance between the points A and B of the circuit, and I the strength of current to be determined; then if the voltmeter, connected as shown, gives a deflection of V volts, the current flowing in r will be

$$I = \frac{V}{r}.$$

For the corrections to be applied in certain cases, see the section on *Importance of High Resistance for Voltmeters.*

Always see that the resistance r has enough carrying capacity to avoid a rise of temperature which would change its resistance.

If the reading is exact to $\frac{1}{p}$ volt the measurement of current will be exact to $\frac{1}{p \times r}$ amperes. If $r = .5$ ohm, and the readings are taken on a low-reading voltmeter, say ranging from 0 to 5 volts, and that can be read to $\frac{1}{300}$ volt, then the possible error will be

$$\frac{1}{300 \times .5} = \frac{1}{150} \text{ ampere.}$$

If r be made equal to 1 ohm, then the volts read also mean amperes.

Measurement of Very Heavy Currents with a Millivoltmeter.

For this purpose the method outlined above is most generally used with the substitution of a millivoltmeter for the voltmeter.

Where portable instruments are used, there must be a calibrated shunt for the millivoltmeter, the shunt being made up of a metal that does not vary in resistance with change of temperature, and which is placed in series in the circuit, the millivoltmeter simply giving the drop around this shunt, its scale being graduated in amperes.

For switchboard instruments the method is the same, being varied sometimes by using as a shunt a measured part of a conductor or bus bar in place of a special resistance.

MEASURING RESISTANCE WITH A VOLTMETER.

General Methods.—In the figure, let $X =$ the unknown resistance that is to be measured, $r =$ a known resistance, E, the dynamo or other steady source of E.M.F.

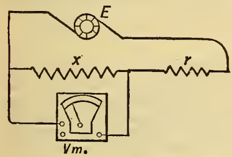


FIG. 45.

When connected as shown in the figure, let the voltmeter reading be V; then connect the voltmeter terminals to r in the same manner and let the reading be V_1; then

$$X : r :: V : V_1$$

and

$$X = \frac{r \times V}{V_1}.$$

If, for instance, $r = 2$ ohms and $V = 3$ volts and $V_1 = 4$ volts then

$$X = \frac{2 \times 3}{4} = 1.5 \text{ ohms}.$$

If readings can be made to $\frac{1}{100}$ volt, the error of resistance measurement will then be

$$100 \times \tfrac{1}{100}\left(\frac{1}{V} + \frac{1}{V_1}\right) \text{ per cent.}$$

and for the above example would be

$$1\,(\tfrac{1}{3} + \tfrac{1}{4}) = 0.58\%.$$

Should there be a considerable difference between the magnitudes of the two resistances X and r, it might be better to read the drop across one of them from one scale, and to read the drop across the other on a lower scale.

Resistance Measurement with Voltmeter and Ammeter.

The most common modification of the above method is to insert an ammeter in place of the resistance r in the last figure, in which case $X = \frac{V}{I}$ where I is the current flowing in amperes as read from the ammeter.

If the readings of the voltmeter be correct to $\frac{1}{100}$ and the ammeter readings be correct to the same degree, the possible error becomes:

$$100 \times \left(\frac{1}{100\,V} + \frac{1}{100\,I}\right) = \text{per cent.}$$

Measurement of Very Small Resistances with a Millivoltmeter and Ammeter.

By using a millivoltmeter in connection with an ammeter, very small resistances, such as that of bars of copper, armature resistance, etc., can be accurately measured.

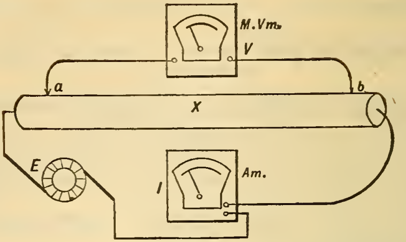


FIG. 46.

In order to have a reasonable degree of accuracy in measuring resistance by the "drop" method, as this is called, it is necessary that as heavy currents as may be available be used. Then, if E be the dynamo or other source of steady E.M.F., X be the required resistance of a portion of the bar, V be the drop in potential between the points a and b, and I be the current flowing in the circuit as indicated by the ammeter, then

$$X = \frac{V}{I}.$$

The applications of this method are endless, and but a few, to which it is especially adapted, need be mentioned here. They are the resistance of armatures, the drop being taken from opposite commutator bars and not from the brush-holders, as then the brush-contact resistance is taken in; the resistance of station instruments and all switchboard appliances, such as the resistance of switch contacts; the resistance of bonded joints on electric railway work, as described in the chapter on railway testing.

Measurement of High Resistances.

With the ordinary voltmeter of high internal resistance, let R be the resistance of the voltmeter, X be the resistance to be measured. Connect them up in series with some source of electromotive force as in the following figure.

Close the switch b, and read the voltage V with the resistance of the voltmeter alone in circuit; then open the switch, thus cutting in the resistance X, and take another reading of the voltmeter, $V_{,}$.

Then $$X = R\left(\frac{V}{V_1} - 1\right).$$

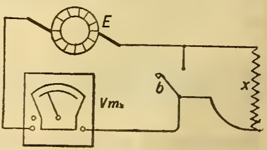


FIG. 47.

If the readings of the voltmeter be correct to $\frac{1}{10}$ of a volt the error of the above result will be $\frac{10}{V_{,}}\left(\frac{V + V_{,}}{V - V_{,}}\right)$ per cent.

MEASURING THE INSULATION OF LIGHTING AND POWER CIRCUITS WITH A VOLTMETER.

For rough measurements, where the exact insulation resistance is not required, but it is wished to determine if such resistance exceeds some stated figure or rate, then the method above given will do, when applied as follows: —

Let $X =$ insulation resistance to ground as in figure,
$X_{,} =$ insulation resistance to ground of opposite lead,
$R =$ resistance of voltmeter,
$V =$ potential of dynamo E,
$V_{,} =$ reading of voltmeter, as connected in figure,
$V_{,,} =$ reading of voltmeter, when connected to opposite lead.

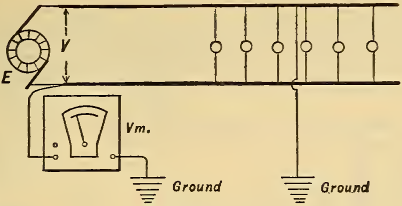


FIG. 48.

Then $$X = R\left(\frac{V}{V_{\prime}} - 1\right),$$

and $$X_{\prime} = R\left(\frac{V}{V_{\prime\prime}} - 1\right).$$

The above formula can be modified to give results more nearly correct by taking into account the fact that the path through the resistance R of the voltmeter is in parallel with the leak to ground on the side to which it is connected as shown in the following figure: —

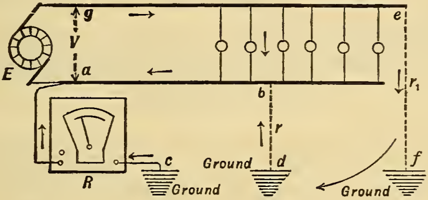


FIG. 49.

In this case the voltage V of the circuit will not only send current through the lamps, but through the leaks $e\ f$ to ground, and through the ground to d and c, thence through d to b, and c to a, these two last paths being in parallel, therefore having less resistance than if one alone was used; thus if r be the resistance of the ground leak $b\ d$, and r_1 be the resistance of the leak $e\ f$, and R be the resistance of the voltmeter, then the total resistance by way of the ground, between the conductors, would be

$$\frac{R \times r}{R + r} + r_1,$$

and if
$V =$ voltage of the circuit,
$v =$ reading of voltmeter from a to c,
$v_{\prime} =$ reading of voltmeter from g to c.

Then $$r = R\left(\frac{V - (v + v_{\prime})}{v_{\prime}}\right),$$

and $$r_1 = R\left(\frac{V - (v + v_{\prime})}{v}\right).$$

The sum of the resistance $r + r_1$ will be $= R\left(\frac{(v + v_{\prime})\,(V - (v + v_{\prime}))}{v + v_{\prime}}\right)$.

Insulation Resistance of Arc Circuits.

As arc lamps are by much the larger extent run in series, the insulation resistance of their circuits is found in a manner similar to that for multiple circuits, but the formula differs a little. Let the following figure be a typical arc circuit, with a partial ground at *c*.

First find the total voltage V between *a* and *b* of the circuit. This can most handily be done with a voltmeter having a high resistance in a separate box and so calibrated with the voltmeter as to multiply its readings by some convenient number. For convenience in locating the ground, get the average volts per lamp by dividing the total volts V by the number of lamps on the circuit; the writer has found 48 volts to be a good average for the ordinary 10 ampere lamp. With the 16 lamps shown in the above figure, V would probably be about 768 volts.

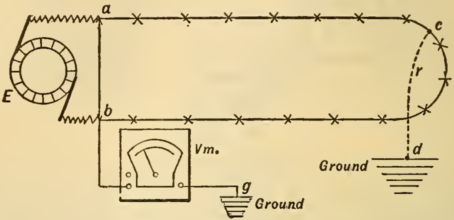


FIG. 50.

Next take a voltmeter reading from each end of the circuit to ground. Call the reading from *a* to ground v, and from *b* to ground $v_{,}$, R being the resistance of voltmeter as before, and r the insulation resistance required.

Then
$$r = R\left(\frac{V-(v+v_{,})}{v+v_{,}}\right),$$
and the location of the ground, provided there be but one and the general insulation of the circuit be good, will be found closely proportional to the readings v and $v_{,}$; in the above figure say we find the voltmeter reading from *a* to ground to be 28, and from *b* to ground to be 36; then the distance of the ground *c* from the two ends of the circuit will be in proportion to the readings 28 and 36 respectively.

There being 16 lamps on the circuit, the number of lamps between *a* and *c* would be $28 \div (28+36) = \frac{28}{64}$ of $16 = 7$, and from *b* to *c* would be $36 \div (28+36) = \frac{36}{64}$ of $16 = 9$; that is, the ground would most likely be found between the seventh and eighth lamps, counting from *a*.

Insulation across a Double Pole Fuse Block or Other Similar Device where Both Terminals are on the Same Base.

Let *f f* be fuses in place on a base,
$V =$ potential of circuit,
$R =$ resistance of voltmeter,
$v =$ reading of voltmeter,
required the resistance r across the base $a\,a_1$ to $b\,b_1$.

Then
$$r = R\frac{V-v}{v}.$$

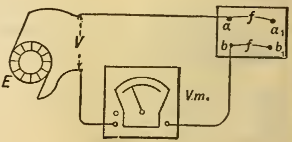


FIG. 51.

MEASURING THE INSULATION OF DYNAMOS.

The same formula as that used for measuring high resistances (see Fig. 47) applies equally well to determining the insulation of dynamo conductors from the iron body of the machine

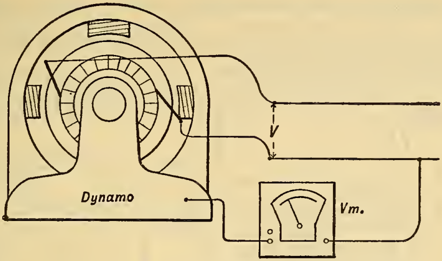


FIG. 52.

Connect, as in Fig. No. 52, all symbols having the same meaning as before.

Let r = insulation resistance of dynamo, then

$$r = R\left(\frac{V}{V_{\prime}} - 1\right).$$

MEASURING THE INSULATION RESISTANCE OF MOTORS.

Where motors are connected to isolated plant circuits with known high insulation, the formula used for insulation of dynamos applies; but where the motors are connected to public circuits of questionable insulation it is necessary to first determine the circuit insulation, which can be done by using the connections shown in Fig. 48. Fig. 53 shows the connections to motor for determining its insulation by current from an operating circuit.

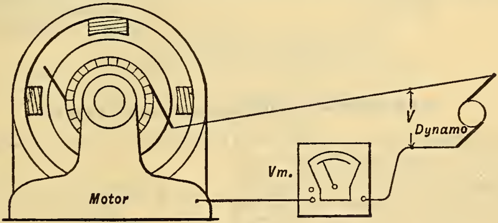


FIG. 53.

Here, as before, the insulation r of the total connected devices $= R\left(\frac{V}{V_{\prime}} - 1\right)$.

If r = total resistance of circuit and motor in multiple to ground, and $r_{\prime}$ is the insulation of the circuit from ground, then X, the insulation of the motor will be

$$X = \frac{r_{\prime} \times r}{r_{\prime} - r}.$$

MEASUREMENT OF THE RESISTANCE OF THE HUMAN BODY.

The jars $j\,j$ of the following figure (No. 54) are filled with a weak solution of caustic potash; the person whose resistance is to be measured places his hands in the jars, if the measurement is to be made from hand to hand, or makes an equally good connection with any other desirable portion of the body.

First take a reading of the voltmeter with the switch K closed; then have the subject plunge his hands into the jars, open the switch K, and take another reading of the voltmeter. The resistance r of the subject will be

$$r = R\left(\frac{V}{V_{,}} - 1\right),$$

in which R is the resistance of voltmeter,
V is the reading of voltmeter alone,
$V_{,}$ is the reading of voltmeter with switch K open and the subject in series with voltmeter.

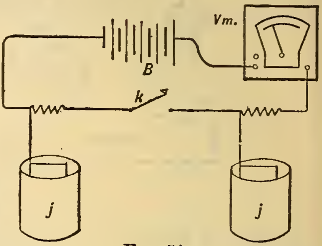


FIG. 54.

MEASUREMENT OF THE INTERNAL RESISTANCE OF A BATTERY.

In the following figure (No. 55), let E be the cell or battery whose resistance is to be measured, K be a switch, and r a suitable resistance.

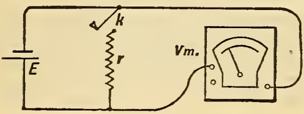


FIG. 55.

Let V = the reading of voltmeter with the key, K, open (this is the E.M.F. of the battery), and
$V_{,}$ = the reading of voltmeter with key, K, closed (this is the drop across the resistance r),

Then the battery resistance

$$r_{,} = r \times \frac{V - V_{,}}{V_{,}} \text{ ohms.}$$

SIEMENS-FROELICH METHOD.

In the following figure (No. 56), let E be the cell or battery to be measured, K a switch for closing resistance r to B or c; r, r_1 and r_2 be suitable resistances connected as shown. The voltmeter should of course be a low-reading one. Close by the key K, A and c, and read the voltmeter; next close by the key K, A and B, and read the voltmeter; then adjust r_2 until the voltmeter reading is the same for either position of the key K, and r_2 is then equal to the resistance of the battery E.

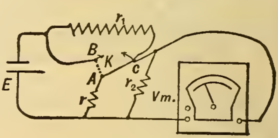


FIG. 56.

In most cases it is best to connect some known resistance in series with the cell, so that the current may not be excessive and harm the cell; if this be done, of course it is necessary to deduct this known resistance from the final reading r_2.

CONDUCTIVITY WITH A MILLIVOLTMETER.

This is a quick and convenient method of roughly comparing the conductivity of a sample of metal with that of a standard piece.

In Fig. 57, R is a standard bar of copper of 100% conductivity at 70° F.; this bar may be of convenient length for use in the clamps, but of known cross section. X is the piece of metal of unknown conductivity, but of the same cross section as the standard. E is a source of steady current, and if a storage battery is available it is much the better for the purpose. M is a millivoltmeter with the contact device d. The distance apart of the two points may be anything, so long as it remains unaltered and will go between the clamps on either of the bars.

Now with the current flowing through the two bars in series the fall of potential between two points the same distance apart and on the same flow-line will, on either bar, be in proportion to the resistance, or in inverse proportion to the conductivity; therefore by placing the points of d on the bars in succession, the readings of the millivoltmeter will give the ratio of the conductivities of the two pieces.

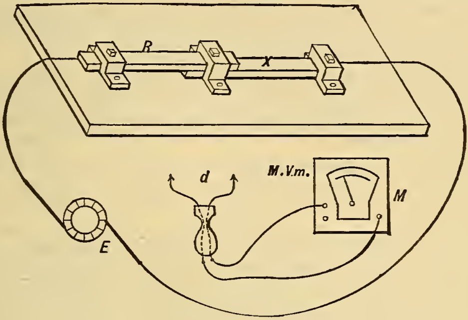


FIG. 57.

For example:—

if the reading from $R = 200$ millivolts,
and the reading from $X = 205$ millivolts,
then the percentage conductivity of X as compared with R is

$$205 : 200 :: 100 : \text{conductivity of } X,$$

or

$$\frac{200 \times 100}{205} = 97.5\%.$$

MAGNETIC PROPERTIES OF IRON.

WITH a given excitation the flux Φ or flux-density $\mathcal{B}$ of an electromagnet will depend upon the quality of the iron or steel of the core, and is usually rated as compared with air.

If a solenoid of wire be traversed with a current, a certain number of magnetic lines of force, $\mathcal{H}$, will be developed per square centimetre of the core of air. Now, if a core of iron be thrust into the coil, taking the place of the air, many more lines of force will flow; and at the centre of the solenoid these will be equal to $\mathcal{B}$ lines per square centimetre.

As iron or steel varies considerably as to the number of lines per square centimetre $\mathcal{B}$ which it will allow to traverse its body with a given excitation, its conductivity towards lines of force, which is called its *permeability*, is numerically represented by the ratio of the flux-density when the core is present, to the flux-density when air alone is present. This permeability is represented by μ.

The permeability μ of soft wrought iron is greater than that of cast iron; and that for mild or open-hearth annealed steel castings as now made for dynamos and motors is nearly, and in some cases quite, equal to the best soft wrought iron.

The number of magnetic lines that can be forced through a given cross-section of iron depends, not only on its permeability, but upon its saturation. For instance, if but a small number of lines are flowing through the iron at a certain excitation, doubling the excitation will practically double the lines of force; when the lines reach a certain number, increasing the excitation does not proportionally increase the lines of force, and an excitation may be reached after which there will be little if any increase of lines of force, no matter what may be the increase of excitation.

Iron or steel for use in magnetic circuits must be tested by sample before any accurate calculations can be made.

Data for $\mathcal{B}$-$\mathcal{H}$ Curves.

Average First Quality American Metal.

(Sheldon.)

$\mathcal{H}$	Ampere turns per cent. length.	Ampere turns per inch length.	Cast Iron.		Cast Steel.		Wrought Iron		Sheet Metal.	
			$\mathcal{B}$ Kilo-gausses.	Kilomax-wells per sq. in.	$\mathcal{B}$ Kilo-gausses.	Kilomax-wells per sq. in.	$\mathcal{B}$ Kilo-gausses.	Kilomax-wells per sq. in.	$\mathcal{B}$ Kilo-gausses.	Kilomax-wells per sq. in.
10	7.95	20.2	4.3	27.7	11.5	74.2	13.0	83.8	14.3	92.2
20	15.90	40.4	5.7	36.8	13.8	89.0	14.7	94.8	15.6	100.7
30	23.85	60.6	6.5	41.9	14.9	96.1	15.3	98.6	16.2	104.5
40	31.80	80.8	7.1	45.8	15.5	100.0	15.7	101.2	16.6	107.1
50	39.75	101.0	7.6	49.0	16.0	103.2	16.0	103.2	16.9	109.0
60	47.70	121.2	8.0	51.6	16.5	106.5	16.3	105.2	17.3	111.6
70	55.65	141.4	8.4	53.2	16.9	109.0	16.5	106.5	17.5	112.9
80	63.65	161.6	8.7	56.1	17.2	111.0	16.7	107.8	17.7	114.1
90	71.60	181.8	9.0	58.0	17.4	112.2	16.9	109.0	18.0	116.1
100	79.50	202.0	9.4	60.6	17.7	114.1	17.2	110.9	18.2	117.3
150	119.25	303.0	10.6	68.3	18.5	119.2	18.0	116.1	19.0	122.7
200	159.0	404.0	11.7	75.5	19.2	123.9	18.7	120.8	19.6	126.5
250	198.8	505.0	12.4	80.0	19.7	127.1	19.2	123.9	20.2	130.2
300	238.5	606.0	13.2	85.1	20.1	129.6	19.7	127.1	20.7	133.5

$\mathcal{H} = 1.258$ ampere turns per cm. $= .495$ ampere turns per inch.

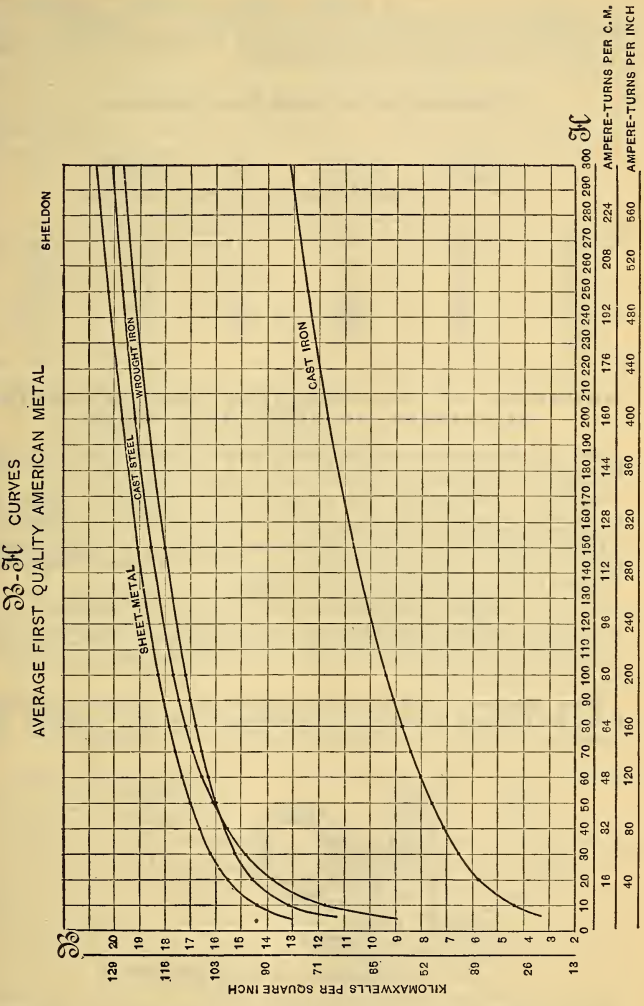


FIG. 1. Magnetic Properties of Iron.

In large generators, having toothed armatures and large flux densities in the air-gap, the flux is carried chiefly by the teeth. This results in a very high tooth flux density, and a correspondingly reduced permeability. The related values of $\mathcal{B}$, $\mathcal{H}$, and μ are given in the following table. These values are for average American sheet metal.

Permeability at High Flux Densities.

$\mathcal{H}$	Ampere Turns per cm. Length.	Ampere Turns per Inch Length.	$\mathcal{B}$ Kilo-gausses.	Kilomax-wells per Square in.	μ
200	159	404	19.8	127	99.0
400	318	808	21.0	135	52.5
600	477	1212	21.5	138	35.8
800	637	1616	21.8	140	27.3
1000	795	2020	22.0	142	22.0
1200	954	2424	22.3	144	1.8
1400	1113	2828	22.5	145	1.6

METHODS OF DETERMINING THE MAGNETIC QUALITIES OF IRON AND STEEL.

The methods of determining the magnetic value of iron or steel for electro-magnetic purposes are divided by Prof. S. P. Thompson into the following classes: *Magnetometric*, *Balance*, *Ballistic*, and *Traction*.

The first of these methods, now no longer used to any extent, consists in calculating the magnetization of a core from the deflection of a magnetometer needle placed at a fixed distance.

In the *Balance* class, the deflection of the magnetometer needle is balanced by known forces, or the deflection due to the difference in magnetization of a known bar and of a test bar is taken.

The *Ballistic* method is most frequently used for laboratory tests, and for such cases as require considerable accuracy in the results. There are really two ballistic methods, the *Ring method* and the *Divided-bar method*.

In either of these methods the ballistic galvanometer is used for measuring the currents induced in a test coil, by reversing the exciting current, or cutting the lines of force.

Ring Method. — The following cut shows the arrangement of instruments for this test, as used by Prof. Rowland. The ring is made of the sample of iron which is to undergo test, and is uniformly wound with the exciting coil or circuit, and a small exploring coil is wound over the exciting coil at one point, as shown. The terminals of the latter are connected to the ballistic galvanometer.

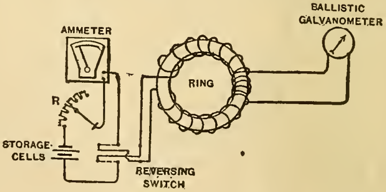


FIG. 2. Connections for the Ring Method.

The method of making a test is as follows: —

The resistance, R, is adjusted to give the highest amount of exciting current. The reversing switch is then commutated several times with the galvanometer disconnected. After connecting the galvanometer the switch is suddenly reversed, and the throw of the galvanometer, due to the reversal of the direction of magnetic lines, is recorded. The resistance, R, is then adjusted for a somewhat smaller current, which is again reversed, and the galvanometer throw again recorded. The test is carried on with various exciting currents of any desired magnitude. In every case the exciting current and the corresponding throw of the galvanometer are noted and recorded.

If $i =$ amperes flowing in the exciting coil,
$n_1 =$ number of turns of wire in exciting coil,
$l =$ length in centimetres of the mean circumference of the ring,
then the magnetizing force

$$\mathcal{H} = \frac{4\pi}{10} \times \frac{n_1 i}{l} \text{ or } 1.257 \times \frac{n_1 i}{l}.$$

If $l'' =$ length of the ring in inches, then

$$\mathcal{H}'' = .495 \times \frac{n_1 i}{l''}.$$

If $\theta =$ the throw of the galvanometer,
$K =$ constant of the galvanometer,
$R =$ resistance of the test coil and circuit,
$n_2 =$ number of turns in the test coil,
$a =$ area of cross-section of the ring in centimetres, then

$$\mathcal{B} = \frac{10^8\, R\, K\, \theta}{2\, a n_2}.$$

To determine K, the constant of the galvanometer, discharge a condenser of known capacity, which has been charged to a known voltage, through it, and take the reading θ^1, then

If $c =$ capacity of the condenser in microfarads,
$e =$ volts pressure to which the condenser is charged,

then the quantity passing through the galvanometer upon discharge in coulombs is $Q = \frac{c\, e}{1{,}000{,}000}$,

and the galvanometer constant

$$K = \frac{c\, e}{1{,}000{,}000\, \theta^1}.$$

Divided-Bar Method. — As it is often inconvenient or impossible to obtain samples in the form of a ring, and still more inconvenient to wind the coils on it, Hopkinson devised the divided-bar method, in which the sample is a long rod $\frac{1}{2}''$ diameter, inserted in closely fitting holes in a heavy wrought iron yoke, as shown in the following cut.

In the cut the exciting coils are in two parts, and receive current from the battery and through the ammeter, resistance, and reversing switch, as shown.

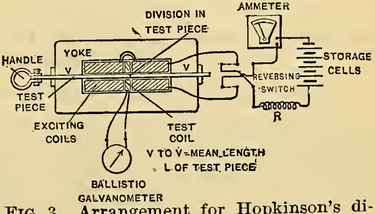


FIG. 3. Arrangement for Hopkinson's divided-bar method of measuring permeability.

The test bar is divided near the centre at the point indicated in the cut, and a small light test coil is placed over it, and so arranged with springs as to be thrown clear out of the yoke when released by pulling out the loose end of the test bar by the handle shown.

In operation, the exciting current is adjusted by the resistance R, the test bar suddenly pulled out by the handle, thus releasing the test coil and producing a throw of the galvanometer. As the current is not reversed, the induced pressure is due to N only, and the equation for $\mathcal{B}$ is

$$\mathcal{B} = \frac{10^8\ R\ K\ \theta}{a n_2}, \text{ and}$$

$$\mathcal{H} = \frac{4\pi}{10} \times \frac{n_1 i}{L} = 1.257\,\frac{n_1 i}{L},$$

Where L = the mean length of the test rod as shown in the cut.

In using the divided-bar method, a correction must be made, for the reason that the test coil is much larger than the test rod, and a number of lines of force pass through the coil that do not through the rod. This correction can easily be determined by taking a reading with a wooden test rod in place of the metal one.

An examination of the cut will show that the bar and yoke can also be used for the method of reversals.

The fourth or *Traction* class is exceedingly simple, and was devised by Prof. Silvanus P. Thompson.

The following cut shows the method with sufficient clearness. A heavy yoke of wrought iron has a small hole in one end through which the test rod is pushed, through the exciting coil shown, and against the bottom of the yoke, which is surfaced true and smooth, as is the end of the test rod.

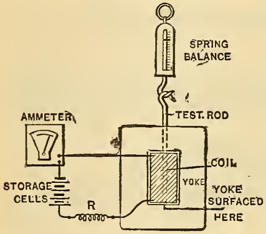


FIG. 4. S. P. Thompson's permeameter.

In operation, the exciting current is adjusted by the resistance R, and the spring balance is then pulled until the sample or test rod separates from the yoke, at which time the pull in pounds necessary to pull them apart is read. Then

$$\mathcal{B} = 1{,}317 \times \sqrt{\frac{P}{A}} + \mathcal{H}.$$

Where P = pull in pounds as shown on the balance,

A = area of contact of the rod and yoke in square inches.

$\mathcal{H}$ is found as in the Hopkinson method preceding this.

Following is a description of a practical adaptation of the *permeameter* to shop-work as used in the factory of the Westinghouse Electric and Manufacturing Co. at Pittsburgh, Pa.

The Permeameter, as used by the Westinghouse Electric and Mfg. Co.

DESIGN AND DESCRIPTION PREPARED BY MR. C. E. SKINNER.

A method of measuring the permeability of iron and steel known as the "Permeameter Method" was devised by Prof. Silvanus P. Thompson, and is based on the law of traction as enunciated by Clerk Maxwell. According to this law the pull required to break any number of lines of force varies as the square of the number of lines broken. (A complete discussion of the theory of the permeameter, with the derivation of the proper formula for calculating the results from the measurements will be found in the "Electro Magnet," by Prof. S. P. Thompson.)

A permeameter which has been in use for several years in the laboratory of the Westinghouse Electric and Manufacturing Company, and which has given excellent satisfaction, is shown in the accompanying drawings. The yoke, *A*, consists of a piece of soft iron 7″ x 8½″ x 2½″, with a rectangular opening in the centre 2½″ x 4″. The sample, *X*, to be tested is ⅝″ in diameter and 7½″ long, and is introduced into the opening through a ⅝″ hole in the yoke, as shown in the drawing. The test sample is finished very accurately to ⅝″ in diameter, so that it makes a very close fit in the hole in the yoke. The lower end of the opening in the yoke and the lower end of the sample are accurately faced so as to make a perfect joint. The upper end of the sample is tapped to receive a ¼″ screw ⅜″ long, twenty threads per inch, by means of which a spring balance is attached to it. The magnetizing coil, *C*, is wound on a brass spool, *S*, 4″ long, with the end flanges turned up so that it may be fastened to the yoke by means of the screws. The axis of the coil coincides with the axis of the yoke and opening. The coil has flexible leads, which allow it to be easily removed trom the opening for the inspection of the surface where contact is made between the yoke and the test sample.

The spring balance, *F*, is suspended from an angle iron fastened to the upright rack, *I*, which engages with the pinion, *J*. The balance is suspended exactly over the centre of the yoke through which the sample passes, to avoid any side pull. A spring buffer, *K*, is provided, which allows perfectly free movement of the link holding the sample for a distance of about ⅛″, and then takes up the jar consequent upon the sudden release of the sample. The frame, *B*, which supports the pulling mechanism, is made of brass, and has feet cast at the bottom, by means of which the complete apparatus is fastened to the table. Two spring balances are provided, one reading to 30 lbs. and the other to 100 lbs. These spring balances are of special construction, having comparatively long scales. (They were originally made self-registering; but this was found unnecessary, as a reading could be taken with greater rapidity and with sufficient accuracy without the self-registering mechanism.) Any good spring balance may be used. The spring should be carefully calibrated from time to time over its whole range; and if there is a correction it will be found convenient to use a calibration curve in correcting the readings. With a sample ⅝″ in diameter, or ⅓ of a square inch area cross-section, the maximum pull required for cast iron is about 25 lbs., and for mild cast steel about 70 lbs.

With the number of turns on the coil given above, the current required for obtaining a magnetizing force of $\mathcal{H} = 300$, is about 12.5 amperes. This is as high a value as is ever necessary in ordinary work. For furnishing the current a storage battery is ordinarily used, and the variations made by means of a lamp board which has in addition a sliding resistance, so that variations of about .01 ampere may be obtained over the full range of current from 0.1 ampere to 12.5 amperes.

The operation of the permeameter is as follows: —

The sample to be tested is first demagnetized by introducing it into the field of an electro-magnet with a wire core, through which an alternating current is passing, and gradually removing it from the field of this electro-magnet. The sample is then introduced into the opening in the yoke, care being taken to see that it can move without friction. Measurements are taken with the smallest current to be used first, gradually increasing to the highest value desired. In no case should a reading be taken with a current of less value than has been reached with the sample in position, unless the sample is thoroughly demagnetized again before reading is taken. It is usually most convenient to make each successive adjustment of current with the sample out of position, then introduce the sample and give it a half turn, to insure perfect contact between the sample and the yoke. The lower end of the sample and the surface on which it rests should be carefully inspected to see that no foreign matter of any kind is present which might introduce serious errors in the measurements. The pull is made by turning the pinion slowly by means of a handle, *E*, carefully noting each position of the index of the spring balance as it advances over the scale, and noting the point of release. The mean of three or four readings is usually taken as the corrected value for pull, the current in the coil remaining constant. With practice the spring balance can be read to within less than 1%; and as the square root of the pull is taken, the final error becomes quite small, especially with high readings.

The evaluation of the results for the above permeameter is obtained by the use of the following formula: —

$$\text{The magnetizing force } \mathcal{H} = \frac{4\pi n_1 i}{10\, l}.$$

Where n_1 = number of turns in the magnetizing coil = 223,
i = current in amperes,
l = length of magnetic circuit in centimetres, estimated in this case as 11.74.

Substituting the known values in the above formula we have

$$\mathcal{H} = 23.8\, i.$$

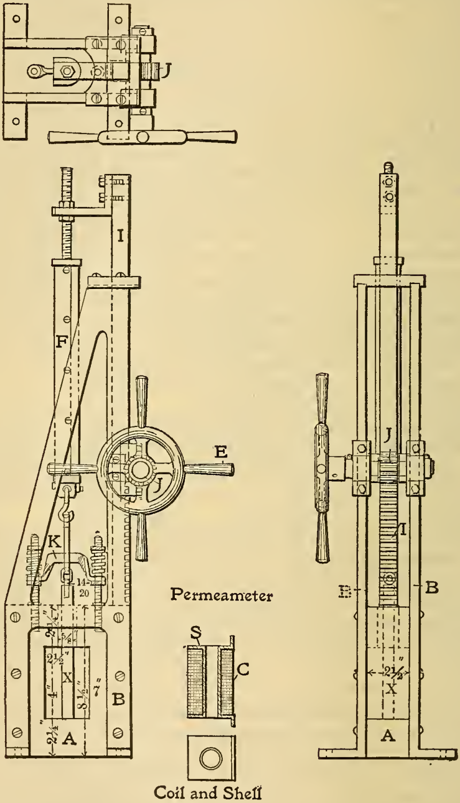


FIG. 5.

The number of lines of force per square centimetre,

$$\mathcal{B} = 1{,}317 \sqrt{\frac{P}{A}} + \mathcal{H}.$$

Where P = pull in lbs.
A = area of the sample in square inches = 0.3068.
$\mathcal{H}$ = value of the magnetizing force for the given pull.

Substituting the value of A in the above formula we have

$$\mathfrak{B} = 2{,}380\sqrt{P} + \mathfrak{H}.$$

There are several sources of error in measurements made by the permeameter which should be carefully considered, and eliminated as far as possible.

a. The unavoidable air gap between the sample and the yoke where it passes through the hole in the upper part of the yoke, together with the more or less imperfect contact at the lower end of the sample, increases the magnetic reluctance and introduces errors for which it is impossible to make due allowance. By careful manipulation, however, these can be reduced to a minimum, and be made practically constant.

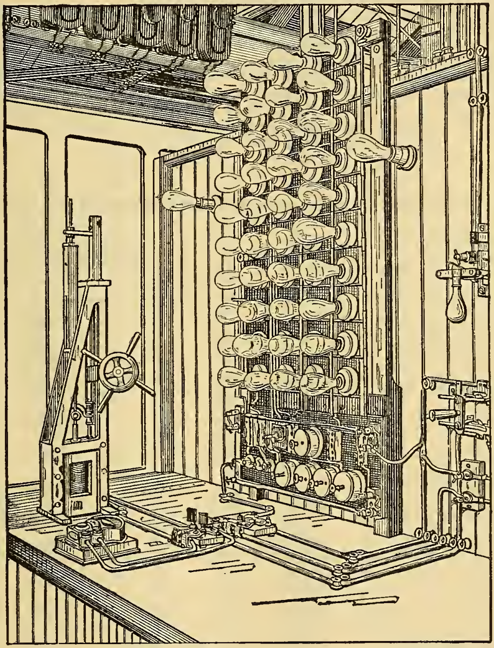


FIG. 6.

b. As the magnetization becomes greater the leakage at the lower end of the sample increases more rapidly; and there is considerable error at very high values from this source, as the leakage lines are not broken with the rest.

c. Errors in the calibration and reading of the spring balance. None but the best quality of spring balance should be used, and the average of several readings taken with the current remaining perfectly constant for each point on the $\mathfrak{B}$-$\mathfrak{H}$ curve. As the square root of the pull is taken, the errors due to reading the spring balance make a larger and larger percentage error in $\mathfrak{B}$ as P approaches zero, thus preventing accurate determinations being made at the beginning of the curve.

From the above it will be seen that the permeameter is not well adapted for giving the absolute values of the quality of iron and steel, but is especially suitable for comparative values, such as are noted in ordinary work, where a large number of samples are to be quickly measured. A complete curve can be taken and plotted in ten minutes. By suitable comparison of known samples measured by more accurate methods, the permeameter readings may be evaluated to a sufficient degree for use in the calculations of dynamo electric machinery.

CORE LOSSES.

These result from *Hysteresis* and *Eddy currents.*

Professor Ewing has given the name *Hysteresis* to that quality in iron which causes the lagging of the *induction* behind the magnetic force. It causes a loss when the direction of the induction is reversed, and results in a heating of the iron. It increases in direct proportion to the number of reversals, and as the 1.6th power of the maximum value of the induction in the iron core. The heat produced has to be dissipated either by radiation or conduction, or by both. Steinmetz gives the following formula for hysteresis loss in ergs per cubic centimeter, of iron per cycle; $h = \eta \mathfrak{B}^{1.6}$, where $\eta =$ a constant depending upon the kind of iron.

Hysteretic Constants for Different Materials.

MATERIAL.	HYSTERETIC CONSTANT. η.
Very soft iron wire	.002
Very thin soft sheet iron	.0015
Thin good sheet iron	.003
Thick sheet iron	.0033
Most ordinary sheet iron	.004
Transformer cores	.003
Soft annealed cast steel	.008
Soft machine steel	.0094
Cast steel	.012
Cast iron	.016
Hardened cast steel	.025

Eddy Currents are the local currents in the iron core caused by the E.M.F's generated by moving the cores in the field, and increase as the square of the number of revolutions per second. The cure is to divide or laminate the core so that currents cannot flow. These currents cause heating, and unless the core be laminated to a great degree, are apt to heat the armature core so much as to char the insulation of its windings.

Wiener gives tables showing the losses by Hysteresis and Eddy currents at one cycle per second, under different conditions. These are changed into any number of cycles by direct proportion. Following are the tables: —

Hysteresis Factors for Different Core Densities.

(Wiener.)

MAGNETIC DENSITY IN ARMATURE CORE. LINES OF FORCE PER SQ. IN.	WATTS DISSIPATED AT A FREQUENCY OF ONE COMPLETE MAGNETIC CYCLE PER SECOND.				MAGNETIC DENSITY IN ARMATURE CORE. LINES OF FORCE PER SQ. IN.	WATTS DISSIPATED AT A FREQUENCY OF ONE COMPLETE MAGNETIC CYCLE PER SECOND.			
	Sheet iron.		Iron wire.			Sheet iron.		Iron wire.	
	p.c.ft. η	p. lb. $\eta \div 480$	p.c.ft. η	per lb. $\eta \div 480$		p.c.ft. η	per lb. $\eta \div 480$	p.c.ft. η	per lb. $\eta \div 480$
10,000	1.25	.0026	14.3	.030	66,000	25.72	.0537	294.0	.613
15,000	2.40	.0050	27.4	.057	67,000	26.34	.0550	301.0	.628
20,000	3.79	.0079	43.3	.090	68,000	26.97	.0563	308.2	.643
25,000	5.42	.0113	62.0	.129	69,000	27.61	.0576	315.5	.658
30,000	7.30	.0152	83.5	.174	70,000	28.26	.0589	322.8	.673
31,000	7.70	.0160	88.0	.183	71,000	28.91	.0603	330.1	.688
32,000	8.10	.0168	92.6	.192	72,000	29.56	.0617	337.6	.704
33,000	8.50	.0177	97.2	.202	73,000	30.22	.0631	345.1	.720
34,000	8.91	.0186	101.8	.212	74,000	30.89	.0645	352.9	.736
35,000	9.33	.0195	106.5	.222	75,000	31.56	.0659	360.7	.752
36,000	9.76	.0204	111.5	.232	76,000	32.23	.0673	368.5	.768
37,000	10.20	.0213	116.5	.242	77,000	32.91	.0687	376.3	.784
38,000	10.65	.0222	121.6	.253	78,000	33.60	.0701	384.2	.800
39,000	11.10	.0231	126.8	.264	79,000	34.29	.0715	392.1	.817
40,000	11.55	.0240	132.0	.275	80,000	34.99	.0730	400.0	.834
41,000	12.01	.0250	137.2	.286	81,000	35.69	.0745	408.0	.851
42,000	12.48	.0260	142.5	.297	82,000	36.40	.0760	416.0	.868
43,000	12.96	.0270	148.0	.308	83,000	37.11	.0775	424.0	.885
44,000	13.45	.0280	153.7	.320	84,000	37.82	.0790	432.4	.902
45,000	13.95	.0290	159.4	.332	85,000	38.54	.0805	440.8	.919
46,000	14.45	.0300	165.1	.344	86,000	39.27	.0820	449.2	.936
47,000	14.95	.0311	170.8	.356	87,000	40.01	.0835	457.0	.954
48,000	15.45	.0322	176.6	.368	88,000	40.75	.0850	466.0	.972
49,000	15.96	.0333	182.4	.380	89,000	41.50	.0865	474.5	.990
50,000	16.48	.0344	188.3	.392	90,000	42.25	.0881	483.0	1.008
51,000	17.01	.0355	194.3	.405	91,000	43.00	.0897	491.5	1.023
52,000	17.55	.0366	200.6	.418	92,000	43.76	.0913	500.0	1.042
53,000	18.10	.0377	206.9	.431	93,000	44.53	.0929	509.0	1.064
54,000	18.65	.0388	213.2	.444	94,000	45.30	.0945	518.0	1.080
55,000	19.21	.0400	219.5	.457	95,000	46.07	.0961	527.0	1.098
56,000	19.78	.0412	226.0	.470	96,000	46.85	.0977	536.0	1.116
57,000	20.35	.0424	232.6	.484	97,000	47.63	.0993	545.0	1.135
58,000	20.92	.0436	239.2	.498	98,000	48.41	.1009	554.0	1.154
59,000	21.50	.0448	245.8	.512	99,000	49.20	.1025	563.0	1.173
60,000	22.09	.0460	252.5	.526	100,000	50.00	.1041	572.0	1.192
61,000	22.69	.0472	259.4	.530	105,000	54.06	.1127	618.0	1.290
62,000	23.29	.0485	266.3	.554	110,000	58.23	.1215	666.0	1.388
63,000	23.89	.0498	273.0	.568	115,000	62.53	.1305	715.0	1.490
64,000	24.50	.0511	280.0	.583	120,000	66.95	.1400	765.0	1.595
65,000	25.11	.0524	287.0	.598	125,000	71.50	.1500	817.5	1.705

The Step-by-Step Method of Hysteresis Test.

The samples for hysteresis tests, being generally of sheet iron, are made in the form of annular disks whose inner diameters are not less than $\frac{5}{8}$ of their external diameter. A number of these disks are stacked on top of each other, and the composite ring is wound with one layer of wire forming the magnetizing coil of n_1 turns. This coil is connected through a reversing switch to an ammeter in series with an adjustable resistance, and a storage battery. A secondary test coil of n_2 turns is connected with a ballistic galvanometer, as shown in Fig. 7.

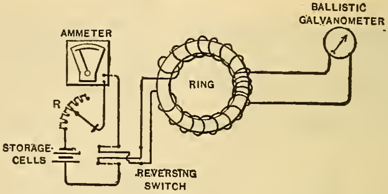


FIG. 7.

To make the test, adjust the resistance for the maximum exciting current. Reverse the switch several times, the galvanometer being disconnected. Then connect the galvanometer, and reduce the current by moving the contact arm of the rheostat up one step. This rheostat must be so constructed that an alteration in resistance can be made *without opening the circuit even for an instant.* Note the throw in the galvanometer corresponding to the change in exciting current. Follow this method by changing resistance step-by-step until the current reaches zero. Reverse the direction, and increase step-by-step up to a maximum and then back again to zero. Reverse once more, and increase step-by-step to the original maximum. In every case note and record the value of the exciting current i, and the corresponding throw of the galvanometer, θ. Form a table having the following headings to its columns: —

i, $\mathcal{H}$, θ, change of $\mathcal{B}$, $\mathcal{B}$.

Values of H are obtained from the formula,

$$\mathcal{H} = \frac{4\pi n_1 i}{10 l}, \text{ when } l = \text{average circumference of the test ring.}$$

Change of $\mathcal{B}$ is obtained by the formula,

$$\frac{10^8 R K \theta}{a n_2},$$

where all letters have the same significance as in the formula on page 67. Remember that we started in our test with a maximum *unknown* value of $\mathcal{B}$, and that we gradually decreased this by steps measurable by the throw of the galvanometer, and that we afterwards raised the $\mathcal{B}$ in an opposite direction to the same maximum *unknown* value, and still further reduced this to zero, and after commutation produced the original maximum value. According to this, if due consideration be paid to the sign of the $\mathcal{B}$ which is determined by the direction of the galvanometer throw, the algebraic sum of the changes in $\mathcal{B}$ should be equal to zero; the algebraic sum of the first or second half of the changes in $\mathcal{B}$ should be equal to twice the value of the original maximum, $\mathcal{B}$. Taking this maximum value as the first under the column of the table headed $\mathcal{B}$, and applying algebraically to this the changes in $\mathcal{B}$ for successive values, we obtain the completed table. Plot a curve of $\mathcal{H}$ and $\mathcal{B}$. The area enclosed represents the energy lost in carrying the sample through one cycle of magnetization between the maximum limits $+\mathcal{B}$ and $-\mathcal{B}$. Measure this area, and express it in the same units as is employed for the co-ordinate axes of the curve. This area divided by 4π

gives the number of ergs of work performed per cycle upon one cubic centimeter of the iron, the induction being carried to the limits $+\mathfrak{B}$ and $-\mathfrak{B}$.

The Wattmeter Method of Hysteresis Tests.

Inasmuch as the iron, a sample of which is submitted for test, is generally to be employed in the manufacture of alternating-current apparatus, it is desirable to make the test as nearly as possible under working conditions. If the samples be disks, as in the previous method, and these be shellacked on both sides before being united into the composite test-ring in order to avoid as much as possible foucault current losses, the test can be quickly made according to the method outlined in the following diagram: —

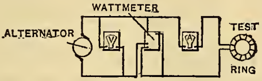


FIG. 8. Wattmeter Test for Hysteretic Constant.

Alternating current of f alternations per second is sent through the test-ring. Its voltage, E, and current strength, i, are measured by the alternating-current voltmeter, V, and ammeter, A. If r be the resistance of the test-ring coil of n_1 turns, then the watts lost in hysteresis W, is equal to the wattmeter reading $W' - i^2r$. If the volume of the iron be V cubic centimeters, and the cross section of the iron ring be a square centimeters, then Steinmetz's hysteretic constant

$$\eta = \frac{10^7\,W}{V\,f}\left(\frac{\sqrt{2}\pi\ n_1 f a}{E\,10^8}\right)^{1.6}.$$

Foucault current losses are neglected in this formula, and the assumption is made that the current is sinusoidal.

Ewing's Hysteresis Tester. — In this instrument, Fig. 9, the test sample is made up of about seven pieces of sheet iron $\frac{5}{8}''$ wide and $3''$ long. These are rotated between the poles of a permanent magnet mounted on knife edges.

The magnet carries a pointer which moves over a scale. Two standards of known hysteresis properties are used for reference. The deflections corresponding to these samples are plotted as a function of their hysteresis losses, and a line joining the two points thus found is referred to in subsequent tests, this line showing the relation existing between deflection and hysteresis loss. The deflections are practically the same, with a great variation in the thickness of the pile of test-pieces, so that no correction has to be made for such variation. This instrument has the advantage of using easily prepared test samples.

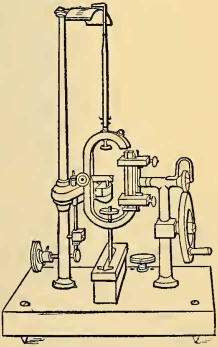


FIG. 9.

Hysteresis Meter, Used by General Electric Co.

DESIGNED AND DESCRIBED BY FRANK HOLDEN.

During the last few weeks of the year 1892 there was built at the works of the General Electric Company, in Lynn, Mass., under the writer's direction, an instrument, shown in Fig. 10, by which the losses in sheet iron were determined by measuring the torque produced on the iron, which was punched in rings, when placed between the poles of a rotating electro-magnet. The rings were held by a fibre frame so as to be concentric with a vertical shaft which worked freely on a pivot bearing at its lower end. They had a width of 1 centimeter, an outside diameter of 8.9 centimeters, and enough were used to make a cylinder about 1.8 centimeters high. The top part of this instrument, which rested on a thin brass cylinder surrounding the rings, was movable. On the upper surface was marked a degree scale, over which passed a pointer, with which the upper end of a helical spring rotated. It was so constructed that when the vertical shaft with the rings and the upper part of the instrument with the spring was put in place, the lower end of the spring engaged with the shaft, and consequently rotated with the rings. A pointer moving with the lower end of the spring reached to the zero of the degree scale when the apparatus was ready for use. By this arrangement it was found what distortion it was necessary to give the spring in order to balance the effect of the rotating magnet, and the spring having been calibrated, the ergs spent on the rings per cycle were determined by multiplying the degrees distortion by a constant.

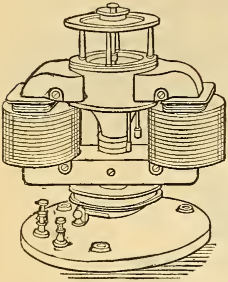


FIG. 10. Hysteresis Meter.

A coil, so arranged that it surrounded but did not touch the rings, made contact at its ends with two fixed brushes that rested in diametrically opposite positions on a two-part commutator, which revolved with a magnet. The segments were connected each to a collector ring against which rubbed a brush, the latter two brushes being joined through a sensitive Weston voltmeter. If this were so arranged that the coil was at right angles to the induction, when the brushes changed contact from one segment to the other, it is evident, the self-induction of the circuit being negligible, that the mean value of the current in the circuit was proportional to the total flux through the coil. Knowing the constant of the voltmeter, the deflection was easily calculated from the speed of the magnet, the number of turns in the coil, cross-section of the rings, and the resistance of the circuit. From an induction of 2,000 gausses to at least 10,000 gausses, the leakage across the interior space of the rings was negligible.

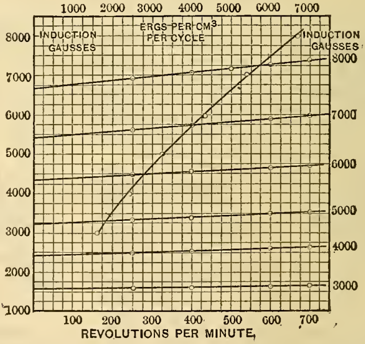


FIG. 11.

Carried on the shaft below the magnet was a pulley around which passed a flat belt driven with a pulley of the same size on an electric motor, so that the speed of the magnet could be found by observing that of the motor. In operating, the deflections to be produced on the voltmeter at a certain speed, with the desired induction in the rings, were first calculated. Five hundred revolutions per minute was generally adopted as the speed in this case. The motor being run at the desired speed, the magnetizing current was adjusted until the calculated deflection was produced on the voltmeter. Keeping the magnetizing current constant, the speed was changed successively in value to certain values, and the corresponding distortions of the spring necessary to balance the effect of the magnet noted. When this process was carried out at different induction values, and the ergs expended per cycle on the rings plotted as a function of the speed, a series of lines was produced, as shown in Figs. 11 and 12. It was found that the slope of the lines decreased very rapidly with the decrease in thickness of the iron sheet used so as to indicate that had it been thin enough the slope would have been zero between 100 and 800 revolutions per minute, which was about the highest speed permissible. From this it would seem that, in these tests, the total loss per cycle had two components; one remaining constant, due to hysteresis, and the other varying as the speed of the magnets, due to currents induced in the iron.

Fig. 15 gives observations of eddy current loss and thickness of iron sheet on this assumption. The line drawn is a parabola, so that it would appear that with the range of observations made the loss varied about as the square of the thickness of the sheets.

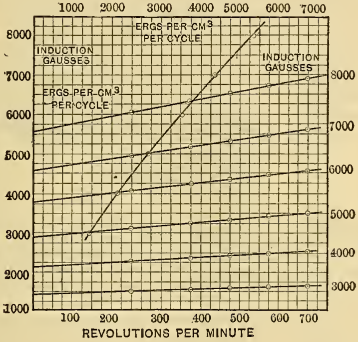


FIG. 12.

Fig. 11 gives lines from iron .04 centimeters thick. Speed readings were not taken lower than 250 revolutions per minute, as it had been found that the lines were always straight, and speeds below this value could not be read with the tachometer available for this particular test. Plotting the hysteresis as a function of the induction, in this case the points are all quite close to a curve whose equation is, Ergs $= A$ constant $\times$ (Density per square centimeter)$^{1.47}$, three points in the latter calculated curve being shown by the crosses. The iron, a test on which is shown in Fig. 12, was .1 centimeter thick, and shows a greater eddy current loss. The equation for the hysteresis curve for this sample is, Ergs $= A$ constant $\times$ (Density per square centimeters)$^{1.4}$, some points in the latter curve being shown by crosses, as before.

The eddy current losses for these two samples are plotted as functions of the induction in Fig. 14. The curves drawn are parabolas; showing that in these cases the eddy current loss varied approximately as the square of the induction, although there were often greater variations from that law than these two samples show. The average exponent for the hysteresis curves was a little over 1.5, although it varied from 1.4 to 1.7. Rings tested in this manner were wound and tested with a ballistic galvanometer, using the step-by-step method. There were discrepancies of as much as 4 per cent between the two results, but an average of ten tests showed the ballistic galvanometer method gave results 2.5 per cent lower than the other. This difference is easily attributable to experimental errors.

It being noticed that for a given induction in the rings, the magnetizing currents for different samples did not vary much, it was planned shortly after completing the above apparatus to construct a modified instrument which would use electro-magnets of such high reluctance that the variations of the rings would be negligible, and induction be dependent only on the current. By making the electro-magnets of suitable iron and of about one-third the cross-section of the rings used, the iron may be so highly saturated that the induction will remain quite constant under considerable variation in the magnetizing current, thus rendering unnecessary any accurate comparisons of magnetizing currents, and the rings can be at about their maximum permeability when thus magnetized. Such an instrument is shown in Fig. 13 in its original experimental form, with the rings in position ready for test. The rings are here allowed to rotate in opposition to the action of a spring and carry a pointer over a scale, so that is is quite direct reading. Twenty-five comparisons of this instrument with the original one gave results that agreed within 6 per cent in all cases, and more than half were within 2 per cent of agreement. Permanent magnets had been previously tried, but the attempt seemed to show that the instrument would not, in that case, compare samples of iron widely different in character; and the writer not being able to give any attention to the matter, no further investigations in that direction were attempted.

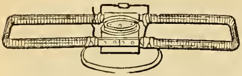


FIG. 13. Modified Hysteresis Meter.

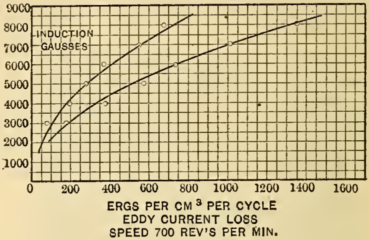


FIG. 14.

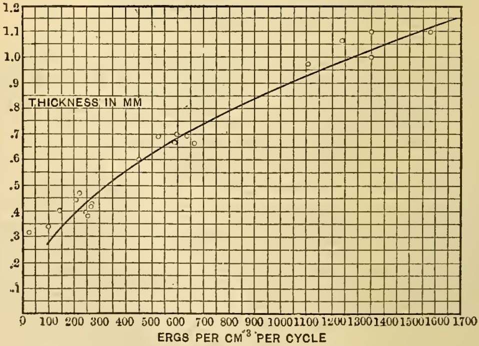


FIG. 15.

The instrument first described has been in use continuously since its completion at the works of the General Electric Company, in Schenectady.

EDDY CURRENT FACTORS FOR DIFFERENT CORE DENSITIES AND FOR VARIOUS LAMINATIONS.

(Wiener.)

Magnetic Density in Armature Core. Lines of Force per sq. in.	Watts dissipated per cubic foot of iron at a frequency of 1 cycle per second.				Magnetic Density in Armature Core. Lines of Force per sq. in.	Watts dissipated per cubic foot of iron at a frequency of 1 cycle per second.			
	Thickness of lamination, δ					Thickness of lamination, δ			
	.010″	.020″	.040″	.080″		.010″	.020″	.040″	.080″
10,000	.0007	.003	.012	.046	66,000	.0315	.126	.503	2.013
15,000	.0016	.007	.026	.104	67,000	.0325	.130	.519	2.075
20,000	.0029	.012	.046	.185	68,000	.0335	.134	.534	2.137
25,000	.0045	.018	.072	.288	69,000	.0345	.138	.550	2.200
30,000	.0065	.026	.104	.416	70,000	.0355	.142	.566	2.265
31,000	.0070	.028	.111	.444	71,000	.0365	.146	.582	2.330
32,000	.0074	.030	.118	.472	72,000	.0375	.150	.599	2.396
33,000	.0079	.032	.126	.503	73,000	.9385	.154	.616	2.463
34,000	.0084	.034	.134	.534	74,000	.0396	.158	.633	2.530
35,000	.0089	.036	.142	.567	75,000	.0407	.163	.650	2.600
36,000	.0094	.038	.150	.600	76,000	.0418	.167	.668	2.670
37,000	.0099	.040	.158	.633	77,000	.0429	.171	.685	2.740
38,000	.0104	.042	.167	.667	78,000	.0440	.176	.703	2.810
39,000	.0110	.044	.176	.703	79,000	.0451	.180	.721	2.883
40,000	.0116	.046	.185	.740	80,000	.0462	.185	.740	2.958
41,000	.0122	.049	.194	.777	81,000	.0474	.190	.758	3.033
42,000	.0128	.051	.204	.815	82,000	.0486	.194	.777	3.108
43,000	.0134	.054	.214	.855	83,000	.0498	.199	.796	3.184
44,000	.0140	.056	.224	.896	84,000	.0510	.204	.815	3.260
45,000	.0146	.059	.234	.937	85,000	.0523	.209	.835	3.340
46,000	.0153	.061	.245	.979	86,000	.0535	.214	.855	3.420
47,000	.0160	.064	.256	1.022	87,000	.0548	.219	.875	3.500
48,000	.0167	.067	.267	1.066	88,000	.0560	.224	.895	3.580
49,000	.0174	.070	.278	1.110	89,000	.0573	.229	.916	3.662
50,000	.0181	.072	.289	1.055	90,000	.0586	.234	.937	3.745
51,000	.0188	.075	.300	1.200	91,000	.0599	.240	.958	3.830
52,000	.0195	.078	.312	1.248	92,000	.0612	.245	.979	3.915
53,000	.0202	.081	.324	1.297	93,000	.0625	.250	1.000	4.000
54,000	.0210	.084	.337	1.346	94,000	.0638	.255	1.021	4.085
55,000	.0218	.087	.349	1.397	95,000	.0651	.261	1.043	4.170
56,000	.0226	.091	.362	1.448	96,000	.0665	.266	1.064	4.257
57,000	.0234	.094	.375	1.500	97,000	.0679	272	1.086	4.345
58,000	.0242	.097	.389	1.555	98,000	.0693	.277	1.109	4.436
59,000	.0251	.101	.403	1.610	99,000	.0707	.283	1.132	4.528
60,000	.0260	.104	.416	1.665	100,000	.0722	.289	1.156	4.622
61,000	.0269	.108	.430	1.720	105,000	.0797	.319	1.274	5.095
62,000	.0278	.111	.444	1.776	110,000	.0875	.350	1.398	5.593
63,000	.0287	.115	.458	1.833	115,000	.0955	.382	1.528	6.113
64,000	.0296	.118	.473	1.891	120,000	.1040	.416	1.664	6.655
65,000	.0305	.122	.486	1.951	125,000	.1128	.451	1.806	7.222

SPECIFIC ENERGY DISSIPATION IN ARMATURE CORE.

(Weiner.)

MAGNETIC DENSITY.		HYSTERESIS LOSS FOR SHEET IRON AT FREQUENCY OF ONE MAGNETIC CYCLE PER SECOND (IN WATTS).				EDDY-CURRENT LOSS FOR .030″(.075 CM.) LAMINATION, AT ONE CYCLE PER SECOND PROPORTIONAL TO FREQUENCY (IN WATTS).			
Gausses.	Lines of force per sq. in.	Per cm.^{3}	Per c. ft.	Per kg.	Per lb.	Per cm.^{3}	Per c. ft.	Per kg.	Per lb.
2,000	12,900	.00007	1.98	.0091	.0041	.0000004	.011	.000051	.000023
3,000	19,350	.00013	3.68	.0140	.0077	.0000009	.026	.000119	.000054
4,000	25,800	.00020	5.75	.0265	.0120	.0000016	.046	.000212	.000096
5,000	32,250	.00029	8.20	.0378	.0171	.0000025	.071	.000327	.000148
6,000	38,700	.00039	11.03	.0508	.0230	.0000036	.102	.000471	.000213
7,000	45,150	.00050	14.15	.0652	.0295	.0000049	.139	.000640	.000290
8,000	51,600	.00062	17.5	.0806	.0365	.0000064	.181	.000833	.000377
9,000	58,050	.00074	20.9	.0963	.0436	.0000081	.229	.001054	.000478
10,000	64,500	.00087	24.6	.1133	.0513	.0000100	.283	.001303	.000590
11,000	70,950	.00102	28.3	.1303	.0590	.0000121	.343	.001580	.000715
12,000	77,400	.00118	33.1	.1524	.0690	.0000144	.408	.001878	.000850
13.000	83.850	.00134	37.9	.1745	.0790	.0000169	.479	.002204	.000998
14,000	90,300	.00150	42.7	.1966	.0890	.0000196	.555	.002553	.001157
15,000	96,750	.00168	47.5	.2193	.0990	.0000225	.637	.002923	.001328
16,000	103,200	.00187	52.9	.2440	.1103	.0000256	.725	.003340	.001512
17,000	109,650	.00206	58.3	.2680	.1212	.0000289	.818	.003770	.001708
18,000	116,100	.00225	63.7	.2932	.1328	.0000324	.917	.004220	.001911
19,000	122,550	.00246	69.6	.3200	.1450	.0000361	1.022	.004710	.002130
20,000	129,000	.00267	75.6	.3480	.1575	.0000400	1.133	.005225	.002362

ELECTRO-MAGNETS,

PROPERTIES OF.

Residual Magnetism is the magnetization remaining in a piece of magnetic material after the magnetizing force is discontinued.

Retentiveness is the measure of the magnitude of residual magnetism.

Coercive Force is the force which holds the residual magnetism, and is measured by the strength of the reverse field required to remove all magnetism.

Permanent magnetism is residual magnetism of great coercive force, as in hard steel, which has little retentiveness; while soft iron has great retentiveness but little coercive force.

The following paragraphs are condensed from S. P. Thompson's "The Electromagnet."

Magneto-Motive Force. — The magneto-motive force, or magnetizing power of an electro-magnet is proportional to the number of turns of wire and the amperes of current flowing through them; that is, one ampere flowing through ten coils or turns will produce the same *magneto-motive force* as ten amperes flowing through one coil or turn.

If $n =$ number of turns in the coil,
$I =$ amperes of current flowing,

$$1.257 = \frac{4\pi}{10} \text{ (to reduce to C. G. S. units).}$$

Magneto-motive force $= 1.257 \times nI = \mathcal{F}$.

Intensity of Magnetic Force. — Intensity of magnetic force in an electro-magnet varies in different parts of the magnet, being strongest in the middle of the coil, and weaker toward the ends. In a long electro-magnet, say a length 100 times the diameter, the intensity of magnetic force will be found nearly uniform along the axis, falling off rapidly close to the ends.

In a long magnet, such as described above, and in an annular ring wound evenly over its full length, the value of the magnetic force, $\mathcal{H}$, is determined by the following expression:—

$$\mathcal{H} = 1.257\,\frac{n\,I}{l}, \text{ in which } l = \text{centimeters.}$$

If the length is given in inches, then

$$\mathcal{H} = .495\,\frac{n\,I}{l_{\prime\prime}}, \text{ in which } l_{\prime\prime} = \text{inches.}$$

If intensity of the magnetic force is to be expressed in lines per sq. inch,

$$\mathcal{H}_{\prime\prime} = 3.193 \times \frac{n\,I}{l_{\prime\prime}}.$$

Value of $\mathcal{H}$ at the centre of a Single-turn of Conductor. — In a single ring or turn of wire of radius r, carrying I amperes of current

$$\mathcal{H} = \frac{2\pi}{10} \times \frac{I}{r} = .6284 \times \frac{I}{r}.$$

Force on Conductor (carrying current) in a Magnetic Field. — A conductor carrying current in a magnetic field is repelled from the field by a certain mechanical force acting at right angles both to the conductor itself and to the lines of force in the field; see cut.

The magnitude of this repelling force is determined as follows, assuming the field to be uniform.

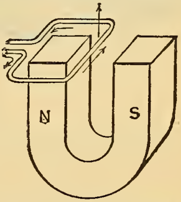


FIG. 1. Action of Magnetic Field, on Conductor carrying current.

$\mathcal{H} =$ magnetizing force, or intensity of the field.
$l =$ length of conductor across the field in c.m.
$l_{\prime\prime} =$ ditto in inches.
$I =$ amperes of current flowing in the conductor.
$F =$ repelling force.

F in dynes $= \dfrac{\mathcal{H}\,l\,I}{10}$. F in dynes $= \dfrac{\mathcal{H}\,l_{\prime\prime}\,I}{25.4}$. F in grains $= \dfrac{\mathcal{H}_{\prime\prime}\,l_{\prime\prime}\,I}{161}$.

Work done by Conductor (carrying Current) in moving across a Magnetic Field.

If the conductor described in the preceding paragraph be moved across the field of force, the work done will be determined as follows: in addition to the symbols there used, let b = breadth of field in and across which the conductor is moved; w = work done in ergs.

$$w = Fb = \frac{b \mathcal{H} l I}{10},$$

$$bl = \text{area of field},$$

$$N = bl \times \phi = \text{number of lines of force cut},$$

$$w = \frac{NI}{10}.$$

Rotation of Conductor (carrying current) around a Magnet Pole.

If a conductor (carrying current) be so arranged that it can rotate about the pole of a magnet, the force producing the rotation, called *torque*, will be determined as follows: The whole number of lines of force radiating from the pole will be 4π times the pole strength m.

$$w = \frac{4\pi\ mI}{10} = 1.257\ mI.$$

Dividing by the angle 2π, the *torque*, T, is

$$T = \frac{2\ mI}{10} = .2\ mI.$$

Every magnetic circuit tends to place itself so as to embrace the maximum flux.

Two electric conductors carrying currents tend to place themselves in position such that their mutual flux may be maximum; otherwise stated: if two currents run parallel and in the same direction, each produces a field of its own, and each conductor tends to move across the other's field.

In two coils or conductors lying parallel to each other, as in a tangent galvanometer, the mutual force varies directly in proportion to the product of their respective ni, and inversely as the axial distance they are apart.

Principle of the Magnetic Circuit.—The resistance that a magnetic circuit offers to the passage or flow of *magnetic lines of force* or *flux*, has been given the name of *reluctance*, symbol $\mathcal{R}$, and is analogous to *resistance*, to the flow of electric current in a conductor.

The *magnetic flux* or lines of force are treated as current flowing in the magnetic circuit, and denoted by the symbol ϕ.

The above two factors, together with the *magneto-motive force* described in the early part of this chapter, bear much the same relation to each other as do resistance, current, and E.M.F. of electric circuits, and are expressed as follows:—

$$\text{Magnetic flux} = \frac{\text{Magneto-motive force}}{\text{reluctance}}.$$

$$\phi = \frac{\mathcal{F}}{\mathcal{R}}.$$

$$\mathcal{F} = \frac{4\pi\ nI}{10} = 1.257\, nI.$$

$$\mathcal{R} = \frac{l}{A\mu}.$$

$$\phi = \frac{1.257\ nI}{\frac{l}{A\mu}}.$$

$$nI = \frac{\phi \frac{l}{A\mu}}{1.257}.$$

If dimensions are in inches, and A is in square inches, then

$$nI = \phi \frac{l_{''}}{A_{''}\mu} \times .3132.$$

$$\text{and } \phi = \mathcal{B}'' A''.$$

The Law of Traction. — The formula for the *pull* or lifting-power of an electro-magnet is as follows: —

$$\text{Pull (in dynes)} = \frac{\mathcal{B}^2 A}{8\pi}.$$

$$\text{Pull (in grammes)} = \frac{\mathcal{B}^2 A}{8\pi \times 981}.$$

$$\text{Pull (in pounds)} = \frac{\mathcal{B}^2 A}{11,183,000}.$$

$$\text{In inch measure, Pull (in pounds)} = \frac{\mathcal{B}^2_{''} A''}{72,134,000}.$$

Magnetization and Traction of Electro Magnets.

$\mathcal{B}$ Lines per sq. cm.	$\mathcal{B}_{''}$ Lines per sq. inch.	Dynes per sq. cm.	Grammes per sq. cm.	Kilogs per sq. cm.	Pounds per sq. inch.
1,000	6,450	39,790	40.56	.04056	.577
2,000	12,900	159,200	162.3	.1623	2.308
3,000	19,350	358,100	365.1	.3651	5.190
4,000	25,800	636,600	648.9	.6489	9.228
5,000	32,250	994,700	1,014	1.014	14.39
6,000	38,700	1,432,000	1,460	1.460	20.75
7,000	45,150	1,950,000	1,987	1.987	28.26
8,000	51,600	2,547,000	2,596	2.596	36.95
9,000	58,050	3,223,000	3,286	3.286	46.72
10,000	64,500	3,979,000	4,056	4.056	57.68
11,000	70,950	4,815,000	4,907	4.907	69.77
12,000	77,400	5,730,000	5,841	5.841	83.07
13,000	83,850	6,725,000	6,855	6.855	97.47
14,000	90,300	7,800,000	7,550	7.550	113.1
15,000	96,750	8,953,000	9,124	9.124	129.7
16,000	103,200	10,170,000	10,390	10.390	147.7
17,000	109,650	11,500,000	11,720	11.720	166.6
18,000	116,100	12,890,000	13,140	13.140	186.8
19,000	122,550	14,360,000	14,630	14.630	208.1
20,000	129,000	15,920,000	16,230	16.230	230.8

Exciting Power and Traction. — If we can assume that there is no magnetic leakage, the *exciting power* may be calculated from the following expression; all dimensions being in inches, and the *pull* in pounds.

$$nI = \frac{\mathcal{B}'' l''}{\mu} \times .3132.$$

$$\mathcal{B}'' = \frac{\mu \times nI}{l'' \times .3132},$$

$$\text{also, } \mathcal{B}'' = 8494 \sqrt{\frac{\text{Pull}}{\text{Area}''}}.$$

$$nI = 2661 \times \frac{l''}{\mu} \times \sqrt{\frac{\text{Pull}}{\text{Area}''}}.$$

If dimensions are in metric measure,

$$nI = 3951 \frac{l}{\mu} \sqrt{\frac{\text{Pull in kilos}}{\text{Area in sq. cms.}}}.$$

$$\mathcal{B} = 1316.6 \sqrt{\frac{\text{Pull in lbs.}}{\text{Area in sq. ins.}}}. \qquad \mathcal{B} = 4965 \sqrt{\frac{\text{Pull in kilos.}}{\text{Area sq. cm.}}}.$$

Winding of Magnet Coils.

The following nomenclature is employed:—

$D =$ diameter of insulated wire in mils.
$d =$ diameter of bare wire in mils.
$t =$ thickness of insulation on wire in inches $\left(\text{i.e., } \frac{D-d}{2}\right)$.
$L =$ total length of wire in coil in feet. a, b, h, and $l =$ coil dimensions in inches.
$K =$ ratio of diameter of insulated wire to bare wire.
$V =$ volume of winding space in cubic inches.
$N =$ total number of convolutions on spool.
$T =$ number of layers of wire on spool.
$n =$ number of convolutions per linear inch.
$\rho =$ resistance in international ohms of mil-foot of pure copper wire. (10.35 ohms at 20° C.)
$R =$ total resistance of coil in ohms.
$r =$ resistance per foot of wire in ohms.
$f = \frac{1}{r} =$ feet in one ohm.
$l_m =$ mean length of convolution in inches.

The winding will vary between two extremes, one the "square" winding in which it is assumed that the convolutions lie together as if the wire was of square cross-section, and the other the "conical" winding in which it is assumed that the wires lie together as if the wire was of hexagonal cross-section. On the assumption that the same volume is occupied by insulating material about 15 per cent more copper volume is obtained by the "conical" method of winding.

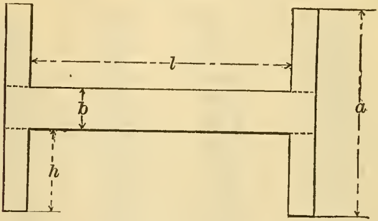


FIG. 2.

The square winding is assumed in the following, unless otherwise specified.

The *diameter* of wire necessary to fill a given coil space with a given number of convolutions is

$$D = \sqrt{\frac{1000000\, l\, h}{N}} = \sqrt{\frac{500000\, l\, (a-b)}{N}},$$

or

$$d = \sqrt{\frac{1000000\, l\, h}{K^2 N}} = \sqrt{\frac{500000\, l\, (a-b)}{K^2 N}}.$$

The total length of wire of given diameter which can be wound in a given coil space is

$$L = \frac{65450\, l\, (a^2 - b^2)}{D^2}.$$

From the above formula the dimensions of a spool to hold a specified length of wire of given diameter may be determined.

If a and b are known

$$l = \frac{LD^2}{65450\, (a^2 - b^2)}.$$

If b and l are known

$$a = \sqrt{\frac{D^2 L + 65450\, l b^2}{65450\, l}}.$$

If a and l are known

$$b = \sqrt{\frac{65450\, l b^2 - D^2 L}{65450\, l}}.$$

The resistance of a coil expressed as a function of the volume is

$$R = \frac{862500\ V}{D^2 d^2}.$$

If the volume of wire is increased ten per cent to allow for the layers fitting into one another,

$$R = \frac{948700\ V}{D^2 d^2}.$$

Hence the diameter of wire necessary to fill a given volume with a given resistance is

$$d^4 = \frac{948700\ V}{K^2 R}.$$

The last three formulæ are general, whatever the shape of the spool, i.e., whether the core is of circular, square, rectangular, elliptical, etc., cross-section.

The next smaller gauge number than the diameter corresponding to the formula should be used in order to allow for irregularities in winding and for insulation between the layers.

If R is taken at other than 68° F (20° C.), a new value of R, i.e., R', must be taken, where

$$R' = R\,(1 + 0.0022\ \theta_f),$$

where θ_f is the rise in temperature above 68° F.

A formula known as Brough's formula is often applicable to the calculations of the diameter of wire necessary to give a stated resistance.

For circular cores,

$$d = \left[\sqrt{\frac{677400\ (a^2 - b^2)\ l}{R} + t^2}\,\right]^{\frac{1}{2}} - t.$$

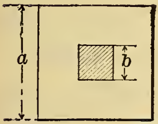


FIG. 3.

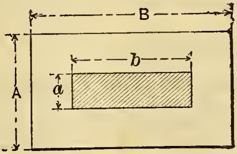


FIG. 4.

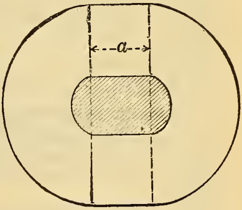


FIG. 5.

For square cores, Fig. 3,

$$d = \left[\sqrt{\frac{862500\ (a^2 - b^2)\ l}{R} + t^2}\,\right]^{\frac{1}{2}} - t.$$

For rectangular cores, Fig. 4,

$$d = \left[\sqrt{\frac{431250\ (A - a)\ (A + B + a + b)}{R} + t^2}\,\right]^{\frac{1}{2}} - t.$$

For core made up of square and two semi-circles, Fig. 5,

radius of core-circle, b.
radius of outer-circle, b.

$$d = \left[\sqrt{\frac{862500\,(B-b)\,[\pi\,(B+b)+2\,a]}{R}} + t^2 \right]^{\frac{1}{2}} - t.$$

Thickness of Wire Insulation. — The thickness of insulation upon wire varies with the manufacturer, and no fixed value can be given to cover all cases. The following table represents the practice of several large manufacturers. To determine the *diameter* of insulated wire, add to the *diameter* of the bare wire.

	FOR COTTON.		FOR SILK.	
B & S Gauge	Single	Double	Single	Double
0 to 10	7 mils	14 mils		
10 to 18	5 mils	10 mils		
18 up	4 mils	8 mils	2 mils	4 mils

The above values correspond to $2t$ in the formulæ.

Relation of Ampere-turns to Dimensions of Coil.

For a coil of stated dimensions it can be shown that

$$NI = 1.16 \frac{E\,d^2}{l_m\,(1. + 0.0022\,\theta_f)},$$

where $E =$ difference of potential across terminals of coil.

The ampere-turns are independent of the length of the coil, of the thickness of insulation, and of the method of winding, depending upon the diameter of the wire, the mean length of a turn, and the temperature of the coil.

To keep the number of ampere-turns constant in a coil of given volume, d^2 of the wire must vary inversely as E.

Relations Holding between Constants of Coils.

In the following it is assumed that the thickness of insulation is proportional to the diameter of wire, and that all coils are uniformly wound. The results obtained under this consideration are practically but not strictly correct.

The weight of copper required to fill a given coil volume is constant, whatever the size of the wire used.

The resistance in a given volume varies inversely as the fourth power of the diameter of the wire used.

The resistance in a given volume varies inversely as the square of the cross-sectional area of the wire used.

The number of convolutions in a fixed volume varies inversely as the square of the diameter, or inversely as the cross-sectional area of the wire used.

The resistance of a coil of given volume varies directly as the square of the number of turns.

The magnetic effect produced by an electro-magnet of given shape, size, and construction is proportional to the product of the current into the square root of the resistance of the coil.

If two coils of same dimensions are wound with different size wire, the current must vary with the cross-sectional area of the wire, in order to obtain the same heating effect, or same temperature rise.

For same energy loss E^2 must vary inversely as (area)^2 of wire, or for same heating effect the voltage across terminals of coil must vary inversely as the cross-sectional area of the wire used.

ALTERNATING-CURRENT ELECTRO-MAGNETS.

The cores of electro-magnets to be used with alternating currents must be laminated, and the laminations must run at right angles to the direction in which eddy currents would be set up. Eddy currents tend to circulate parallel to the coils of the wire, and the laminations must therefore be longitudinal to or parallel with the axis of the cores.

The coils of an alternating-current electro-magnet offer more resistance to the passage of the alternating current than the mere resistance of the conductor in ohms. This extra resistance is called *inductance*, and this combined with the resistance of the conductor in ohms produces the quality called *impedance*. (See Index for Impedance, etc.)

If $L =$ coefficient of self-induction,
$N =$ periods per second,
$R =$ resistance,

$$\text{Impedance} = \sqrt{R^2 + 4\pi^2 N^2 L^2};$$

and,

$$\text{Maximum current} = \frac{\text{Maximum E.M.F.}}{\text{Impedance}}.$$

$$\text{Mean current} = \frac{\text{Mean E.M.E.}}{\text{Impedance.}}$$

If the current lags behind the E.M.F. by the angle ϕ, then

$$\text{Mean current} = \frac{\text{Mean E.M.F.}}{\text{Resistance}} \times \cos\phi.$$

HEATING OF MAGNET COILS.

Professor Forbes.

$I =$ current permissible.
$r_1 =$ resistance of coil at permissible temperature.
Permissible temperature $=$ cold $r \times 1.2$.
$t =$ rise in temperature C°.
$s =$ sq. cms. surface of coil exposed to air.

$$I = \sqrt{\frac{.0003 \times t \times s}{.24 \times r_1}}.$$

PERMISSIBLE AMPERAGE AND PERMISSIBLE DEPTH OF WINDING FOR MAGNETS WITH COTTON-COVERED WIRE.

(Walter S. Dix, *Electrical Engineer*, Dec. 21, 1892.)

$$I = \sqrt{\frac{12 \times W}{\frac{\omega}{M} \times T \times n}}.$$

Where $I =$ current;
$W =$ emissivity in watts per sq. inch;
$\omega =$ ohms per mil-foot;
$M =$ circular mils;
$T =$ turns per linear inch;
$n =$ number of layers in depth.

The emissivity is taken at .4 watt per sq. in. for stationary magnets for a rise of temperature of 35° C. (63° F.). For armatures, according to Esson's experiments, it is approximately correct to say that .9 watt per sq. in. will be dissipated for a rise of 35° C.

The insulation allowed is .007 inch on No. 0 to No. 11 B. and S.; .005 inch on No. 12 to 24; and .0045 inch on No. 25 to No. 31 single; twice these values for insulation of double-covered wires. Fifteen per cent is allowed for imbedding of the wires.

The standard of resistance employed is 9.612 ohms per mil-foot at 0°. The running temperature of tables is taken at $25° + 35° = 60°$ C. The column giving the depth for one layer is the diameter over insulation.

Permissible Amperage and Permissible Depth of Winding for Magnets with Single Cotton-Covered Wire.

Gauge.		Diam. bare, inches.	Circular Mils.	Ohms per foot at 60 degrees C.	Lbs. per Foot.	Turns per linear inch.	Layers.																					
B. and S.	Bir.				Cov'd		1		2		3		4		6		8		10		12		14		16		18	
							Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.
	2	.284	80656	.000150		3.44	96.7	.291	68.3	.56	55.8	.80	48.4	1.05	39.5	1.55	34.2	2.06	30.7	2.57	27.9	3.08	25.8	3.58	24.2	4.08	22.8	4.60
	3	.259	67081	.000180		3.76	84.3	.266	59.6	.50	48.6	.73	42.2	.96	34.4	1.42	29.8	1.89	26.7	2.35	24.3	2.81	22.6	3.28	21.1	3.74	19.9	4.20
2		.2576	66373	.000182		3.78	83.6	.2646	59.1	.50	48.2	.73	41.8	.96	34.1	1.41	29.6	1.87	26.5	2.34	24.1	2.80	22.4	3.26	20.9	3.72	19.7	4.18
	4	.238	56644	.000213		4.08	74.3	.245	52.5	.46	42.8	.67	37.1	.89	30.3	1.31	26.1	1.74	23.6	2.16	21.4	2.59	19.9	3.02	18.6	3.44	17.5	3.87
3		.2294	52634	.000229		4.23	70.4	.2364	49.8	.44	40.6	.65	35.2	.86	28.8	1.26	24.9	1.67	22.3	2.09	20.3	2.50	18.8	2.91	17.6	3.32	16.6	3.73
	5	.22	48400	.000249		4.41	66.2	.227	46.8	.43	38.2	.62	33.1	.82	27.0	1.21	23.4	1.61	21.0	2.00	19.1	2.40	17.7	2.80	16.6	3.19	15.6	3.58
4		.2043	41743	.000289	.143	4.73	59.3	.2113	41.9	.40	34.2	.58	29.9	.76	24.2	1.13	21.0	1.50	18.8	1.86	17.1	2.23	15.8	2.60	14.8	2.97	14.0	3.33
	6	.203	41209	.000292		4.76	58.8	.210	39.5	.39	33.9	.58	29.6	.76	24.0	1.12	20.8	1.49	18.6	1.85	16.9	2.22	15.7	2.59	14.7	2.95	13.9	3.32
5		.1819	33102	.000365	.111	5.29	49.9	.189	35.3	.36	28.8	.52	24.9	.68	20.4	1.01	17.7	1.34	15.8	1.67	14.4	2.00	13.3	2.33	12.5	2.86	11.8	2.99
	7	.18	32400	.000273		5.35	49.1	.187	34.7	.35	28.3	.51	24.5	.67	20.0	1.00	17.3	1.33	15.5	1.65	14.1	1.98	13.1	2.30	12.27	2.63	11.6	2.95
	8	.165	27225	.000443		5.81	43.2	.172	30.5	.32	24.9	.47	21.6	.62	17.6	.92	15.3	1.22	13.7	1.52	12.5	1.82	11.5	2.12	10.80	2.42	10.2	2.72
6		.162	26251	.000459	.0869	5.92	42.1	.169	29.7	.32	24.2	.46	21.1	.61	17.2	.90	14.9	1.20	13.3	1.49	12.1	1.79	11.2	2.08	10.52	2.38	9.94	2.67
	9	.148	21904	.000551		6.45	36.8	.155	26.0	.29	21.2	.43	18.4	.56	15.0	.83	13.0	1.10	11.65	1.37	10.6	1.64	9.83	1.91	9.20	2.18	8.68	2.45
7		.1443	20817	.000580	.0714	6.61	35.4	.1513	25.0	.28	20.4	.42	17.7	.55	14.4	.81	12.5	1.07	11.21	1.33	10.2	1.60	9.46	1.86	8.85	2.13	8.35	2.39
	10	.134	17956	.000672		7.09	31.7	.141	22.4	.26	18.3	.39	15.8	.51	12.9	.75	11.2	1.00	10.04	1.24	9.15	1.49	8.48	1.74	7.92	1.98	7.48	2.23
8		.1285	16510	.000731	.0571	7.38	29.9	.1355	21.2	.25	17.2	.37	14.9	.49	12.2	.72	10.6	.96	9.48	1.20	8.63	1.43	7.99	1.67	7.47	1.90	7.06	2.14
	11	.12	14400	.000838		7.87	27.0	.127	19.1	.24	15.55	.35	13.5	.46	11.0	.68	9.56	.90	8.56	1.12	7.79	1.34	7.22	1.56	6.75	1.79	6.37	2.00
9		.1144	13094	.000922	.0454	8.24	25.1	.1214	17.8	.23	14.45	.33	12.57	.44	10.2	.65	8.90	.86	7.95	1.07	7.25	1.28	6.71	1.50	6.27	1.71	5.92	1.92
	12	.109	11881	.001015		8.62	23.4	.116	16.6	.22	13.48	.32	11.70	.42	9.55	.62	8.28	.82	7.44	1.02	6.75	1.23	6.25	1.43	5.85	1.63	5.52	1.83
10		.1019	10382	.001161	.0370	9.18	21.3	.1089	15.1	.204	12.26	.30	10.63	.39	8.20	.58	7.54	.77	6.75	.96	6.15	1.15	5.70	1.34	5.32	1.53	5.03	1.72
	13	.095	9025	.001336		9.80	19.2	.102	13.56	.191	11.05	.28	9.60	.37	7.84	.55	6.80	.72	6.08	.90	5.54	1.08	5.13	1.26	4.80	1.43	4.53	1.61
11		.0907	8234	.001465	.0294	10.24	17.9	.0977	12.65	.183	10.60	.27	8.95	.35	7.31	.57	6.34	.69	5.67	.86	5.17	1.03	4.78	1.20	4.97	1.37	4.22	1.54

Permissible Amperage and Permissible Depth of Winding for Magnets with Single Cotton-Covered Wire. — Continued.

Gauge.		Diam. Bare, inches.	Circular Mils.	Ohms per foot at 60 degrees C.	Lbs. per Foot.	Turns per linear inch.	Layers.																					
							1		2		3		4		6		8		10		12		14		16		18	
B. and S.	Bir.				Cov'd		Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.
	14	.083	6889	.00175		11.36	15.37	.088	10.85	.165	8.86	.24	7.68	.32	6.27	.47	5.44	.62	4.87	.78	4.43	.93	4.10	1.08	3.84	1.24	3.62	1.39
12		.0808	6530	.001845	.0238	11.66	14.93	.0858	10.55	.161	8.62	.236	7.46	.31	6.10	.46	5.28	.61	4.73	.76	4.31	.91	3.99	1.06	3.73	1.21	3.52	1.35
13	15	.072	5184	.002325	.0182	12.99	12.61	.077	8.92	.144	7.28	.212	6.30	.28	5.15	.41	4.47	.55	4.00	.68	3.64	.82	3.37	.95	3.15	1.08	2.98	1.22
	16	.065	4225	.00286		14.29	10.84	.07	7.66	.131	6.26	.192	5.42	.25	4.43	.38	3.84	.50	3.44	.62	3.12	.74	2.90	.86	2.71	.98	2.56	1.10
14		.0641	4107	.002935	.0147	14.47	10.63	.0691	7.52	.129	6.14	.190	5.31	.25	4.34	.37	3.76	.49	3.37	.61	3.07	.73	2.84	.85	2.66	.97	2.51	1.09
15		.0571	3257	.00370	.0115	16.10	8.98	.0621	6.34	.116	5.18	.170	4.49	.224	3.66	.33	3.18	.44	2.85	.55	2.59	.66	2.40	.77	2.24	.87	2.12	.98
16		.0508	2583	.004665	.00909	17.92	7.58	.0558	5.36	.105	4.37	.153	3.79	.202	3.10	.30	2.68	.40	2.40	.49	2.19	.59	2.03	.69	1.89	.79	1.79	.88
17		.0453	2048	.00589	.00714	19.88	6.41	.0503	4.53	.094	3.69	.138	3.21	.181	2.62	.27	2.27	.36	2.08	.44	1.85	.53	1.71	.62	1.60	.71	1.51	.80
18		.0403	1624	.00742	.00571	22.08	5.41	.0453	3.82	.085	3.12	.124	2.71	.164	2.21	.24	1.91	.32	1.71	.40	1.56	.48	1.44	.56	1.35	.64	1.27	.72
19		.0359	1288	.00935	.00455	24.45	4.59	.0409	3.24	.077	2.65	.112	2.29	.148	1.87	.22	1.62	.29	1.46	.36	1.32	.43	1.23	.51	1.15	.58	1.08	.65
20	21	.032	1024	.0118	.00357	27.03	3.88	.037	2.74	.069	2.24	.102	1.94	.137	1.58	.198	1.37	.26	1.26	.33	1.12	.39	1.04	.46	.970	.52	.916	.58
21		.0285	810	.0149	.00278	29.85	3.28	.0335	2.32	.063	1.89	.092	1.64	.121	1.34	.179	1.16	.24	1.04	.30	.946	.35	.877	.41	.820	.47	.774	.53
22		.0253	642	.01874	.00222	33.00	2.79	.0303	1.97	.057	1.61	.082	1.39	.109	1.14	.162	.988	.22	.885	.27	.805	.32	.746	.37	.697	.43	.658	.48
23		.0226	509	.02365	.00178	36.23	2.37	.0276	1.67	.052	1.365	.076	1.184	.100	.968	.148	.839	.20	.752	.24	.683	.29	.633	.34	.592	.39	.559	.44
	24	.022	484	.0249		37.04	2.29	.027	1.616	.051	1.320	.074	1.142	.098	.935	.144	.810	.19	.726	.24	.661	.29	.612	.33	.572	.38	.540	.43
24		.0201	404	.0298	.00140	39.84	2.01	.0251	1.420	.047	1.157	.069	1.005	.091	.820	.134	.712	.178	.637	.22	.580	.27	.537	.31	.502	.35	.474	.40
25		.0179	320	.0377	.00110	44.64	1.69	.0224	1.193	.042	.975	.062	.845	.081	.690	.120	.598	.159	.536	.197	.487	.24	.452	.28	.322	.32	.399	.35
26		.0159	254	.0475	.000858	49.02	1.436	.0204	1.014	.038	.828	.055	.718	.073	.587	.109	.508	.145	.455	.180	.414	.21	.384	25	.309	.29	.339	.32
27		.0142	201	.0600	.000692	53.48	1.223	.0187	.865	.035	.707	.051	.611	.068	.499	.100	.433	.133	.388	.165	.353	.198	.327	.23	.306	.26	.289	.30
28		.0126	159.8	.0755	.000552	58.48	1.043	.0171	.737	.032	.602	.047	.521	.062	.427	.092	.369	.121	.331	.151	.301	.181	.279	.21	.261	.24	.244	.27
29		.0113	126.7	.0952	.000439	63.29	.893	.0158	.631	.030	.515	.043	.446	.057	.364	.085	.316	.112	.283	.139	.258	.167	.239	.195	.223	.22	.211	.25
30		.01003	100.5	.1200	.000356	68.97	.762	.0145	.538	.027	.439	.040	.381	.052	.311	.078	.270	.103	.242	.128	.220	.153	.204	.179	.190	.20	.180	.23

With Double Cotton-Covered Wire.

Gauge.		Diam. Bare, inches.	Circular mils.	Ohms per foot at 60° C.	Lbs. per foot.		Turns per linear inch.	Layers.							
								1		5		10		20	
B. and S.	Bir.				Bare.	Covered.		Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.
	2	.284	80656	.0001495	.244		3.36	97.8	.298	43.7	1.334	31.0	2.63	21.9	5.23
	3	.259	67081	.000180	.203		3.66	85.4	.273	38.1	1.222	27.1	2.41	19.1	4.79
2		.2576	66373	.000182	.201		3.68	84.6	.2716	37.7	1.216	26.8	2.40	18.9	4.76
	4	.238	56644	.000213	.172		3.97	75.4	.252	33.6	1.128	23.9	2.21	16.8	4.42
3		.2294	52634	.000229	.159		4.11	71.5	.2434	31.9	1.090	22.7	2.15	16.0	4.27
	5	.22	48400	.000249	.146		4.27	67.2	.234	30.0	1.046	21.3	2.07	15.0	4.10
4		.2043	41743	.000289	.126	.159	4.58	60.3	.2183	26.9	.980	19.1	1.93	13.5	3.84
	6	.203	41209	.000292	.125		4.61	59.8	.217	26.7	.974	18.9	1.92	13.4	3.80
5		.1819	33102	.000365	.100	.122	5.10	50.8	.196	22.7	.880	16.1	1.73	11.4	3.44
	7	.18	32400	.0002725	.0979		5.16	50.0	.194	22.3	.871	15.8	1.71	11.2	3.40
	8	.165	27225	.000443	.0825		5.59	44.1	.179	19.7	.804	13.9	1.58	9.85	3.14
6		.162	26251	.000459	.0794	.0942	5.68	42.9	.176	19.1	.791	13.6	1.55	9.61	3.09
	9	.148	21904	.000551	.0663		6.17	37.6	.162	16.8	.727	11.9	1.43	8.41	2.84
7		.1443	20817	.0005795	.0628	.0796	6.32	36.2	.1583	16.1	.712	11.5	1.40	8.10	2.78
	10	.134	17956	.000672	.0544		6.76	32.5	.148	14.5	.665	10.3	1.31	7.27	2.59
8		.1285	16510	.000731	.0501	.0617	7.02	30.6	.1425	13.6	.640	9.70	1.26	6.84	2.50
	11	.12	14400	.000838	.0436		7.46	27.7	.134	12.3	.602	8.78	1.18	6.20	2.35
9		.1144	13094	.000922	.0393	.0505	7.79	25.7	.1284	11.5	.577	8.14	1.13	5.75	2.25

Table of Spaces occupied by Wires of Different Sizes, with Single Cotton Insulation, together with Data of the Copper.

Compiled by SCHUYLER S. WHEELER.

Data of the Insulated Wire.									
No. American or B. & S. Gauge.	Turns to the Inch.	Layers to the Inch.	Turns to the Sq. Inch.	Feet per Cubic Inch.	Ohms per Cubic Inch.	Lbs. per Cubic Inch.	Feet per Lb.	No.	Per cent of Solid Copper in any Volume of Winding.
1									
2									
3									
4	4.5	4.87	22.1	1.84	.0004576	.24	7.	4	.75
5	5.09	5.82	29.6	2.46	.0007738	.24	9.	5	.74
6	5.66	6.41	36.3	3.02	.0011963	.24	11.5	6	.74
7	6.2	7.3	45.3	3.77	.001780	.24	14.	7	.73
8	7.05	8.	56.5	4.7	.0029654	.24	17.5	8	.73
9	7.66	8.42	64.5	5.37	.0042574	.24	22.	9	.73
10	8.54	9.6	82.	6.83	.00683	.238	27.	10	.72
11 *	9.7	11.	116.7	9.72	.012254	.236	34.	11	.72
12	11.2	12.8	143.4	11.95	.0150654	.233	42.	12	.71
13 *	12.	14.	168.	14.	.03627	.23	55.	13	.71
14	13.	15.4	200.	16.66	.0431627	.227	68.	14	.70
15	15.37	17.9	275.5	22.96	.071520	.224	87.	15	.68
16	16.74	19.4	324.7	27.06	.108757	.22	110.	16	.64
17	17.74	21.33	378.4	31.53	.15980	.217	140.	17	.62
18 *	19.5	23.	448.5	37.38	.2389	.19	175.	18	.61
19	22.77	24.9	567.	47.25	.39165	.185	220.	19	.60
20	25.7	29.7	763.3	63.60	.6464	.184	280.	20	.58
21	28.3	32.5	920.	76.6	.98163	.182	360.	21	.57
22	31.	36.	1116.	93.	1.502	.18	450.	22	.55
23	34.4	40.36	1390.3	115.86	2.36	.178	560.	23	.52
24	36.9	44.6	1649.	137.4	3.53	.168	715.	24	.45
25	38.	47.	1790.	149.2	4.734	.145	910.	25	.43
26 *	42.	50.5	2100.	170.	7.	.14	1165.	26	.41
27 *	48.	55.5	2600.	210.	10.5	.135	1445.	27	.40
28	53.28	61.1	3256.	271.3	17.63	.13	1810.	28	.39
29 *	59.	68.	4000.	335.	27.	.125	2280.	29	
30	63.26	76.8	4860.	405.	41.84	.121	2805.	30	.38
31									
32									
33									
34									
35									
36									

* Estimated.

RELATION AND DIMENSIONS OF CONDUCTORS FOR DISTRIBUTION.

RELATION OF E.M.F.; CURRENT; DISTANCE, CROSS-SECTION, AND WEIGHT OF CONDUCTORS.

a. Current or E.M.F. varies directly with the amount of energy transmitted.

b. Given the work done, loss on the line, and the E.M.F. at the motor terminals and point of distribution; then the cross-section of conductor varies directly with the distance and weight as the square of the distance.

c. With the same conditions as above, the weight of conductor will vary inversely as the square of the E.M.F. at the motor terminals.

d. With a given cross-section of conductor, the distance over which a given amount of power can be transmitted will vary as the square of the E.M.F.

e. Given, the weight of conductor, the amount of power transmitted, and the loss in distribution; then the distance over which the power can be transmitted will vary directly as the E.M.F.

PRECISION OF CALCULATIONS OF DISTRIBUTING SYSTEMS.

While it is possible and in every way the best to make complete computations for the conductors for isolated plants and for plants of a permanent nature, it is practically impossible to make anything like precise computations for large public systems of distributions, such as a large Edison system.

In the early days of the Edison stations, exact sizes of conductors were computed for entire systems; but when the network system was introduced, and it became possible to keep the E.M.F. constant all over a system by varying the number of feeders, all such exact computations were dropped; and to-day such systems are equipped with a few standard sizes of conductors, feeders being of one or two sizes only, and mains being of but two or three sizes, judgment of the management being used as to which size will best fit given conditions.

ECONOMICAL CONDITIONS.

In the laying out of a system of electrical distribution, there are eight points to bear in mind in order to obtain the best economy; and they have been so well stated by Abbott, that I quote from his book the following: —

"1. The conductors *must* be so proportioned that the energy transmitted through them will not cause an undue rise of temperature.

2. The conductors *must* have such mechanical properties as to enable them to be successfully erected, and so durable as to require a minimum of annual maintenance.

3. The conductors *may* be so designed as to entail a minimum first cost in line construction.

4. The conductors *may* be designed to attain a minimum first cost for station construction.

5. The conductors *may* be so designed as to reduce first cost of plant, and cost of operation and maintenance to a minimum.

6. The conductors *may* be designed to secure minimum total first cost of installation.

7. The conductors *may* be so designed as to secure maximum conditions of good service.

8. The conductors *may* be so designed as to attain a maximum of income with a minimum of station first cost."

1. If cost of production of electric energy is low, and cost of conductors high, make conductors small in cross-section, and of such size that the interest on its cost plus the expense of maintaining it will be a minimum, and balance the cost of energy lost in heating.

In no case, however, should the conductor be made of a size so small as to heat dangerously, for which see tables in "National Code."

When the cost of electric energy is high, and that of the conductors low, then the cross-section of conductor must be larger, in order that the cost of energy lost may not be too high; but the balance, with that of interest and maintenance, should still be maintained.

2. In all cases, conductors of sufficient size to have mechanical strength to suit the particular position they are to occupy, should be used. Due attention should be given to liability of snow and sleet, breaking of poles, etc., if conductors are overhead.

3. When a plant is installed for a temporary purpose, and the line salvage will be small, while no harm will be done to the generating plant, the cost of the line should be a minimum, and the conductors may well be of a size just sufficient to carry the current with safety, both as regards heating and mechanical strength.

4. The minimum first cost of station can be obtained, as far as influenced by the distribution system, by reducing the losses in the conductors to a minimum, thus calling for the smallest amount of current to do the work.

5. As a decrease in the expenditure for line and construction demands an increase in the cost of central station, and apparatus for producing the extra energy lost in the line, and increases the operating expense of the station likewise, it is evident there must be a point where the total of the interest and depreciation on the line can be made practically equal to the cost of the energy lost in the line; and at this point the expenses will be the least. Care must be used in applying this law, which was first stated by Lord Kelvin in 1881, as follows: "The most economical area of conductor will be that for which the annual interest on capital outlay equals the annual cost of energy wasted." One side of this equation would be the interest, depreciation, repairs, and maintenance of the conductor, the other would be the cost of producing the energy at the generator terminals, including interest, depreciation, and operating expense.

Kapp says that the above law only applies where the capital outlay is proportional to the weight of metal contained in the conductor, a condition seldom obtaining in practice, and states the correct rule as follows: —

"The most economical area of conductor is that for which the annual cost of energy wasted is equal to the annual interest on that portion of the capital outlay which can be considered to be proportional to the weight of metal used."

Prof. George Forbes, in his Cantor lectures in 1885, called that portion of the cost of the distributing system which is proportional to the weight of metal used, "the cost of laying one additional ton of copper;" and he shows that, for a given rate of interest charge (inclusive of depreciation), and a given cost of copper, "the most economical section of the conductor is independent of the E.M.F., and of the distance, and is proportional to the current."

Professor Forbes at the same time published some tables to facilitate the calculations; and Prof. H. S. Carhart has enlarged them, and reduced the values to United States money.

Tables for Determining the Most Economical Cross-section of Conductor.

G. FORBES.

COST OF LAYING ONE ADDITIONAL TON OF COPPER.

Annual allowance for interest and depreciation in %.	$300	$325	$350	$375	$400	$425	$450	$475	$500	$550	$600	$650	$700	$750	$800	$900	$1000	$1100	$1200	$1400	$1600	$1800	$2000
5	030	033	035	038	040	043	045	048	050	055	060	065	070	075	080	090	100	110	120	140	160	180	200
6	036	039	042	045	048	051	054	057	060	066	072	078	084	090	096	108	120	132	144	168	192	216	240
7	042	046	049	053	056	060	063	067	070	077	084	091	098	105	112	126	140	154	168	196	224	252	280
8	048	052	056	060	064	068	072	076	080	088	096	104	112	120	128	144	160	176	192	224	256	288	320
9	054	059	063	068	072	077	081	086	090	099	108	117	126	135	144	162	180	198	216	252	288	324	360
10	060	065	070	075	080	085	090	095	100	110	120	130	140	150	160	180	200	220	240	280	320	360	400
12	072	078	084	090	096	102	108	114	120	132	144	156	168	180	192	216	240	264	288	336	384	432	480
14	084	091	098	105	112	119	126	133	140	154	168	182	196	210	224	252	280	308	336	392	448	504	560
16	096	104	112	120	128	136	144	152	160	176	192	208	224	240	256	288	320	352	384	448	512	576	640
18	108	117	126	135	144	153	162	171	180	198	216	234	252	270	288	324	360	396	432	504	576	648	720
20	120	130	140	150	160	170	180	190	200	220	240	260	280	300	320	360	400	440	480	560	640	720	800
25	150	163	175	188	200	213	225	238	250	275	300	325	350	375	400	450	500	550	600	700	800	900	1000

Tables for Determining the Most Economical Cross-section of Conductor.

G. FORBES.

SECTIONAL AREA FOR 100 AMPERES IN SQUARE INCHES AND CIRCULAR MILS.

Circular Mils.		127,320	140,052	152,784	165,516	178,248	190,980	203,712	216,444	229,176	241,908	254,640	267,372	280,104	292,836	305,568	318,300	331,032	343,764	356,496	369,228	381,960	394,692	407,424	420,156	432,888	445,620
Sq. Ins.		.10	.11	.12	.13	.14	.15	.16	.17	.18	.19	.20	.21	.22	.23	.24	.25	.26	.27	.28	.29	.30	.31	.32	.33	34.	.35
Annual cost of one electrical horse-power at generator terminals. (Inclusive of interest and depreciation on buildings, motive power, and generator.)	$25	291	240	202	172	148	129	114	101	090	081	073	066	060	055	051	047	043	040	037	035	032	...	...	...	...	...
	30	349	289	242	207	178	155	136	121	108	097	087	079	072	066	061	056	052	048	045	042	039	036	...	...	...	...
	35	407	337	283	241	208	181	159	141	126	113	102	092	084	077	071	065	060	056	052	048	045	042	040	...	...	...
	40	465	385	323	275	238	207	182	161	144	129	116	105	096	088	081	074	069	064	059	055	052	048	045	043	...	...
	45	524	433	364	310	267	233	204	181	162	145	131	118	108	099	091	084	077	072	067	062	058	054	051	048	045	...
	50	582	481	404	344	297	259	227	201	180	161	146	132	120	110	101	093	086	080	074	069	065	061	057	053	050	048
	55	640	529	445	379	327	285	250	221	198	177	160	145	132	121	111	103	095	088	082	076	071	067	063	059	055	052
	60	698	577	485	413	356	310	273	241	216	193	175	158	144	132	121	112	103	096	089	083	076	073	068	064	060	057
	65	757	625	526	448	386	336	295	261	234	209	190	171	156	143	131	121	112	104	097	090	084	079	074	069	065	062
	70	815	673	566	482	416	362	318	281	252	225	204	185	168	154	141	131	120	112	104	097	091	085	080	075	070	067
	75	873	721	606	517	445	388	341	302	270	241	219	198	180	165	152	140	129	120	111	104	097	091	085	080	076	071
	80	931	769	647	551	475	414	364	322	287	257	233	211	192	176	162	149	138	128	119	111	103	097	091	086	081	076
	85	989	817	687	585	505	440	386	342	305	274	248	224	204	187	172	158	146	136	126	118	110	103	097	091	086	081
	90	1047	865	727	620	534	466	409	362	323	290	262	237	216	198	182	167	155	144	134	125	116	109	102	096	091	086
	95	....	914	768	654	564	491	432	383	341	306	277	251	228	209	192	177	164	152	141	131	123	115	108	102	096	090
	100	....	...	808	689	594	517	455	403	359	322	291	264	240	220	202	186	172	160	148	138	129	121	114	107	101	095
	105	....	...	...	723	624	543	477	423	377	339	306	277	252	231	212	195	181	168	156	145	136	127	119	112	106	100
	110	....	...	...	...	653	569	500	443	395	355	320	290	264	242	222	204	189	176	163	152	142	133	125	118	111	105
	115	....	...	...	...	...	595	523	463	413	371	335	304	276	253	232	214	198	184	171	159	149	139	131	123	116	109
	120	....	...	...	...	...	...	546	483	431	387	349	317	288	264	242	223	207	192	178	166	155	145	136	128	121	114
	125	....	...	...	...	...	...	...	503	449	403	364	330	301	275	253	233	215	200	186	173	162	151	142	134	126	119
	130	....	...	...	...	...	...	...	...	467	419	378	343	313	286	263	242	224	208	193	180	168	157	148	139	131	124

The engineer first decides on what will be the cost of laying one additional ton of copper, and the rate of interest (+ depreciation); then, referring to the first table, he finds in the top line the amount corresponding to his cost of copper, and follows it down to the line corresponding to the rate of interest he is to charge; and the number found at this intersection must then be taken to the second table, where, commencing on the line giving, at the left, the estimated cost of one electrical horse-power per annum, he follows to the right, stopping at the number nearest in value to that determined from the first table. At the top of this column will be found the area in circular mils and in square inches of the most economical conductor for 100 amperes of current, and size for other currents is in proportion.

The preceding rule determines the most economical cross-section of conductor for a maximum current, and not for the varying current of practice; therefore it is necessary to multiply the result obtained from the previous tables by a ratio found in the following table, which was also calculated by Professor Forbes from the following formula:—

$$\text{Mean current} = \text{current} = \sqrt{\frac{\left(\frac{1}{4}\right)^2 t_1 + \left(\frac{1}{2}\right)^2 t_2 + \left(\frac{3}{4}\right)^2 t_3 + t_4}{t_1 + t_2 + t_3 + t_4}},$$

where t_1, t_2, t_3, t_4 represent the number of hours per annum during which one-quarter, one-half, three-quarters of the full current and the full current is respectively passing through the conductor.

TO FIND MEAN ANNUAL CURRENT.

Fraction of time per year during which				Ratio.	Fraction of time per year during which				**Ratio.**
¼ Current	½ Current	¾ Current	Full Current		¼ Current	½ Current	¾ Current	Full Current	
is passing through the conductor.					is passing through the conductor.				
0	0	0	1	1.000	¼	¼	0	½	.760
0	0	¼	¾	.944	¼	0	½	¼	.744
0	¼	0	¾	.901	½	0	0	½	.729
0	0	½	½	.884	0	½	¼	¼	.718
¼	0	0	¾	.875	¼	¼	¼	¼	.685
0	¼	¼	½	.838	0	¾	0	¼	.661
0	0	¾	¼	.820	½	0	¼	¼	.650
¼	0	¼	½	.810	¼	½	0	¼	.611
0	½	0	½	.790	½	¼	0	¼	.586
0	¼	½	¼	.771	¾	0	0	¼	.545

The figures in the columns headed, "¼ current," "½ current," "¾ current," and "Full current," represent fractions of the total annual time during which ¼, ½, ¾ of the full current and the full current is passing through the conductor.

The figures in the column headed "Ratio" are those with which the most economical area for the maximum current must be multiplied to obtain the most economical area for a varying current.

The following table constructed under the direction of Professor Forbes, by the writer, will assist in approximate quick determinations, and can be used for any cost of power or copper.

For example: What would be the most economical density of current for a line, with copper at 14 cents per pound, and power costing 19 dollars per horse-power per annum.

Multiply the constant difference, .0406 in column *h*, by the cost of power, $19 \times .0406 = .7714$, and divide this result by the cost of copper in cents, 14, or $\frac{.7714}{14} = .0551$.

Now look in column *f* of differences for the nearest number to this result.

which is .0546; and to the left in the first column will be found 375 amperes per square inch.

All other data can be calculated from the data given in the other columns.

I. Horse-power at Motor-Terminals. 7.46 amperes at 100 volts, distance 1000 feet.

Am. Inst. E.E. standard, pure, soft-drawn copper at 20° *C.*; 1000 ft., 1 sq. in. weighs 3851.16 lbs.; $R = .008129$.

Density Amperes per Square inch.	Square inches per Horse-power.	Pounds of Copper, 2 sides.	Cost of Copper at 10 cents per pound.	5 % per annum on cost of Copper.	Differences.	Power wasted. Horse-power.	Cost of power wasted at $10.00 annum.	Pressure required at Generator terminals.	Volts drop in line. 2 sides.
a.	*b.*	*c.*	*d.*	*e.*	*f.*	*g.*	*h.*	*m.*	*x.*
100	.07460	574.58	$57.458	$2.8729		.01626	$.1626	101.626	1.626
125	.05968	459.68	45.968	2.2984	.5745	.02032	.2032	102.032	2.032
150	.04973	383.06	38.306	1.9153	.3831	.02439	.2439	102.439	2.439
175	.04262	328.28	32.828	1.6414	.2739	.02845	.2845	102.845	2.845
200	.03730	287.28	28.728	1.4364	.2050	.03252	.3252	103.252	3.252
225	.03316	255.40	25.540	1.2770	.1594	.03658	.3658	103.658	3.658
250	.02984	229.84	22.984	1.1492	.1278	.04065	.4065	104.065	4.065
275	.02713	208.94	20.894	1.0447	.1045	.04471	.4471	104.471	4.471
300	.02486	191.52	19.152	.9576	.0871	.04878	.4878	104.878	4.878
325	.02295	176.79	17.679	.8839	.0737	.05284	.5284	105.284	5.284
350	.02131	164.14	16.414	.8207	.0632	.05691	.5691	105.691	5.691
375	.01989	153.22	15.322	.7661	.0546	.06097	.6097	106.097	6.097
400	.01865	143.64	14.364	.7182	.0479	.06504	.6504	106.504	6.504
425	.01755	135.19	13.519	.6759	.0423	.06910	.6910	106.910	6.910
450	.01658	127.70	12.770	.6385	.0374	.07317	.7317	107.317	7.317
475	.01570	120.97	12.097	.6048	.0337	.07723	.7723	107.723	7.723
500	.01492	114.92	11.492	.5746	.0302	.08130	.8130	108.130	8.130
525	.01420	109.44	10.944	.5472	.0274	.08536	.8536	108.536	8.536
550	.01356	104.47	10.447	.5223	.0249	.08942	.8942	108.942	8.942
575	.01297	99.93	9.993	.4996	.0227	.09348	.9348	109.348	9.348
600	.01244	95.76	9.576	.4788	.0208	.09756	.9756	109.756	9.756
625	.01193	91.93	9.193	.4596	.0192	.10162	1.0162	110.162	10.162
650	.01147	88.39	8.839	.4419	.0177	.10568	1.0568	110.568	10.568
675	.01105	85.12	8.512	.4256	.0163	.10974	1.0974	110.974	10.974
700	.01066	82.08	8.208	.4104	.0152	.11382	1.1382	111.382	11.382
725	.01029	79.25	7.925	.3962	.0142	.11788	1.1788	111.788	11.788
750	.00995	76.61	7.661	.3830	.0132	.12194	1.2194	112.194	12.194
775	.00962	74.14	7.414	.3707	.0123	.12600	1.2600	112.600	12.600
800	.00933	71.82	7.182	.3591	.0116	.13008	1.3008	113.008	13.008
825	.00905	69.64	6.964	.3482	.0109	.13414	1.3414	113.414	13.414
850	.00878	67.59	6.759	.3379	.0103	.13820	1.3820	113.820	13.820
875	.00854	65.66	6.566	.3283	.0096	.14226	1.4226	114.226	14.226
900	.00829	63.84	6.384	.3192	.0091	.14634	1.4634	114.634	14.634
925	.00807	62.12	6.212	.3106	.0086	.15040	1.5040	115.040	15.040
950	.00785	60.48	6.048	.3024	.0082	.15446	1.5446	115.446	15.446
975	.00766	58.93	5.893	.2946	.0078	.15852	1.5822	115.852	15.852
1000	.00746	57.46	5.746	.2873	.0073	.16258	1.6258	116.258	16.258

Constant difference, .0406.

Res. of 1000 ft., 1 sq. in. at 80° C. = .010,0678.

6. When a plant is installed for more or less temporary work, it is, of course, policy to make the first cost a minimum; and again, in many places, and perhaps in most places, it is impossible to predetermine the cost of power per unit, or number of hours it will be necessary to run, or the number of hours of heavy and of light load, and many other items necessary to be known in order to determine and calculate the most economical form of plant to install.

In such cases it is often necessary to feel one's way by installing a plant of low cost until the market is developed or its direction determined, after which it is much easier to lay out a plant that will produce the most economical results.

Sprague says that the least cost of plant is determined when the variation in the cost of the generator is equal to that in the cost of the line; which is practically true, provided the cost of motors and generators per horse-power or unit capacity is the same. Sprague then develops the following law: —

"With fixed conditions of cost and of efficiency of apparatus, the number of volts fall to get the minimum cost of plant, is a function of distance alone, and is independent of the E.M.F. used at the motor."

"With any fixed couple and commercial efficiency, the cost of the wire bears a definite and fixed ratio to the cost of the generating plant."

"The cost of the wire varies directly with the cost of the generating plant."

"If we do not limit ourselves in the E.M.F. used, the cost per horse-power delivered exclusive of line erection is, for least cost and for a given commercial efficiency, absolutely independent of the distance."

Without going into the detail, if we work out problems based on the above laws, the result shows that the law first stated by Professor Forbes, i.e., that "the most economical section of conductor is independent of the distance or E.M.F., and is proportional to the current," is correct.

Badt develops the following law: —

"For minimum initial cost of plant, and assuming certain prices per horse-power of motors and generators and power plant (all erected and ready for operation), and assuming a certain price per pound for copper (delivered at the poles), the total cost of the plant, excluding line construction, is a constant for a certain efficiency of the electric system, no matter what the E.M.F. of the motor and the distance may be."

"At a given efficiency of the electric system, the E.M.F. of the motor and distance will increase and decrease in the same ratio."

7. In designing for the accomplishment of the best service, series circuits can be economically laid out under some of the previous rules; but in designing circuits for parallel distribution, they must be arranged for furnishing a constant and unvarying pressure at the lamps or motors of the customer, regardless of the cost of conductors; and therefore service requirements and not minimum first cost govern, as no service will be a paying investment that has not a uniform pressure and is not continuous in its character.

Parallel distribution is fully treated in another chapter.

8. It is the attempt of all engineers to attain a maximum income from a minimum first cost of plant.

If power is cheap and transportation costly, it is better to construct plant under Section 3. In some cases, though, so much of the station capacity might be wasted in the conductors as to leave little from which an income could be received; but increasing the carrying capacity of the conductors somewhat, provided it did not cost too much to accommodate the extra machinery, would enable a paying income to be made.

In order to determine the proper relation of line to station and plant, it is necessary to study the prospective loads. If street-lighting by series arcs is to be one of the sources of income, then a study of the hours of lighting must be made, and all the data as to number of hours burning, etc., will be found in the chapter on lighting schedules.

For parallel and other methods of distribution, it will be necessary for some one acquainted with the system to make the necessary examination of the territory, and determine from its nature the probable load-curves.

Efficiency in Electric Power Transmission.

From Badt's "Electric Transmission Hand-Book."

1.	2.	3.	4.	5.	6.
Mech. H.P. required at motor shaft. N.	El. H.P. to be transmitted to motor.	Per cent loss in conductor. %	El. H.P. required in generator.	Mech. H.P. to be delivered at generator pulley.	Efficiency of whole system in per cent. l.
1.00	1.1111	0.0	1.1111	1.2346	81.00
1.00	1.1111	1.0	1.1223	1.2470	80.19
1.00	1.1111	2.0	1.1337	1.2597	79.38
1.00	1.1111	3.0	1.1454	1.2727	78.57
1.00	1.1111	4.0	1.1574	1.2860	77.76
1.00	1.1111	5.0	1.1696	1.2995	76.95
1.00	1.1111	6.0	1.1721	1.3134	76.14
1.00	1.1111	7.0	1.1947	1.3275	75.33
1.00	1.1111	8.0	1.2077	1.3419	74.52
1.00	1.1111	9.0	1.2210	1.3567	73.71
1.00	1.1111	10.0	1.2345	1.3717	72.90
1.00	1.1111	12.5	1.2698	1.4109	70.88
1.00	1.1111	15.0	1.3072	1.4524	68.85
1.00	1.1111	17.5	1.3468	1.4964	66.83
1.00	1.1111	20.0	1.3888	1.5447	64.80
1.00	1.1111	22.5	1.4336	1.5929	62.78
1.00	1.1111	25.0	1.4815	1.6461	60.75
1.00	1.1111	27.5	1.5325	1.7028	58.73
1.00	1.1111	30.0	1.5873	1.7636	56.70
1.00	1.1111	32.5	1.6464	1.8293	54.68
1.00	1.1111	35.0	1.7094	1.8993	52.65
1.00	1.1111	37.5	1.7778	1.9753	50.63
1.00	1.1111	38.3	1.8000	2.0000	50.00
1.00	1.1111	40.0	1.8518	2.0576	48.60
1.00	1.1111	42.5	1.9323	2.1470	46.58
1.00	1.1111	45.0	2.0210	2.2446	44.55
1.00	1.1111	47.5	2.1164	2.3515	42.53
1.00	1.1111	50.0	2.2222	2.4622	40.50

CALCULATION OF THE SIZE OF CONDUCTORS FOR CONTINUOUS CURRENTS.

Parallel distribution:—

Resistance of one mil-foot pure copper at 0° C = 9.59 ohms;
Temp. coefficient for 70° F. = 1.084
Resistance of 1 mil-foot of pure copper at 70° F. = 10.395 ohms;
Resistance of 1 mil-foot of 96% conductivity copper wire at 70° F. = 10.81 ohms;

Resistance of a copper wire conductor is then equal to

$$\frac{\text{Length in feet} \times 10.81}{\text{dia.}^2} = R. \text{ ohms.} \qquad (1)$$

and the cross-section in circular mils or

$$\text{dia.}^2 = \frac{\text{Length in feet} \times 10.81}{\text{Resistance}}. \qquad (2)$$

For lamps:—

Let w = watts per candle-power;
then candle-power × w = watts per lamp, = W;
and if E = voltage, or P.D. of circuit;
then $\frac{W}{E} = I$ = current in amperes per lamp.

A voltage at which lamps are to be run is usually assumed, and a drop or loss of pressure of a certain percentage of this, determined on, and all wiring is calculated with those points as data. For instance, the most common voltage is 110 or thereabouts, and 5% drop, or 5.5 volts, is commonly assumed as the loss in pressure; then the size of wire to produce this drop, with a given number of lamps, N, taking, say, I amperes will be

$$\frac{10.81 \times 2 \text{ distance} \times I}{\text{volts drop } 5.5} = \text{dia.}^2\text{, or circular mils of copper.} \qquad (3)$$

For example: 120 lamps taking .5 amp. each are to be wired at a distance of 60 feet from the dynamo to the centre of distribution, at a drop of 3 volts.

$$\text{Then, } \frac{10.81 \times 2 \times 60' \times 60 \text{ amps.}}{3 \text{ volts.}} = 25944 \text{ cir. mils, or No. 6 B. and S.}$$

If the hot resistance of one lamp be given, and the number of lamps and distance, with the percentage of loss, then

$$\text{cir. mils} = \frac{10.81 \times 2 \text{ distance} \times \text{no. of lamps}}{\text{Resistance of one lamp}} \times \frac{100}{\% \text{ loss}}. \qquad (4)$$

Example:—Take the same case as above: 120 lamps; distance 60 feet; drop in circuit, 3 %; hot resistance of lamp, 200 ohms.

$$\text{Then, } \frac{10.81 \times 2 \times 60' \times 120}{200} \times \frac{100}{3} = 25944 \text{ cir. mils.}$$

For motors:—

1 Electric horse-power = 746 watts.
Therefore, horse-power × 746 = watts.
And watts ÷ volts = amperes.

Let E = volts at terminals of motor.
v = volts lost in conductor.
$E + v$ = E.M.F. at generator terminals.
I = current required at motor to deliver N mechanical h.p. at shaft of motor.
D = single distance between motor and generator.
N = number of mechanical h.p. delivered at motor shaft.
A = area of cross-section of conductor in cir. mils.
R = conductor resistance both ways.
wt = weight in pounds of conductor copper.
$m\%$ = commercial efficiency of motor.
$g\%$ = commercial efficiency of generator.
$l\%$ = commercial efficiency of whole system.
$c\%$ = per cent of energy lost in conductor.
all % expressed as a decimal, as, 90 % = .90,

Then, $\frac{N}{m\%}$ = electrical horse-power delivered at motor terminals;

and

$$I = \frac{746\, N}{E \times m\%} = \text{amperes.} \qquad (5)$$

By formula No. 1, $R = \frac{2\,D \times 10.81}{A}$ = resistance of conductor both ways.

Or, reducing $R = \frac{D \times 21.62}{A}$.

The drop or loss in the line $v = I R$, or

$$v = \frac{I \times D \times 21.62}{A}; \qquad (6)$$

and

$$A = \frac{I \times D \times 21.62}{v}. \qquad (7)$$

Substituting the value for I,

we have,

$$A = \frac{746 \times N \times D \times 21.62}{E \times m\% \times v}; \qquad (8)$$

and reducing we have, $\frac{16128.5 \times N \times D}{E \times m\,\% \times v}$.

EXAMPLE: —

Motor 20 h.p. $m\%$ = 90%.
Volts at terminals = 500.
Distance = 200 ft.
Loss in conductors = 5 %.

Then, E.M.F. of generator $= \frac{500}{.95} = 526.3$ volts,

and drop in line, $v = 526.3 - 500 = 26.3$;

and $A = \frac{16128.5 \times 20 \times 200}{500 \times .90 \times 26.3} = 5458$ cir. mils = No. 15 B. W. G.

But by formula (5), $I = \frac{746\,N}{E \times m\,\%}$, or $I = \frac{746 \times 20}{500 \times .90} = 33$ amperes;

and the National code only allows 8 amperes for No. 16, and 33 amperes would need at least No. 10 wire.

The volts drop and per cent loss in No. 10 B. and S. wire, required to carry the 33 amperes as above shown, will be found as follows: —

R of No. 10 B. and S. = .0009972 per foot;
R of 400 ft. = .39888 ohms;
Volts drop $= IR = 33 \times 39888 = 13.16$ volts;
Volts at generator $= 500 + 13. = 513$.
Per cent drop $= \frac{13}{513} = 2.5\,\%$.

SIZES OF CONDUCTORS FOR INCANDESCENT CIRCUITS.

(By W. D. WEAVER.)

The most accurate method of determining the proper sizes of incandescent lamp conductors is to refer *all* measurements back to the dynamo, converter, or street tap.

To illustrate, suppose we have an installation of 150 lights, consisting of a feeder or dynamo main 20 feet long (to distributing point), and several mains, A, B, and C, their lamps and lamp centres being respectively 60, 50, and 40 in number, and 38, 60, and 90 feet from the end of the feeder. Let us calculate the sizes of the feeder and one main, and of one branch having 12 lamps, with centre 20 feet from the main, the branch starting 18 feet from the distributing point. (See cut.)

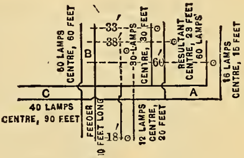


FIG. 1.

To find the size of the branch wire, refer to the appropriate table with 20 + 18 + 20 feet, or 58 feet for 12 lamps.

To find the size of the main, imagine the branches on one side to be revolved (or lay them out thus on a diagram), so that *all are on the same side* *of the main;* then estimate or calculate the lamp centre of the resultant group, which in this case we will suppose to be 23 feet from the main, and 38 feet from the distributing point measured along the main, and refer to the table with 20 + 38 + 23 feet for 12 + 30 + 18 lamps, or 81 feet for 60 lamps.

To find the size of the feeder, suppose the mains to be revolved about the distributing point so that they all overlap, and with all the branches on one side of the overlapping mains; then estimate or calculate the lamp centre of the resultant group (comprising all the lamps), which in this case we will suppose to be 20 feet from the overlapping mains measured at right angles, and 48 feet from the distributing point measured along the main, and refer to the table with 20 + 48 + 20 feet, or 88 feet for 150 lights, *or for the largest number of lights that will ever be used at one time.*

In simple cases the quantities may be estimated either directly (especially for branches) or from rough diagrams; and for more complex cases, or where a perfectly accurate result is desired, the following rules are given:—

For **Branches**, follow the method given above.

For **Mains**, multiply the number of lamps on each branch of a main by the distance of their lamp centre from the distributing point, *always measured along the lead of the main and branch;* add the products thus obtained for all the branches on the main, and divide by the whole number of lamps on the branches. Add the length of feeder, and refer to the table with the resultant distance and lamps.

EXAMPLE:—(See cut, main A.)

$$(18+20)\times 12 = 456$$
$$(33+30)\times 30 = 1890$$
$$(60+15)\times 18 = 1350$$

$$\frac{456+1890+1350}{12+30+18}+20 = 81 \text{ feet for 60 lamps.}$$

For **Feeders**, add the sum of the products obtained as above for all the mains, divide by the entire number of lamps on the feeder, add the length of the feeder, and refer to the table with this distance and all the lamps on the feeder, *or the largest number that will ever be used at one time.*

EXAMPLE:—(See cut.)

Main A. $456+1890+1350=3696$
Main B. $60\times 50=3000$
Main C. $90\times 40=3600$

$$\frac{3696+3000+3600}{150}+20 = 88 \text{ feet for 150 lamps.}$$

Care must be taken not to confound a *lamp* centre (so-called) with a *geometrical* centre. For example, suppose a series of branches of equal length radiating from the end of a main like the spokes of a wheel, and having lamps at equal intervals. Here the geometrical centre is the radiating point, while the lamp centre is on a circle passing through the centres of the various groups, or the length of the radius from the radiating point. In the case of the main A given above, the geometrical centre is 15 feet from the main, while the true lamp centre is 23 feet. It is to preclude the error of geometrical centres that the branches and mains are laid down, or imagined, revolved.

Sub-branches and **Taps** may in general be considered as groups of lamps directly on the branch itself, and thus included in the calculation for the branch.

The above method is applicable to all systems of wiring, and is particularly valuable and economical in securing proper distribution of light on low voltage circuits having a small percentage of loss. By stringing the branches first, when possible, this method may be easily followed without the aid of a diagram, even in complex cases. With the "closet" system of wiring, diagrams and calculations as a rule will not be required.

The "tree" system of wiring is to be avoided where possible, on account of the unequal distribution of light it entails. In many cases, secondary centres of distribution may be substituted; and if carefully calculated, the weight of wire in the latter case need not exceed that in the former.

The voltmeter should always be connected with the centre of distribution, and not with the feeder near the dynamo, unless it is desirable to have a steady light in a particular locality, when it should be connected with the line there.

Owing to the exceedingly small current passing through a voltmeter, the resistance of even a very small wire in ordinary cases will not practically affect its readings. Where the line is very long, a No. 12 or 14 insulated iron wire may be used, and the voltmeter at the dynamo set once for all by comparison with a standard voltmeter temporarily attached at the point which is to be maintained at a constant potential.

CALCULATION OF THE SIZE OF CONDUCTORS FOR ALTERNATING CURRENT CIRCUITS.

When alternating currents first came into use, it was customary to calculate the sizes of conductors by the ordinary rules used in connection with direct currents. This did very well as long as small currents were in use, and distances were comparatively short; but before long new effects began on the lines that were unaccountable to any one not familiar with the action of such currents in a conductor, and this led to a more thorough study of the problems.

Briefly stated there are, besides the ohmic resistance of the copper, the following effects, due to the use of alternating currents: —

Skin effect, a retardation of the current due to the property of alternating currents of apparently flowing along the outer surface or shell of the conductor, thus not making use of the full area.

Inductive effects, *a*, *self-induction* of the current due to its alternations, inducing a counter E.M.F. in the conductor; and *b*, *mutual inductance*, or the effect of other *alternating current circuits.*

Capacity Effects, due to the fact that all lines of conductors act as electrical condensers, which are alternately charged and discharged with the fluctuations of the E.M.F.

Skin Effect.

The increase in resistance due to skin effect can be found by the use of the following table: —

Skin Effect Factors, for Conductors carrying Alternating Currents.

NOTE. — For true resistance, multiply ohmic resistance by factor from this table.

Diam. and B. & S. gauge.	FREQUENCIES.									
	15	20	25	33	40	50	60	80	100	130
2″	1.111	1.160	1.265	1.405	1.531	1.682	1.826	2.074	2.290	2.560
1¾	1.072	1.114	1.170	1.270	1,366	1.495	1.622	1.841	2.030	2,272
1½	1.042	1.064	1.098	1.161	1.223	1.321	1.420	1.610	1.765	1.983
1¼	1.019	1.030	1.053	1.084	1.118	1.176	1.239	1.374	1.506	1.694
1⅛	1.010	1.019	1.035	1.059	1.080	1.124	1.168	1.270	1.382	1.545
1″	1.005	1.010	1.020	1.038	1.052	1.080	1.111	1.181	1.263	1.397
¾″	1.002	1.002	1.007	1.014	1.016	1.028	1.040	1.066	1.100	1.156
½″	1.001	1.001	1.002	1.005	1.006	1.007	1.008	1.011	1.022	1.039
0000			1.001	1.003	1.005	1.005	1.006	1.010	1.015	1.027
000				1.001	1.002	1.002	1.005	1.007	1.010	1.017
00					1.001	1.001	1.002	1.004	1.006	1.010
0							1.001	1.002	1.005	1.008
1								1.001	1.002	1.005
2									1.001	1.002
3										1.001
4										1.000

For other frequencies, Emmet gives the following table : —

Product of Cir. Mils by Cycles per sec.	Factor.
10,000,000	1.00
20,000,000	1.01
30,000,000	1.03
40,000,000	1.05
50,000,000	1.08
60,000,000	1.10
70,000,000	1.13
80,000,000	1.17
90,000,000	1.20
100,000,000	1.25
125,000,000	1.34
150,000,000	1.43

Factors in the above table multiplied by the resistance in ohms will give the resistance of circular copper conductors to alternating currents.

Effects of Self-induction. — Owing to the periodic variations of current in alternating-current circuits, a counter E.M.F. is set up, which does not coincide with the current, and which is not continuous, but periodic; and, owing to the fact that such E.M.F. is the strongest when the current is increasing or decreasing most rapidly, the counter E.M.F. differs in phase with the current by 90°.

If there be no inductive effect in a circuit (without considering anything else at present), the current produced by an impressed E.M.F. would be in phase, and the watts would be, as in direct currents, the product of the E.M.F. and current. Taking into account the inductive effect, the current is never in phase with the impressed E.M.F., and the watts are therefore never equal to the product of the two, but are less, according to the angle of phase difference; and if they could be in quadrature, the product would be zero.

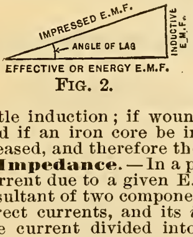


FIG. 2.

The E.M.F. impressed on the circuit may be said to be made up of two components, one in phase with the current, as in direct currents, and the other in quadrature with it, as shown below in a right-angle triangle.

Counter or inductive E.M.F. varies with the frequency of alternations; but if the out-going and returning wires are close together, there is little induction; if wound in a coil, the self-induction is much increased, and if an iron core be introduced into the coil, the flux is very much increased, and therefore the self-induction.

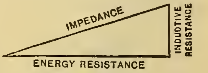


FIG. 3.

Impedance. — In a plain, alternating-current circuit without iron, the current due to a given E.M.F. will depend upon a resistance which is the resultant of two components: its resistance as in direct currents, and its *inductive* resistance, or the current divided into the *inductive E.M.F.* These two components are compounded at right angles, and the resultant is called *impedance*, and can be represented by the same triangle as was used to illustrate the two E.M.F.'s and their resultant.

Impedance also varies with the rate of alternations the same as does the counter or inductive E.M.F.

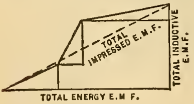


FIG. 4.

If we have a circuit including a number of parts in series, each having a different angle of lag, and represented as below by different triangles joined together, it will be seen that the sum of all the E.M.F.'s impressed upon the parts or impedances is greater than the E.M.F. impressed upon the whole circuit; and in order to arrive at the latter value, it is necessary to lay out each case separately, all the horizontal lines representing energy

E.M.F.'s (or resistances), and all the vertical lines representing inductive E.M.F.'s (or resistances, now called reactances).

To find the impedance equal to two impedances in parallel, construct a parallelogram, the adjacent sides of which will be the reciprocals of their values; the diagonal of this parallelogram will be the reciprocal of the value of the resulting impedance; and, as the lines representing the given impedances are joined at the proper phase angle with each other, the direction of the diagonal will represent the resulting phase.

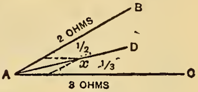


FIG. 5.

In the above figure $\frac{1}{AB} = \frac{1}{2}$.

$$\frac{1}{AC} = \frac{1}{3}.$$

$$\frac{1}{Ax} = AD = 1.3 \text{ ohms.}$$

If two impedances, connected in parallel, have such values as to give a phase difference of 90°, i.e., are at right angles with each other, their resultant value can be found by constructing a right-angle triangle, whose adjacent sides represent in direction and length the values of the two impedances in parallel. Join the two ends, and a line drawn from this hypothenuse at right angles and meeting the others at their junction, will be equal to and in the direction of the resultant value.

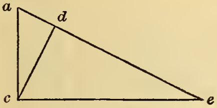


FIG. 6.

If *ac* and *ce* are two impedances in parallel, with a difference in phase of 90°, then *cd* equals in direction and in length the resultant of the two.

Capacity Effects. — A condenser connected in multiple across the leads of an a.c. circuit is charged as the E.M.F. rises, and discharged as the E.M.F. falls, thus returning E.M.F. to the line just at the time that the inductive E.M.F. is opposing the line E.M.F., and both can be so arranged as to neutralize each other, or enough capacity can be introduced to cause a negative lag-angle, as shown in the following figure.

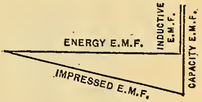


FIG. 7.

When a condenser or a line having capacity is subjected to an alternating E.M.F., current will flow in to fill the capacity equal to $E \times C \times \omega$, where E is the E.M.F., C, the capacity in farads, and $\omega = 2\pi N$.

Thus, if a line has a capacity of 3 micro-farads, $E = 2000$ volts, and $N = 30$, then —

$$\text{Amperes } I = \frac{3}{1{,}000{,}000} \times 2000 \times 30 \times 6.28 = 1.1304.$$

And a condenser may be said to have a reactance of $\frac{1}{C\omega}$.

This reactance is also in quadrature with the energy E.M.F., as is the inductive reactance, but acting in the opposite direction to that of the inductance; and may therefore be so arranged as to neutralize it. Line capacity acts like a condenser placed in multiple at the middle point of the length of the line.

Lag angles and power factors of alternating-current motors of the induction type vary with the load they carry and with the design and size, some of large size having power factors as high as 97% at full load, while poorly designed motors may have but 75% or less.

Synchronous motors run with a separately excited field, which may be so varied as to produce a leading or lagging current, or be made to take from or return energy to the line. When running with but little load, with field current high, energy will be absorbed from the line as the impressed E.M.F.

rises, and returned to the line as it falls, thus acting like a condenser, and tending to steady the E.M.F. of the circuit, which may be disturbed and lowered by the inductance of induction motors.

Closed circuit transformers with secondary open have a power factor of about 70%, and when loaded with non-inductive load, large sizes have a power factor of over 99%, with an induction component of say 6%, even at half-load the power factor is over 99%.

In the ordinary alternating-current lighting circuits, the elements are, the lamps, the secondary circuits, the transformers, the primary mains, and feeders.

If distances are considerable and the wires large, there will be some induction due to the primary and secondary mains ; but most of the effect will come from the transformer, provided, of course, that nothing but incandescent lamps are used as load on the secondary. With good-sized transformers, the total power factor will be above 99%.

In the following table will be found the angles of lag, together with the power-factors and factors of induction due to each, from which may be computed the effects on lines of different inductances.

Power Factors and Induction Factors for Different Angles of Lag.

Angle of Lag θ.	Power Factors.	Factors of Induction.	Angle of Lag θ.	Power Factors.	Factors of Induction.	Angle of Lag θ.	Power Factors.	Factors of Induction.	Angle of Lag θ.	Power Factors.	Factors of Induction.
Degrees.	Cos θ.	Sin θ.	Degrees.	Cos θ.	Sin θ.	Degrees.	Cos θ.	Sin θ.	Degrees.	Cos θ.	Sin θ.
1	.9998	.0174	24	.9135	.4067	46	.6946	.7193	69	.3584	.9336
2	.9994	.0349	25	.9063	.4226	47	.6820	.7313	70	.3420	.9397
3	.9986	.0523	26	.8988	.4384	48	.6691	.7431	71	.3256	.9455
4	.9976	.0698	27	.8910	.4540	49	.6561	.7547	72	.3090	.9511
5	.9962	.0872	28	.8829	.4695	50	.6428	.7660	73	.2924	.9563
6	.9945	.1045	29	.8746	.4848	51	.6293	.7771	74	.2756	.9613
7	.9925	.1219	30	.8660	.5000	52	.6156	.7880	75	.2588	.9659
8	.9903	.1392	31	.8572	.5150	53	.6018	.7986	76	.2419	.9703
9	.9877	.1564	32	.8480	.5299	54	.5878	.8090	77	.2249	.9744
10	.9848	.1736	33	.8387	.5446	55	.5736	.8191	78	.2079	.9781
11	.9816	.1908	34	.8290	.5592	56	.5592	.8290	79	.1908	.9816
12	.9781	.2079	35	.8191	.5736	57	.5446	.8387	80	.1736	.9848
13	.9744	.2249	36	.8090	.5878	58	.5299	.8480	81	.1564	.9877
14	.9703	.2419	37	.7986	.6018	59	.5150	.8572	82	.1392	.9903
15	.9659	.2588	38	.7880	.6156	60	.5000	.8660	83	.1219	.9925
16	.9613	.2756	39	.7771	.6293	61	.4848	.8746	84	.1045	.9945
17	.9563	.2924	40	.7660	.6428	62	.4695	.8829	85	.0872	.9962
18	.9511	.3090	41	.7547	.6561	63	.4540	.8910	86	.0698	.9976
19	.9455	.3256	42	.7431	.6691	64	.4384	.8988	87	.0523	.9986
20	.9397	.3420	43	.7313	.6820	65	.4226	.9063	88	.0349	.9994
21	.9336	.3584	44	.7193	.6946	66	.4067	.9135	89	.0174	.9998
22	.9272	.3746	45	.7071	.7071	67	.3907	.9205			
23	.9205	.3907				68	.3746	.9272			

Inductive Resistance of Lines.—As previously stated, two parallel wires carrying alternating currents induce in each other counter or inductive E.M.F.'s that tend to retard the flow of current. The closer together these wires are, the less is this effect, and the more nearly the current waves are to the simple harmonic curve, the less is the retardation.

The counter E.M.F. is somewhat larger for small wires than for large, provided the current and distance between centres be the same, and the effect is about 150 times greater in iron wire circuits than with copper, as will be seen by reference to the following formulæ, by which both are calculated.

INDUCTANCE FACTORS.

In Tables I. and II. below are given the formulæ for inductance of two parallel wires of copper and of iron; and in Table III. the inductance per mile for two copper wires has been computed for different inter-axial distances.

Table I.—Inductance for Parallel Copper Wires.

$d =$ distance apart, centre to centre, of wires.
$r =$ radius of wires.
$L =$ inductance of each wire in millihenrys.

Formula,

$$L = \left[.5 + \left(2 \log_\epsilon \frac{d}{r} \right) \right] 10^{-6}, \text{ per centimeter.}$$

Then

$$\begin{aligned}
L \text{ per centimeter} &= .000{,}000{,}5 + .000{,}004{,}6 \log \frac{d}{r}. \\
L \text{ per inch} &= .000{,}001{,}27 + .000{,}011{,}68 \log \frac{d}{r}. \\
L \text{ per foot} &= .000{,}015{,}24 + .000{,}14 \log \frac{d}{r}. \\
L \text{ per 1,000 feet} &= .01524 + .14 \log \frac{d}{r}. \\
L \text{ per mile} &= .0805 + .741 \log \frac{d}{r}.
\end{aligned}$$

Table II.—Inductance for Parallel Iron Wires.

$d =$ distance apart, centre to centre, of wires.
$r =$ radius of wires.
$L =$ inductance of each wire in millihenrys.

Formula,

$$L = \left[75. + \left(2 \log_\epsilon \frac{d}{r} \right) \right] 10^{-6}, \text{ per centimeter.}$$

$$\begin{aligned}
L \text{ per centimeter} &= .000{,}075 + .000{,}004{,}6 \log \frac{d}{r}. \\
L \text{ per inch} &= .000{,}191 + .000{,}011{,}68 \log \frac{d}{r}. \\
L \text{ per foot} &= .002{,}286 + .000{,}14 \log \frac{d}{r}. \\
L \text{ per 1,000 feet} &= 2.286 + .14 \log \frac{d}{r}. \\
L \text{ per mile} &= 12.070 + .741 \log \frac{d}{r}.
\end{aligned}$$

Table III.—Inductance in Millihenrys, per Mile, for each of Two Copper Wires Parallel to each other.

B. and S. gauge.	Interaxial Distance in Inches.					
	3.	6.	12.	24.	36.	48.
0000	0.907	1.130	1.353	1.576	1.707	1.799
000	0.944	1.168	1.391	1.614	1.745	1.836
00	0.982	1.205	1.425	1.651	1.784	1.874
0	1.019	1.242	1.465	1.688	1.818	1.911
1	1.056	1.280	1.502	1.725	1.856	1.949
2	1.094	1.317	1.540	1.764	1.893	1.986
3	1.131	1.354	1.577	1.800	1.931	2.023
4	1.168	1.392	1.614	1.838	1.968	2.061
5	1.206	1.429	1.652	1.875	2.005	2.099
6	1.243	1.466	1.689	1.912	2.043	2.135
7	1.280	1.503	1.727	1.949	2.079	2.172
8	1.317	1.540	1.764	1.986	2.117	2.209
9	1.355	1.578	1.801	2.025	2.155	2.248
10	1.392	1.615	1.838	2.061	2.192	2.285
11	1.429	1.652	1.875	2.099	2.229	2.322
12	1.467	1.690	1.913	2.135	2.266	2.359

Inductance in Millihenrys per 1000 feet of Copper Circuit.

2 AERIAL WIRES.

Interaxial Distance.	1″ dia.	¾″ dia.	½″ dia.	B. and S. 0000	000	00	0
3″	.248	.283	.333	.344	.358	.373	.386
6	.333	.369	.417	.428	.442	.456	.471
12	.417	.451	.500	.513	.527	.540	.555
24	.500	.538	.587	.597	.611	.625	.640
48	.587	.621	.671	.681	.695	.710	.724

Interaxial Distance.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
3″	.400	.415	.429	.442	.457	.472	.484	.499	.513	.527
6	.485	.498	.513	.527	.541	.555	.570	.583	.597	.612
12	.570	.583	.597	.612	.626	.640	.654	.668	.683	.696
24	.654	.668	.682	.696	.711	.724	.738	.753	.767	.781
48	.738	.752	.767	.781	.795	.808	.823	.837	.851	.865

Formula =

$$\left(.5 + \left(\frac{2 \log \frac{d}{r}}{.4343} \right) \right) 10^{-6} = \text{millihenrys per centimeter};$$

and $.01524 + .14 \log \frac{d}{r} =$ millihenrys per 1000 ft. of copper wire.

Inductive resistance =

$$\frac{2 \pi n \times \text{millihenrys from above table}}{1000} = \text{henrys per 1000 feet of circuit.}$$

Inductive drop = current × inductive resistance.

INDUCTANCE PER MILE OF CIRCUIT THREE-PHASE SYSTEM, 60 p. p. s.

(Dr. F. A. C. Perrine and Frank G. Baum in Trans. A. I. E. E.)

Size B. & S.	Diameter in Inches.	Distance d in Inches.	Self. Ind. L_{ab} Henrys.	Inductance $L_{ab} \times 2\pi \times 60$ Ohms.	Size B. & S.	Diameter in Inches.	Distance d in Inches.	Self. Ind. L_{ab} Henrys.	Inductance $L_{ab} \times 2\pi \times 60$ Ohms.
0000	.46	12	.00234	0.884	4	.204	12	.00280	1.057
		18	.00256	.967			18	.00300	1.133
		24	.00270	1.015			24	.00315	1.189
		48	.00312	1.178			48	.00358	1.351
000	.41	12	.00241	.910	5	.182	12	.00286	1.080
		18	.00262	.989			18	.00307	1.159
		24	.00277	1.046			24	.00323	1.220
		48	.00318	1.201			48	.00356	1.344
00	.365	12	.00248	.937	6	.162	12	.00291	1.098
		18	.00269	1.016			18	.00313	1.182
		24	.00285	1.076			24	.00329	1.243
		48	.00330	1.246			48	.00360	1.393
0	.325	12	.00254	.959	7	.144	12	.00298	1.125
		18	.00276	1.042			18	.00310	1.204
		24	.00293	1.106			24	.00336	1.269
		48	.00331	1.250			48	.00377	1.423
1	.289	12	.00260	.983	8	.128	12	.00303	1.144
		18	.00281	1.061			18	.00325	1.227
		24	.00298	1.125			24	.00341	1.288
		48	.00338	1.276			48	.00384	1.450
2	.258	12	.00267	1.008	9	.114	12	.00310	1.171
		18	.00288	1.083			18	.00332	1.253
		24	.00304	1.148			24	.00348	1.314
		48	.00344	1.299			48	.00389	1.469
3	.229	12	.00274	1.035	10	.102	12	.00318	1.201
		18	.00294	1.110			18	.00340	1.284
		24	.00310	1.171			24	.00355	1.340
		48	.00351	1.335			48	.00396	1.495

Basis of Table.

$$L_{ab} = 2\sqrt{3}\left[\frac{log\left(\frac{d}{r}\right)}{0.434}+\frac{1}{4}\right] = \text{self-ind. in C. G. S. units for loop } a.\ b. \text{ (per cm.)}$$

$$L_{ab} = 0.000558\left[2.303\ log_{10}\left(\frac{d}{r}\right) + .25\right] L, \text{ in henrys.}$$

Inductive drop in loop $ab = L_{ab} \times 2\pi \times f \times I$.

d = distance between wires (inch).
r = radius of wire (inch).
L = length of circuit in miles.
f = cycles per second.
I = current in one wire.

For self-induction of one wire divide L_{ab} by $\sqrt{3}$.

Inductive Resistance of Two Parallel Insulated Wires.

FREQUENCY 100.

Diam. B. & S. gauge.	Interaxial Distance.							
	$\frac{3}{8}''$	$\frac{3}{4}''$	$1\frac{1}{2}''$	3″	6″	12″	24″	48″
	Ohms per 1000 ft. dist.	Ohms per 1000 ft. dist.	Ohms per 1000 ft. dist.	Ohms per 1000 ft. dist.	Ohms per 1000 ft. dist.	Ohms per 1000 ft. dist	Ohms per 1000 ft. dist.	Ohms per 1000 ft. dist.
2″				.106	.159	.213	.267	.322
$1\frac{1}{2}$				.128	.182	.236	.290	.344
1			.106	.160	.213	.267	.321	.375
$\frac{3}{4}$			.128	.182	.236	.290	.344	.398
$\frac{1}{2}$			.159	.213	.267	.321	.375	.429
0000	.060	.114	.168	.222	.275	.329	.383	.437
000	.069	.123	.177	.230	.284	.338	.392	.446
00	.078	.132	.186	.239	.293	.347	.401	.455
0	.087	.141	.195	.248	.302	.356	.410	.464
1	.096	.150	.203	.257	.311	.366	.419	.473
2	.105	.158	.212	.266	.320	.375	.428	.482
3	.114	.167	.221	.275	.329	.384	.437	.491
4	.122	.176	.230	.284	.338	.393	.446	.500
5	.131	.185	.239	.293	.346	.402	.455	.509
6	.140	.194	.248	.301	.355	.411	.464	.518
7	.149	.203	.256	.310	.364	.419	.473	.527
8	.158	.212	.265	.319	.373	.428	.482	.536
9	.167	.220	.274	.328	.382	.437	.491	.545
10	.176	.229	.283	.337	.391	.446	.500	.554

Inductive resistances at other frequencies are proportional to this table.

CAPACITY OF CONDUCTORS.

The following formulæ have been developed by examination of the best authorities.

Table I. — Capacity of Insulated Lead-Protected Cables.

k = specific inductive capacity of insulating material. See page 975 for table.
D = diameter of cable outside of insulation.
d = diameter of conductor.

Microfarads per centimeter length, $$\frac{.000,000,241,5.\,k.}{\log \frac{D}{d}.}$$

Microfarads per inch length, $$\frac{.000,000,613,4.\,k.}{\log \frac{D}{\mathrm{d}}.}$$

Microfarads per foot length, $$\frac{.000,007,361.\,k.}{\log \frac{D}{d}.}$$

Microfarads per 1,000 feet length, $$\frac{.007,361.\,k.}{\log \frac{D}{d}.}$$

Microfarads per mile length, $$\frac{.038,83\,k.}{\log \frac{D}{d}.}$$

Table II. — Capacity of Single Overhead Wires with Earth Return.

$h =$ height above ground in mils or centimeters.
$d =$ diameter of conductor in mils or centimeters.

Microfarads per centimeter length, $\dfrac{.000{,}000{,}241{,}5}{\log \frac{4h}{d}}$.

Microfarads per inch length, $\dfrac{.000{,}000{,}613{,}4}{\log \frac{4h}{d}}$.

Microfarads per foot length, $\dfrac{.000{,}007{,}361}{\log \frac{4h}{d}}$.

Microfarads per 1,000 feet length, $\dfrac{.007{,}361}{\log \frac{4h}{d}}$.

Microfarads per mile length, $\dfrac{.038{,}83}{\log \frac{4h}{d}}$.

Table III. — Capacity of each of Two Parallel Bare Ærial Wires.

$D =$ distance apart from centre to centre.
$r =$ radius of wire $= \frac{1}{2}$ of diameter.

Microfarads per centimeter length, $\dfrac{.000{,}000{,}120{,}8}{\log \frac{D}{r}}$.

Microfarads per inch length, $\dfrac{.000{,}000{,}306{,}7}{\log \frac{D}{r}}$.

Microfarads per foot length, $\dfrac{.000{,}003{,}681}{\log \frac{D}{r}}$.

Microfarads per 1,000 feet iength, $\dfrac{.003{,}681}{\log \frac{D}{r}}$.

Microfarads per mile length, $\dfrac{.019{,}42}{\log \frac{D}{r}}$.

Capacities per 1,000 ft. of Copper Circuit, 2 Wires.

AERIAL. MICROFARADS.

Interaxial distance, inches.	1″ dia.	¾″ dia.	½″ dia.	B. and S. 0000	000	00	0
3	.00946	.00815	.00682	.0066	.00631	.00605	.00581
6	.00682	.00611	.005326	.0052	.00502	.00485	.00469
12	.005326	.00489	.00436	.00428	.00416	.00404	.00393
24	.00436	.004075	.00371	.00364	.00356	.00347	.00339
48	.00371	.003492	.00322	.00317	.00311	.00304	.00298

Capacities per 1,000 ft. of Copper Circuit. 2 Wires.

(Continued.)

Interaxial distance.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
3	.005585	.005375	.00518	.00501	.00484	.00468	.00454	.00441	.004275	.00416
6	.004545	.00441	.00428	.00415	.00404	.00393	.00383	.00374	.00364	.003555
12	.00383	.00374	.00364	.00355	.00347	.00339	.00331	.00324	.00317	.00310
24	.00331	.00324	.00317	.00310	.003035	.00298	.00292	.00286	.00281	.00275
48	.00292	.002865	.00281	.00275	.00271	.00265	.00261	.00256	.00251	.00247

Capacity and Self-Induction to Balance each other on Circuits. Microfarads, or Henrys.

A. C. CREHORE.

Frequency.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
15	112.58	56.29	37.53	28.15	22.52	18.76	16.08	14.07	12.51	11.258
20	63.328	31.664	21.109	15.832	12.666	10.555	9.047	7.916	7.036	6.3328
25	40.528	20.264	13.509	10.132	8.106	6.755	5.789	5.066	4.503	4.0528
33	23.259	11.629	7.419	5.815	4.652	3.877	3.323	2.907	2.584	2.3259
40	15.831	7.915	5.277	3.958	3.166	2.638	2.262	1.979	1.759	1.5831
60	7.036	3.518	2.345	1.759	1.407	1.173	1.005	.889	.782	.7036
80	3.958	1.979	1.319	.989	.792	.659	.566	.495	.439	.3958
100	2.533	1.266	.844	.633	.507	.422	.362	.316	.281	.2533
130	1.498	0.749	.499	.375	.299	.249	.214	.187	.166	.1498

Frequency.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.
15	10.235	9.38	8.66	8.04	7.505	7.035	6.622	6.255	5.925	5.629
20	5.757	5.2775	4.8714	4.5235	4.222	3.958	3.7252	3.518	3.3330	3.1664
25	3.684	3.3775	3.1175	2.8945	2.702	2.533	2.3840	2.2515	2.1330	2.0264
33	2.114	1.9385	1.7891	1.6615	1.551	1.4535	1.3682	1.292	1.2242	1.1629
40	1.439	1.3190	1.2179	1.1310	1.055	.9895	.9312	.8795	.8332	.7915
60	.639	.5865	.5412	.5025	.469	.4445	.4139	.3910	.3703	.3518
80	.359	.3295	.3044	.2830	.264	.2475	.2328	.2195	.2083	.1979
100	.2303	.2110	.1948	.1810	.169	.1580	.1490	.1405	.1333	.1266
130	.1362	.1245	.1152	.1070	.0996	.0935	.0812	.0830	.0788	.0749

Formula:

$$L\,C = \frac{10^6}{(2\,\pi\,n)^2}.$$

Where $L =$ coefficient of self induction.
$C =$ capacity.
$10^6 =$ microfarads.
$n =$ frequency.

CAPACITY IN MICRO-FARADS AND CHARGING CURRENT, PER MILE OF CIRCUIT, THREE-PHASE SYSTEM.

(Dr. F. A. C. Perrine and Frank G. Baum in Trans. A. I. E. E.)

Line E.M.F. — 10,000 volts. 60 P.P.S.

Size B & S.	Diameter in Inch.	Distance d in Inch.	Capacity c M. F.	Charge cur. in Amperes.	Size B. & S.	Diameter in Inch.	Distance d in Inch.	Capacity c in M. F.	Charg. cur. in Amperes.
0000	.46	12	.0226	.0492	4	.204	12	.01874	.0408
		18	.0204	.0447			18	.01726	.0377
		24	.01922	.0418			24	.01636	.0356
		48	.01474	.0364			48	.01452	.0317
000	.41	12	.0218	.0474	5	.182	12	.01830	.0399
		18	.01992	.0414			18	.01690	.0368
		24	.01876	.0408			24	.01602	.0349
		48	.01638	.0356			48	.01426	.0311
00	.365	12	.0214	.0465	6	.162	12	.01788	.0389
		18	.01946	.0423			18	.01654	.0360
		24	.01832	.0399			24	.01560	.0342
		48	.01604	.0349			48	.0140	.0305
0	.325	12	.02078	.0453	7	.144	12	.01746	.0389
		18	.01898	.0413			18	.01618	.0352
		24	.01642	.0379			24	.01538	.0335
		48	.01570	.0342			48	.01374	.0290
1	.289	12	.02022	.0440	8	.128	12	.01708	.0372
		18	.01952	.0403			18	.01586	.0341
		24	.01748	.0380			24	.01508	.0328
		48	.0154	.0337			48	.01350	.0294
2	.258	12	.01972	.0372	9	.114	12	.01660	.0364
		18	.01818	.0305			18	.01552	.0337
		24	.01710	.0372			24	.01478	.0317
		48	.01510	.0328			48	.01326	.0289
3	.229	12	.01938	.0421	10	.102	12	.01636	.0356
		18	.01766	.0385			18	.01522	.0329
		24	.01672	.0364			24	.01452	.0310
		48	.01480	.0322			48	.01304	.0284

Basis of Table.

$$C = \frac{1}{3\, log_e \left(\frac{d}{r}\right)},$$

in electro-static units per cm. of circuit.

$$C = \frac{0.0776 \times L}{2\, log_{10} \left(\frac{d}{r}\right)},$$

in micro-farads between one wire and neutral point for L miles of circuit.

$$\text{Charging current per wire} = \frac{E \times C \times 2\,\pi \times f}{\sqrt{3} \times 10^6}$$

d = distance between wires (inch).
r = radius of wire (inch).
L = length of circuit in miles.
E = E.M.F. between wires.
f = cycles per second.
C = capacity in M.F. between one wire and neutral point.

Charging current three-phase $= \frac{2}{\sqrt{3}}$ (= 15.5%) × charging current single-phase for same d, r, L, *and* E.

CHARGING CURRENT PER MILE OF CIRCUIT.

TWO PARALLEL WIRES.

LINE E.M.F.=10,000 VOLTS; FREQUENCY=60 P.P.S; SINE WAVE ASSUMED.

Stanley Electric Manufacturing Co., Pittsfield, Mass.

Size B. & S.	Distance D in inches.	Charging Current in Amperes.			Size B. & S.	Distance D in inches.	Charging Current in Amperes.		
0000	12	.0426			4	12	.0353		
	18	.0385				18	.0326		
	24	.0362				24	.0308		
	48	.0315				48	.0274		
000	12	.0411			5	12	.0345		
	18	.0375				18	.0319		
	24	.0353				24	.0302		
	48	.0308				48	.0269		
00	12	.0403			6	12	.0337		
	18	.0366				18	.0312		
	24	.0345				24	.0296		
	48	.0302				48	.0264		
0	12	.0392			7	12	.0329		
	18	.0358				18	.0305		
	24	.0328				24	.0290		
	48	.0296				48	.0259		
1	12	.0381			8	12	.0322		
	18	.0349				18	.0295		
	24	.0329				24	.0284		
	48	.02905				48	.02545		
2	12	.0372			9	12	.0315		
	18	.0342				18	.02925		
	24	.0322				24	.0278		
	48	.0284				48	.0250		
3	12	.0365			10	12	.0308		
	18	.0333				18	.0285		
	24	.0315				24	.0273		
	48	.0279				48	.0246		

Charging currents $= \frac{2\pi NkE}{10^6}$.

$E =$ Line E.M.F.
$N =$ Frequency.
$k =$ Capacity per mile of line in M.F.

STANLEY ELECTRIC MANUFACTURING COMPANY, PITSFIELD, MASS.

Line Constants for Power Transmission. Per Mile of Wire.

Size of Wire B. & S.	Weight.	Diameter.	Area Circular Mils.	Com'l Resistance.	Inductance Henrys.	Capacity Microf'ds 2 Wires.	Charging Cur. of Line 2 Wires, 60 P.P.S. 10,000 Volts.	(1) Reactance at.				(2) Impedance at.				(3) Apparent resistance. P. F. 90.				P. F. 80.			
No.	lbs.	mils.	C.M.	R.	L.	K.	C. (4)	S 25	S 33.3	S 60	S 125	U 25	U 33.3	U 60	U 125	A 25	A 33.3	A 60	A 125	A 25	A 33.3	A 60	A 125
0000	3376	460	211600	.266	.00148	.0102	.0385	.232	.309	.558	1.16	.353	.408	.618	1.19	.341	.375	.485	.749	.353	.399	.555	.911
000	2677	410	167800	.335	.00152	.00996	.0375	.239	.318	.573	1.19	.411	.462	.664	1.236	.407	.442	.554	.826	.412	.460	.613	.984
00	2123	365	133100	.422	.00156	.00973	.0366	.245	.326	.588	1.22	.488	.533	.724	1.291	.488	.523	.639	.917	.485	.524	.692	1.073
0	1685	325	105500	.533	.00160	.00949	.0358	.251	.334	.603	1.26	.589	.629	.805	1.368	.590	.627	.745	1.034	.577	.628	.789	1.185
1	1335	289	83690	.671	.00163	.00926	.0349	.256	.341	.614	1.28	.718	.753	.909	1.445	.716	.754	.874	1.167	.691	.742	.907	1.308
2	1059	258	66370	.845	.00166	.00909	.0342	.261	.347	.625	1.30	.884	.914	1.051	1.550	.875	.913	1.036	1.333	.833	.885	1.053	1.459
3	840	229	52630	1.067	.00170	.00883	.0333	.267	.355	.641	1.33	1.100	1.124	1.245	1.705	1.078	1.117	1.242	1.545	1.015	1.068	1.240	1.655
4	666	204	41740	1.346	.00173	.00863	.0326	.272	.362	.652	1.36	1.373	1.394	1.496	1.913	1.331	1.370	1.498	1.809	1.241	1.295	1.470	1.897
5	528	182	33100	1.700	.00177	.00845	.0319	.278	.370	.667	1.39	1.723	1.740	1.826	2.196	1.652	1.693	1.824	2.141	1.528	1.583	1.763	2.197
6	419	162	26250	2.138	.00181	.00827	.0312	.284	.378	.682	1.42	2.157	2.171	2.244	2.567	2.049	2.091	2.224	2.549	1.882	1.938	2.121	2.565
7	332	144	20820	2.698	.00184	.00809	.0305	.289	.385	.693	1.44	2.713	2.725	2.786	3.058	2.555	2.598	2.733	3.062	2.332	2.390	2.576	3.025
8	263	128	16510	3.406	.00188	.00793	.0295	.295	.393	.708	1.48	3.419	3.429	3.479	3.714	3.195	3.238	3.377	3.717	2.902	2.962	3.152	3.616

S 40	S 50	S 66.6	S 133	U 40	U 50	U 66.6	U 133	A 40	A 50	A 66.6	A 133	A 40	A 50	A 66.6	A 133
.372	.465	.619	1.24	.457	.536	.674	1.268	.403	.444	.512	.785	.437	.493	.586	.960
.382	.478	.636	1.27	.508	.584	.719	1.313	.470	.512	.582	.861	.498	.556	.651	1.033
392	.490	.652	1.30	.576	.647	.777	1.367	.552	.596	.667	.952	.574	.633	.730	1.139
.402	.502	.669	1.34	.667	.739	.855	1.442	.657	.701	.774	1.070	.668	.729	.829	1.234
409	.512	.682	1.36	.785	.844	.956	1.516	.784	.829	.904	1.202	.783	.845	.948	1.356
.417	.522	.694	1.39	.942	.993	1.093	1.627	.944	.989	1.066	1.372	.927	.991	1.094	1.514
.427	.534	.711	1.42	1.149	1.193	1.282	1.776	1.148	1.195	1.273	1.585	1.111	1.175	1.283	1.709
.435	.544	.724	1.44	1.415	1.452	1.528	1.971	1.403	1.450	1.530	1.845	1.339	1.405	1.513	1.944
.445	.556	.740	1.48	1.757	1.789	1.854	2.254	1.726	1.775	1.856	2.181	1.628	1.695	1.806	2.251
.455	.568	.757	1.51	2.186	2.212	2.268	2.618	2.125	2.174	2.257	2.588	1.984	2.052	2.166	2.620
.462	.578	.770	1.54	2.737	2.759	2.806	3.107	2.632	2.683	2.767	3.106	2.436	2.506	2.622	3.086
.472	.590	.786	1.57	3.439	3.457	3.495	3.750	3.273	3.325	3.411	3.756	3.009	3.080	3.198	3.670

Current in main conductor. Values of T.

System.	Per cent power factor.				
	100	.95	.90	.85	.80
Single phase	1.000	1.052	1.111	1.172	1.250
Two phase (4 wire)	.500	.526	.555	.588	.625
Three phase (3 wire)	.576	.607	.642	.679	.729

(1) $S = 2 \times 3.1416\, NL$

$$= \frac{\text{Wattless E.M.F. consumed by line}}{\text{current in line}}.$$

(2) $U = \sqrt{R^2 + S^2}$.

(3) $A = \dfrac{\text{drop of voltage in line}}{\text{current in line}}$; corresponding to *PF* of .90 or .80 inductance factor of .44 or .602.

(4) Charging current of line: $C = 2 \times 3.1416\, NKE\, 10^{-6}$.

E = E.M.F. N = frequency. K = capacity in microfarads. L = inductance in Henrys. Values of *S.U.A.* per mile of wire.

Values of C & K per mile of circuit. Distance between wires 18″. Current in main conductors $= \dfrac{\text{output in watts}}{E} \times T$.

IMPEDANCE AND REACTANCE OF ALTERNATING CURRENT CIRCUITS.

By Steinmetz.

Let
$R =$ resistance in ohms.
$Z =$ impedance.
$E =$ power E.M.F.
$e =$ impressed E.M.F.
$\omega = 2 \pi n$.
$L =$ coefficient of self-induction.
$I =$ current.
$c =$ capacity.

Then:

In circuits containing **Resistance** and **Inductance**,

$$\text{Impedance, } Z, = \sqrt{R^2 + L^2 \omega^2},$$

and

$$e = \sqrt{E^2 + I^2 L^2 \omega^2};$$

or diagrammatically,

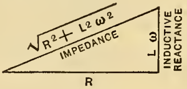


FIG. 8.

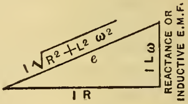


FIG. 9.

Circuits containing **Resistance** and **Capacity.**

$$\text{Impedance, } Z, = \sqrt{R^2 + \frac{1}{c^2 \omega^2}}.$$

$$\text{and } e = \sqrt{E^2 + \frac{I^2}{c^2 \omega^2}}.$$

or diagramatically,

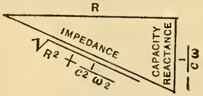


FIG. 10.

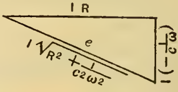


FIG. 11.

Circuits containing **Resistance, Inductance,** and **Capacity.**

$$\text{Impedance, } Z, = \sqrt{R^2 + \left(L\omega - \frac{1}{c\omega}\right)^2}.$$

$$\text{and } e = \sqrt{E^2 + I^2\left(L\omega - \frac{1}{c\omega}\right)^2}.$$

or diagramatically,

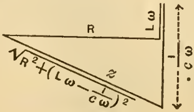


FIG. 12.

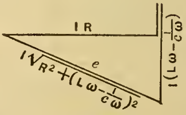


FIG. 13.

TABLE OF INDUCTANCE AND IMPEDANCE.

PER MILE OF WIRE.

Stanley Electric Manufacturing Co., Pittsfield, Mass.

Size B. & S.	Ohms per Mile.	D″	Coef. of Self-Ind. Henrys.	INDUCTANCE.						IMPEDANCE.					
				N 133	N 125	N 66.6	N 60	N 40	N 25	N 133	N 125	N 66.6	N 60	N 40	N 25
0000	.2656	6	.00113	.944	.887	.473	.426	.284	.177	.981	.926	.542	.502	.389	.319
		12	.00135	1.13	1.06	.565	.509	.339	.212	1.161	1.093	.624	.574	.431	.340
		18	.00148	1.24	1.16	.619	.558	.372	.232	1.268	1.190	.674	.618	.457	.353
		24	.00156	1.30	1.22	.652	.588	.392	.245	1.327	1.249	.704	.645	.474	.361
000	.3348	6	.00116	.969	.911	.485	.437	.291	.182	1.025	.971	.589	.551	.444	.381
		12	.00139	1.16	1.09	.581	.524	.349	.218	1.207	1.140	.671	.622	.484	.400
		18	.00152	1.27	1.19	.636	.573	.382	.239	1.313	1.236	.719	.664	.508	.411
		24	.00161	1.34	1.26	.673	.607	.404	.253	1.381	1.304	.752	.693	.525	.420
00	.4224	6	.00121	1.01	.950	.506	.456	.304	.190	1.095	1.040	.659	.622	.520	.463
		12	.00143	1.19	1.12	.598	.539	.359	.225	1.263	1.197	.732	.685	.554	.479
		18	.00156	1.30	1.22	.652	.588	.392	.245	1.367	1.291	.777	.724	.576	.488
		24	.00165	1.38	1.30	.690	.622	.414	.259	1.443	1.367	.809	.752	.591	.495
0	.5328	6	.00124	1.04	.973	.519	.467	.311	.195	1.169	1.109	.744	.709	.617	.567
		12	.00147	1.23	1.15	.615	.554	.369	.231	1.340	1.267	.814	.769	.648	.581
		18	.00160	1.34	1.26	.669	.603	.402	.251	1.442	1.368	.855	.805	.667	.589
		24	.00169	1.41	1.33	.707	.637	.425	.265	1.507	1.433	.885	.830	.682	.595
1	.6706	6	.00128	1.07	1.00	.535	.482	.322	.201	1.263	1.204	.858	.826	.744	.700
		12	.00150	1.25	1.18	.627	.565	.377	.236	1.419	1.357	.918	.877	.770	.711
		18	.00163	1.36	1.28	.682	.614	.409	.256	1.516	1.445	.956	.909	.785	.718
		24	.00172	1.44	1.35	.719	.648	.432	.270	1.580	1.507	.983	.933	.798	.723
2	.8448	6	.00130	1.09	1.02	.544	.490	.327	.204	1.379	1.324	1.005	.977	.906	.869
		12	.00154	1.29	1.21	.644	.580	.387	.242	1.542	1.476	1.062	1.025	.929	.879
		18	.00166	1.39	1.30	.694	.625	.417	.261	1.627	1.550	1.093	1.051	.942	.884
		24	.00176	1.47	1.38	.736	.663	.442	.276	1.695	1.618	1.120	1.074	.953	.889
3	1.067	6	.00134	1.12	1.05	.560	.505	.337	.210	1.547	1.497	1.205	1.180	1.119	1.087
		12	.00158	1.32	1.24	.661	.595	.397	.248	1.697	1.636	1.255	1.222	1.138	1.095
		18	.00170	1.42	1.33	.711	.641	.427	.267	1.776	1.705	1.282	1.245	1.149	1.100
		24	.00179	1.50	1.41	.749	.674	.450	.281	1.841	1.768	1.304	1.262	1.158	1.103
4	1.346	6	.00138	1.15	1.08	.577	.520	.347	.217	1.770	1.726	1.464	1.443	1.390	1.363
		12	.00162	1.35	1.27	.678	.610	.407	.254	1.906	1.851	1.507	1.478	1.406	1.370
		18	.00173	1.44	1.36	.724	.652	.435	.272	1.971	1.913	1.528	1.496	1.415	1.373
		24	.00182	1.52	1.43	.761	.686	.457	.286	2.030	1.964	1.546	1.511	1.421	1.376
5	1.700	6	.00141	1.18	1.11	.590	.531	354	.221	2.069	2.030	1.799	1.781	1.736	1.714
		12	.00165	1.38	1.30	.690	.622	.414	.259	2.190	2.140	1.835	1.810	1.750	1.720
		18	.00177	1.48	1.39	.740	.667	.445	.278	2.254	2.196	1.854	1.826	1.757	1.723
		24	.00187	1.56	1.47	.782	.705	.470	.294	2.307	2.247	1.871	1.840	1.764	1.725
6	2.138	6	.00145	1.21	1.14	.606	.546	.364	.228	2.457	2.423	2.222	2.207	2.169	2.150
		12	.00168	1.40	1.32	.703	.633	.422	.264	2.556	2.513	2.251	2.230	2.179	2.154
		18	.00181	1.51	1.42	.757	.682	.455	.284	2.618	2.567	2.268	2.244	2.186	2.157
		24	.00190	1.59	1.49	.795	.716	.477	.298	2.664	2.606	2.281	2.255	2.191	2.159
7	2.698	6	.00149	1.24	1.17	.623	.561	.374	.234	2.969	2.941	2.769	2.756	2.724	2.708
		12	.00172	1.44	1.35	.719	.648	.432	.270	3.058	3.017	2.792	2.775	2.732	2.711
		18	.00184	1.54	1.44	.770	.693	.462	.289	3.107	3 058	2.806	2.786	2.737	2.713
		24	.00194	1.62	1.52	.811	.731	.487	.305	3.147	3.097	2.817	2.795	2.742	2.715
8	3.406	6	.00153	1.28	1.20	.640	.577	.384	.240	3.639	3.611	3.466	3.455	3.428	3.414
		12	.00175	1.46	1.37	.732	.659	.440	.275	3.706	3.671	3.484	3.469	3.434	3.417
		18	.00188	1.57	1.48	.786	.708	.472	.295	3.750	3.714	3.495	3.479	3.439	3.419
		24	.00197	1.65	1.55	.824	.742	.495	.309	3.785	3.742	3.504	3.486	3.442	3.420
9	4.293	6	.00157	1.31	1.23	.657	.592	.394	.246	4.488	4.466	4.343	4.334	4.311	4.300
		12	.00179	1.50	1.41	.749	.674	.450	.281	4.548	4.519	4.358	4.346	4.317	4.302
		18	.00192	1.60	1.51	.803	.723	.482	.301	4.581	4.551	4.367	4.354	4.320	4.304
		24	.00201	1.68	1.58	.841	.757	.505	.316	4.610	4.575	4.375	4.359	4.323	4.305
10	5.417	6	.00161	1.34	1.26	.673	.607	.404	.253	5.580	5.562	5.459	5.451	5.432	5.423
		12	.00184	1.54	1.44	.770	.693	.462	.289	5.632	5.605	5.471	5.461	5.437	5.425
		18	.00196	1.64	1.54	.820	.739	.492	.308	5.660	5.632	5.479	5.467	5.439	5.426
		24	.00205	1.71	1.61	.857	.772	.515	.322	5.680	5.651	5.484	5.472	5.441	5.427

D″ = distance in inches between the wires. N = cycles per second.

Impedance Factors and Multipliers.

FREQUENCY = 100.

Diameter and Gauge.	Dist. between centres, 6″.		Dist. between centres, 12″.		Dist. between centres, 24″.		Dist. between centres, 48″.	
	Factor.	Multi-plier.	Factor.	Multi-plier.	Factor.	Multi-plier.	Factor.	Multi-plier.
2″	30.813	.094844	41.263	.170170	51.717	.26737	62.171	.386420
1½	19.809	.039142	25.692	.065905	31.574	.099596	37.459	.140223
1	10.362	.010636	12.919	.016683	15.573	.024151	18.182	.032957
¾	6.4873	.004108	7.9445	.006212	9.4039	.008745	10.869	.011712
½	3.3829	.001044	4.0118	.001509	4.6474	.002059	5.2874	.002696
0000	2.9793	.000787	3.5060	.001129	4.0400	.001532	4.5787	.001996
000	2.5004	.000525	2.9078	.000746	3.3225	.001000	3.7426	.001301
00	2.1227	.000351	2.4341	.000492	2.7528	.000658	3.0794	.000848
0	1.8316	.000235	2.0679	.000328	2.3130	.000435	2.5642	.000558
1	1.6021	.000157	1.7778	.000216	1.9622	.000285	2.1531	.000363
2	1.4306	.000105	1.5592	.000143	1.6958	.000187	1.8386	.000238
3	1.3024	.000069	1.3944	.000094	1.4935	.000123	1.5982	.000155
4	1.2092	.000046	1.2737	.000062	1.3439	.000081	1.4190	.000101
5	1.1428	.000031	1.1868	.000041	1.2357	.000053	1.2884	.000066
6	1.0968	.000020	1.1266	.000027	1.1598	.000035	1.1960	.000043
7	1.0649	.0000134	1.0847	.0000176	1.1070	.0000225	1.1313	.0000279
8	1.0440	.0000089	1.0573	.0000118	1.0722	.0000149	1.0886	.0000185
9	1.0288	.0000058	1.0373	.0000076	1.0470	.0000096	1.0576	.0000118
10	1.0196	.0000039	1.0234	.0000049	1.0309	.0000063	1.0377	.0000077

To find factor for any frequency, $\sqrt{(\text{Multiplier} \times f^2) + 1}$ = factor required.

For convenience of the engineer impedance factors for the frequencies most generally used have been computed by Prof. Forbes, and follow. To find the true drop in line, multiply ohmic drop by factors in tables below. Diameters are given in inches and B. & S. gauge.

Impedance Factors.

Diam. and Gauge.	Distance 6 in. Factor.	Distance 12 in. Factor.	Distance 24 in. Factor.	Distance 48 in. Factor.
	Frequency $f = 15$			
1	1.842	2.182	2.535	2.904
¾	1.387	1.546	1.720	1.903
½	1.111	1.157	1.210	1.267
0000	1.085	1.120	1.167	1.203
000	1.057	1.081	1.108	1.137
00	1.038	1.054	1.068	1.090
0	1.0264	1.036	1.048	1.061
	$f = 20$			
1	2.291	2.771	3.261	3.768
¾	1.624	1.863	2.116	2.378
½	1.190	1.263	1.351	1.441
0000	1.146	1.206	1.271	1.341
000	1.100	1.139	1.184	1.233
00	1.067	1.093	1.123	1.155
0	1.046	1.063	1.084	1.106

Diam. and Gauge.	Distance 6 in. Factor.	Distance 12 in. Factor.	Distance 24 in. Factor.	Distance 48 in. Factor.
	Frequency $f = 25$			
2	7.7638	10.37	12.912	15.55
1½	5.014	6.454	7.831	9.017
1	2.7654	3.3826	4.012	4.642
¾	1.889	2.209	2.543	2.885
½	1.285	1.393	1.513	1.637
0000	1.222	1.3068	1.3996	1.498
000	1.152	1.2104	1.2763	1.345
00	1.1034	1.1422	1.1876	1.235
0	1.0710	1.0973	1.1277	1.160
1	1.0478	1.0676	1.0853	1.108
2	1.0324	1.0443	1.0583	1.071
3	1.0216	1.0293	1.0384	1.048
4	1.0142	1.0191	1.0247	1.031
5	1.0094	1.0126	1.0162	1.0203
6	1.0063	1.0084	1.0107	1.0134

Impedance Factors. — *Continued.*

Diam.* and Gauge.	Distance 6 in. Factor.	Distance 12 in. Factor.	Distance 24 in. Factor.	Distance 48 in. Factor.
Frequency $f = 25$				
7	1.0042	1.0055	1.0070	1.0087
8	1.0027	1.0035	1.0045	1.0056
9	1.0018	1.0023	1.0029	1.0036
10	1.0011	1.0015	1.0019	1.0024
$f = 33$				
1	3.51	4.381	5.221	6.081
¾	2.338	2.781	3.237	3.700
½	1.462	1.625	1.803	1.982
0000	1.362	1.495	1.634	1.780
000	1.252	1.344	1.445	1.551
00	1.173	1.238	1.311	1.384
0	1.121	1.165	1.215	1.268
$f = 40$				
1	4.2447	5.2661	6.2961	7.3302
¾	2.7520	3.3072	3.8719	4.4428
½	1.6342	1.8480	2.0726	2.3050
0000	1.5033	1.6753	1.8579	2.0480
000	1.3566	1.4808	1.6136	1.7553
00	1.2493	1.3371	1.4326	1.5354
0	1.1747	1.2345	1.3023	1.3756

Diam.* and Gauge.	Distance 6 in. Factor.	Distance 12 in. Factor.	Distance 24 in. Factor.	Distance 48 in. Factor.
$f = 60$				
1	6.2681	7.8194	9.3778	10.938
¾	3.9738	4.8334	5.6995	6.5698
½	2.1817	2.5365	2.9009	3.2718
0000	1.9583	2.2505	2.5527	2.8614
000	1.7002	1.9194	2.1480	2.3838
00	1.5040	1.6651	1.8352	2.0134
0	1.3593	1.4763	1.6019	1.7627
$f = 80$				
1	8.3108	10.387	12.474	14.557
¾	5.2244	6.3840	7.5478	8.7151
½	2.7720	3.2649	3.7339	4.2722
0000	2.4577	2.8683	3.2873	3.7119
000	2.0884	2.4024	2.7249	3.0536
00	1.8011	2.0376	2.2825	2.5355
0	1.5833	1.7597	1.9451	2.1373
$f = 130$				
1	13.444	16.832	20.227	23.623
¾	8.3925	10.295	12.191	14.104
½	4.3185	5.1487	5.9842	6.8233
0000	3.7828	4.4814	5.1860	5.8942
000	3.1426	3.6878	4.2387	4.7939
00	2.6316	3.0529	3.4808	3.9161
0	2.2328	2.5567	2.8898	3.2283

To find true drop in line, multiply ohmic drop by factors in these tables.
* Diameter in inches, Gauge Brown & Sharp.

Impedance Determinations for Three-phase Circuits. — In theory the phases of a three-phase circuit differ 120°, although seldom exactly so in practice. This phase difference affects each wire as if it had one return wire in place of two; and in calculating the inductive effects, each wire must be treated as if it had a return wire in the position of one of the other two, that is, the three wires may be treated as if each was a separate circuit having no return wire.

Two- or Quarter-phase Circuits. — As used at Niagara, the two phases are separate, and all inductive determinations can be made as if for two separate and adjacent circuits.

Mutual Induction of Circuits. — When two alternating-current circuits are carried close together, and especially if the adjacent wires of the two circuits lie near together as compared to the two wires of the circuit, there is apt to be an interference or mutual induction of one current or the other, unless measures are taken to prevent it. It is caused by the linking together of lines of force from the two circuits, and must be compensated for by so arranging the relative positions of the circuits that at some other point on the line an equal number of lines will be interlinked in the opposite direction, and thus neutralize each other.

When alternating circuits were first erected, it was customary to place all the right-hand wires of the circuit on one side of a pole, and all the left-hand wires on the other; and most commonly the two outside wires were of one circuit, the next two inside the next circuit, and so on.

In many places where this method was used, and the distances great and the current high, it was soon found that incandescent lamps fluctuated in a regular periodic manner, which was first laid to engine fly-wheels and too heavily loaded engines. Of course, this was soon found to be an error, the fault discovered, and the conductors rearranged.

The effect is caused by one circuit acting as a secondary to the other; and if the cycles are similar, the mutual induction will tend to increase the drop in one circuit and diminish it in the other. If, however, the cycles are not alike, the potential will rise and fall periodically when the maximum values coincide, or the tops of the waves come into step at the same moment. Both conditions are annoying, and under certain particular arrangements are capable of producing damaging results.

Mutual induction, or rather its evil effects, can be overcome by arranging the conductors in such relative positions as to make the flux from one part of a circuit counteract that in another part, as shown in the following diagrams.

If lines are not very long, and potentials not too high, so as to induce bad effects from static capacity, it will be sufficient to place both wires of a circuit near together as compared with the distance between adjacent circuits.

Arrangement of Lines for no Mutual Induction.

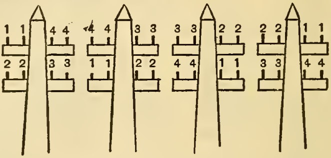


FIG. 14.

The above change should be made so as to cover the entire distance, each location of circuit being for one-quarter of the entire length.

Niagara Line. — The conductors on this line are bare cables of 19 strands, equivalent to 350,000 circuit mils, and are arranged as shown in the following diagram. The first arrangement was with two three-wire circuits on the upper cross-arm, the wires being 18 inches apart. So much trouble was experienced from short circuits by wires and other material being thrown across the conductors, that the middle wire was lowered to the bottom cross-arm as shown, since which time no trouble has been experienced. With porcelain insulators tested to 40,000 volts there is no appreciable leakage. These circuits are interchanged at a number of points to avoid inductive effects.

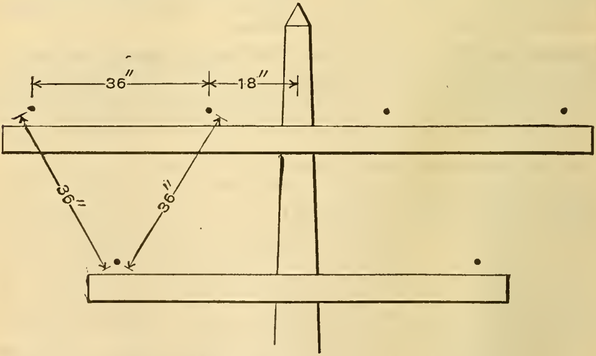


FIG. 15. Niagara-Buffalo Line. 11000 to 22000 Volts.

Three-phase Circuits. — The diagram (Fig. 16) shows the favorite arrangement of one of the larger companies as it makes lines conveniently accessible for repairs. Under the ordinary loads usual in the smaller plants the unbalancing effect is so small as to be inappreciable.

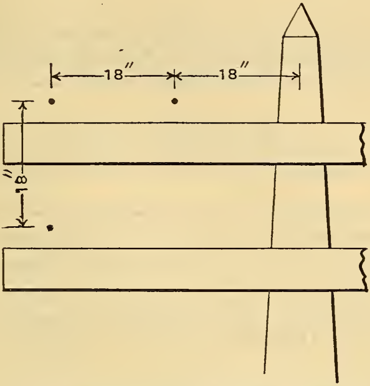


FIG. 16. Convenient Arrangement of Three-phase Lines for 6000–10000 Volts.

Balanced Line, Three-Phase. — The following diagram shows an arrangement of the conductors of a three-phase circuit, which will be balanced in all its effects if there be but one circuit. The distances, 18 inches apart, are about standard for pressures as high as 12,000· volts.

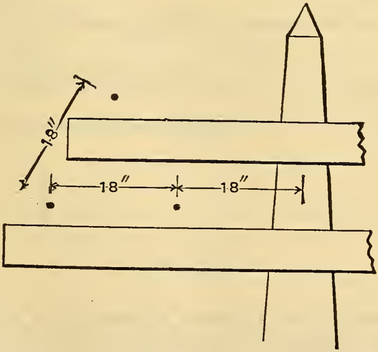


FIG. 17. Balanced Arrangement for Three-phase Lines.

This arrangement is perhaps not so convenient for repairs, but is symmetrical in all respects.

If there be more than one circuit of this balanced arrangement, and the difference of phase is enough so that interference is found, then one or more of the circuits will have to be changed as shown in the following diagram (Fig. 18), the principle being to bring each of the three wires of a circuit into the same relation with other circuits for an equal length or distance.

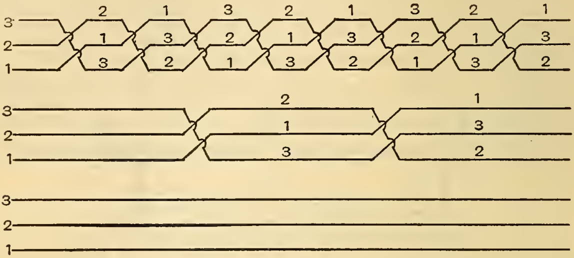


FIG. 18. Arrangement of Three Three-phase Circuits, each Equilaterally Placed. In this Arrangement there is no Effect from One Circuit on Another.

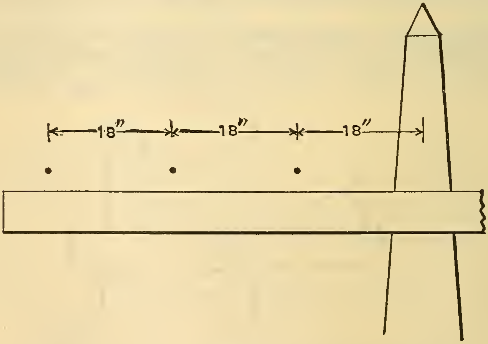


FIG. 19.

Three-phase Circuit in Same Plane.—It is sometimes advantageous to place all the conductors on one cross-arm on the same level as in the preceding diagram. In this case, if the load is heavy enough to cause interference between conductors, then two interchanges of wires should be made, dividing the circuit into three equal parts as shown. This will bring every wire into similar relations with all others, and the interference will therefore be the same on all. In order that this balancing effect should be correct along a line having branches, the reversals should be made between all branches; for instance, between the dynamo and the first branch there should be two reversals as shown, and between the first and second branches the reversals should be repeated, and so on.

If Wires of Three-phase Circuit are on same Plane, then they should be interchanged twice between Points when Branches are attached, as in Fig. 20.

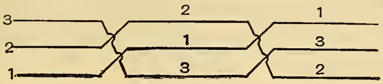


FIG. 20.

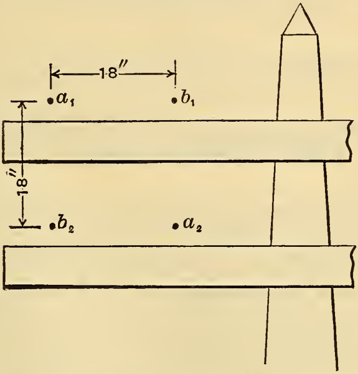


FIG. 21. Another Arrangement of Two-phase Circuit. No Reversal of Phases necessary.

Two-phase Four-wire Circuits.—The arrangement of conductors shown in Fig. 21 is probably the best for two-phase work, as no

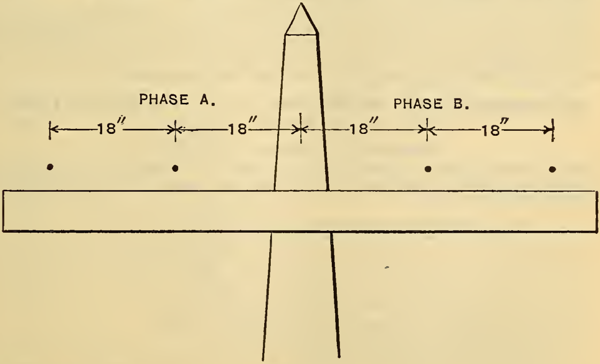


FIG. 22.

reversals of wires are needed, the inductive effects of the wires of one circuit on those of the other are neutralized.

Two-Phase Circuits in Same Plane. — If the phases are treated as separate circuits, and carried well apart, the interference is trifling; and should the loads carried be heavy enough to cause noticeable effect, the reversal of one of the phases in the middle of its length will obviate it. The following diagram illustrates the meaning.

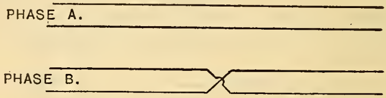


FIG. 23. Arrangement of Two-phase Four-wire Circuit with Wires on same Plane. Wires of One Phase should be interchanged at the Middle Point of the Distance between Branches, and between its Origin and First Branch.

Messrs. Scott and Mershon of the Westinghouse Electric and Manufacturing Co. have made special studies of the question of mutual induction of circuits, both in theory and practice; and their papers can be found in the files of the technical journals, and supply full detail information.

Capacity and Inductance. — In order to completely neutralize phase displacement due to distributed inductance a distributed capacity is essential. Localized capacity can, however, produce a partial neutralization. Excessive distributed capacity can also be partially neutralized by inserting inductances at proper intervals. In treating of local neutralization of capacity by inductance, the assumption is frequently made that the capacity is constant irrespective of the voltage, and that the inductance is constant irrespective of the current. Under these conditions neutralization can be obtained. As, however, inductance is dependent upon the permeability of the associated magnetic circuit, and permeability varies with the saturation of the iron, — that is with the current, — complete neutralization cannot be obtained with iron inductances.

Over-excited synchronous motors, or synchronous converters, take currents which lead the electromotive force impressed upon them, and they therefore operate as condensers, and they may be utilized advantageously in neutralizing the line inductance. The power factor of the transmission system can therefore be varied by varying their excitation.

ALTERNATING WIRING AND CONNECTIONS.

By General Electric Company.

General Wiring Formulæ.

The following general formulæ may be used to determine the size of conductors, volts lost in the line, and current per conductor for any system of electrical distribution.

$$\text{Area of conductor, Circular Mils} = \frac{D \times W}{P \times E^2} \times K.$$

$$\text{Volts loss in line} = \frac{P \times E}{100} \times M.$$

$$\text{Current in main conductors} = \frac{W}{E} \times T.$$

$D =$ Distance of transmission (one way), in feet.
$W =$ Total watts delivered to consumer.
$P =$ Per cent loss in line of W.
$E =$ Voltage between main conductors at receiving or consumers' end of circuit.

System.	Values of A.	Values of K.					Values of T.				
		Per cent power factor.					Per cent power factor.				
		100	95	90	85	80	100	95	90	85	80
Single-phase	6.04	2160	2400	2660	3000	3380	1.00	1.05	1.11	1.17	1.25
Two-phase (four-wire)	12.08	1080	1200	1330	1500	1690	.50	.53	.55	.59	.62
Three-phase (three-wire)	9.06	1080	1200	1330	1500	1690	.58	.61	.64	.68	.72

The value of K for any particular power factor is obtained by dividing 2160, the value for continuous current, by the square of that power factor for single-phase, and by twice the square of that power factor for three-wire three-phase, or four-wire two-phase.

The value of M depends on the size of wire, frequency and power factor. It is equal to 1 for continuous current, and for alternating current with 100 per cent power factor and sizes of wire given in the following table of wiring constants.

The figures given are for wires 18 inches apart, and are sufficiently accurate for all practical purposes, provided the displacement in phase between current and *E.M.F.* at the receiving end is not very much greater than that at the generator; in other words, provided that the reactance of the line is not excessive, or the line loss unusually high. For example, the constants should not be applied at 125 cycles if the largest conductors are used, and the loss 20 % or more of the power delivered. At lower frequencies, however, the constants are reasonably correct, even under such extreme conditions. They represent about the true values at 10 % line loss, are close enough at all losses less than 10 %, and often, at least for frequencies up to 40 cycles, close enough for even much larger losses. Where the conductors of a circuit are nearer each other than 18″, the volts loss will be less than given by the formulae, and if close together, as with multiple conductor cable, the loss will be only that due to resistance.

The value of T depends on the system and power factor. It is equal to 1 for continuous current, and for single-phase current of 100 per cent power factor.

The value of A and the weights of the wires in the table are based on .00000302 lb. as the weight of a foot of copper wire of one circular mil area.

In using the above formulae and constants, it should be particularly observed that P stands for the per cent loss in the line of the *delivered power*, not for the per cent loss in the line of the power at the generator; and that E is the potential at the end of the line and not at the generator.

When the power factor cannot be more accurately determined, it may be assumed to be as follows for any alternating system operating under average conditions: Lighting with no motors, 95%; lighting and motors together, 85 %; motors alone, 80 %.

In continuous current three-wire systems, the neutral wire for feeders should be made of one-third the section obtained by the formulae for either of the outside wires. In both continuous and alternating current systems, the neutral conductor for secondary mains and house-wiring should be taken as large as the other conductors.

When both motors and lights are used on the Monocyclic System, the primary circuit should be figured as if all the power was transmitted over the outside wires, and the size of the power wire should be in the proportion to either outside wire as the motor load in amperes is to the total load in amperes. Secondary wires leading directly to induction motors on the Monocyclic system should all be of the same size as for a single-phase circuit of the same kilowatt capacity and power factor. The three wires of a three-phase circuit, and the four wires of a two-phase circuit should all be made the same size, and each conductor should be of the cross section given by the first formula.

No. of Wire. B. & S. Gauge.	Area Wire. Circular Mils.	Weight of Bare Wire Per 1000 Feet, Pounds.	Resistance of Wire Per 1000 Feet at 20° C. Ohms.	Values of M. for Wires 18 inches apart C. to C.																No. of Wired. B. & S. Gauge.
				25 Cycles.				40 Cycles.				60 Cycles.				125 Cycles.				
				Per Cent Power Factor.				Per Cent Power Factor.				Per Cent Power Factor.				Per Cent Power Factor.				
				95	90	85	80	95	90	85	80	95	90	85	80	95	90	85	80	
0000	211 600	640.73	.04879	1.23	1.29	1.33	1.34	1.52	1.53	1.61	1.67	1.62	1.84	1.99	2.09	2.35	2.86	3.24	3.49	0000
000	167,805	508.12	.06154	1.18	1.22	1.24	1.24	1.40	1.41	1.48	1.51	1.49	1.66	1.77	1.95	2.08	2.48	2.77	2.94	000
00	133,079	402.97	.07758	1.14	1.16	1.16	1.16	1.25	1.32	1.35	1.37	1.34	1.52	1.60	1.66	1.86	2.18	2.40	2.57	00
0	105,560	319.00	.09775	1.10	1.11	1.10	1.09	1.19	1.24	1.26	1.26	1.31	1.40	1.46	1.49	1.71	1.96	2.13	2.25	0
1	83,694	253.43	.1234	1.07	1.07	1.05	1.03	1.14	1.17	1.18	1.17	1.24	1.30	1.34	1.36	1.56	1.75	1.88	1.97	1
2	66,373	200.98	.1556	1.05	1.04	1.02	1.00	1.11	1.12	1.12	1.10	1.18	1.23	1.25	1.26	1.45	1.60	1.70	1.77	2
3	52,633	159.38	.1962	1.03	1.02	1.00	1.00	1.07	1.08	1.07	1.05	1.14	1.17	1.18	1.17	1.35	1.46	1.53	1.57	3
4	41,742	126.40	.2473	1.02	1.00	1.00	1.00	1.05	1.06	1.03	1.00	1.11	1.12	1.11	1.10	1.27	1.35	1.40	1.43	4
5	33,102	100.23	.3120	1.00	1.00	1.00	1.00	1.03	1.01	1.00	1.00	1.08	1.08	1.06	1.04	1.21	1.27	1.30	1.31	5
6	26,250	79.49	.3934	1.00	1.00	1.00	1.00	1.02	1.00	1.00	1.00	1.05	1.04	1.02	1.00	1.16	1.20	1.21	1.21	6
7	20,816	63.03	.4958	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.03	1.02	1.00	1.00	1.12	1.14	1.14	1.13	7
8	16,509	49.99	.6250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.00	1.00	1.00	1.09	1.10	1.09	1.07	8
9	13,090	39.60	.7886	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1 00	1.00	1.00	1.00	1.06	1.06	1.04	1.02	9
10	10,382	31.40	.9940	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.04	1.03	1.00	1.00	10

GENERATORS.

The generators are rated by their volt-ampere capacity and their apparent watts, and not their actual watts, so that the size has to be increased if the power-factor of the system is low.

TRANSFORMERS.

For lighting circuits using small transformers, the voltage at the primaries of the step-down transformers should be made about 3% higher than the secondary voltage multiplied by the ratio of transformation, to allow for the drop in transformers. In large lighting transformers this drop may be as low as 2%. Standard lighting transformers have a ratio of 10 to 1 or some multiple thereof.

For motor circuits, the voltage at the primaries of step-down transformers should be made about 5% higher than the secondary voltage multiplied by the ratio of transformation. Transformers used with 110 volt motors on any 60-cycle system should have a ratio of 4½ to 1, 9 to 1, or 18 to 1 respectively for 1040, 2080, and 3120 volt generators. Transformers with a ratio of 10 or 20 to 1 should on no account be installed with motors operated from Monocyclic generators of standard voltage. The transformer capacity in *kilowatts* should be the same as the motor rating in *horse-power* for medium-sized motors, and slightly larger for small motors, and where only two transformers are used.

Capacities of Transformers to be used with 60-Cycle Induction Motors.

Size of Motor. Horse-Power.	Kilowatts per Transformer.	
	Two Transformers.	Three Transformers.
1	.6	.6
2	1.5	1
3	2	1.5
5	3	2
7½	4	3
10	5	4
15	7.5	5
20	10	7.5
30	15	10
50	25	15
75		25

INDUCTION MOTORS.

The standard (General Electric) induction motors for three-phase and for monocyclic circuits are wound for 110 volts, 220 volts, and 550 volts; motors of 50 H. P. and above are, in addition, wound for 1040 volts and 2080 volts. Motors for the two latter voltages are not built in sizes of less than 50 H. P. Where the four-wire three-phase distribution system is used, motors can also be wound for 200 volts.

The output of an induction motor varies with the square of the voltage at the motor terminals. Thus, if the volts at the terminals happen to be 15% low, that is, only 85% of the rated voltage, a motor, which at the rated voltage gives a maximum of 150% of its rated output, will be able to give at the 15% lower voltage, only $(\frac{85}{100})^2 \times 150 = 108\ \%$ of its rated output, and at full load will have no margin left to carry over sudden fluctuations of load while running.

Thus it is of the utmost importance to take care that the volts at the motor terminals are not below the rated volts, but rather slightly above at no load, so as not to drop below rated voltage at full-load or over-load.

The output of the motor may be increased by raising the potential; in this case, however, the current taken is increased, especially at light loads.

The direction of rotation of an induction motor on a three-phase or monocyclic circuit, can be reversed by changing any two of the leads to the field.

Like all electrical apparatus, the induction motor works most efficiently at or near full load, and its efficiency decreases at light load. Besides this, when running at light load, or no load, the induction motor draws from the lines a current of about 30% to 35% of the full-load current. This current does not represent energy, and is not therefore measured by the recording watt-meter; it constitutes no waste of power, being merely what is called an idle or "wattless" current. If, however, many induction motors are operated at light loads from a generator, the combined wattless currents of the motors may represent a considerable part of the rated current of the generator, and thus the generator will send a considerable current over the line. This current is wattless, and does not do any work, so that in an extreme case an alternator may run at apparently half-load or nearly full-load current, and still the engine driving it run light. While these idle currents are in general not objectionable, since they do not represent any waste of power, they are undesirable when excessive, by increasing the current-heating of the generator. Therefore it is desirable to keep the idle currents in the system as low as possible, by carefully choosing proper capacities of motors. These idle currents are a comparatively small per cent of the total current at or near full-load of the motor, but a larger per cent at light loads. Therefore care should be taken not to install larger motors than necessary to do the required work, since in this case the motors would have to work continuously at light loads, thereby producing a larger per cent of idle current in the system than would be produced by motors of proper capacity; that is, motors running mostly between half-load and full-load.

Current taken by General Electric Co. Three-phase Induction Motors at 110 Volts.

H. P. of Motor.	Full-Load Current.	Starting Current at 150% of Full-Load Torque.	Starting Current at Full-Load Torque.
1	6.3	19	
2	12	36	
3	18	54	
5	28	*42–84	28
10	54	70	54
15	81	120	81
20	112	167	112
30	168	252	168
50	268	400	268
75	390	585	390
100	550	825	550
150	780	1180	780

* The 5 H. P. motor is made with or without starting-switch.

The current taken by motors of higher voltage than 110 will be proportionally less. The above are average current values, and in particular cases the values may vary slightly.

CONNECTIONS.

Isolated motors running on the Monocyclic System are operated from two transformers, connected as shown in Fig. 24. Where there is no high-tension transmission line, the step-up and step-down transformers are not required, and only the two motor transformers shown at the right in the diagram are used.

The connections of a Monocyclic circuit for the operation of a three-wire secondary lighting system and motors is shown in Fig. 25. The main transformer has three terminals brought out from each winding, and a supplementary motor transformer is used and connected as shown.

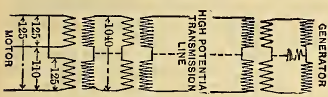


FIG. 24.

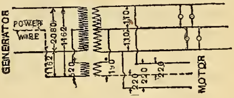


FIG. 25.

Where this connection is used for the operation of a single motor, the *kilowatt* rating of the supplementary transformer should be about one-half of the motor rating in *horse-power.* This arrangement is primarily intended for secondary mains carrying lights and a number of motors. Judgment should be exercised in the use of this arrangement, since, if the motors connected are large as compared with the total capacity of the transformers, the fluctuations of load may effect the lights to an objectionable degree through variations of drop in the transformers. The motor load being inductive, it will cause wider variations of voltage in the transformers than would be experienced with the same current delivered to lights.

The connections of three transformers, with their primaries, to the generator and their secondaries to the induction motor, in a three-phase system, are shown in Fig. 26. The three transformers are connected with their primaries between the three lines leading from the generator, and the three secondaries are connected to the three lines leading to the motor, in what is called delta connection.

The connection of two transformers for the supply of an induction motor from a three-phase generator is shown in Fig. 27. It is identical with the arrangement in Fig. 26, except that one of the transformers is left out, and the two other transformers are made correspondingly larger. The copper required in any three-wire, three-phase circuit for a given power and loss is 75%, as compared with the two-wire single-phase, or four-wire two-phase system having the same voltage between lines.

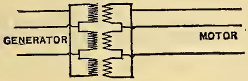


FIG. 26.

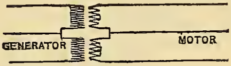


FIG. 27.

The connections of three transformers for a low-tension distribution system by the four-wire three-phase system are shown in Fig. 28. The three transformers have their primaries joined in delta connection, and their secondaries in "Y" connection. The three upper lines are the three main three-phase lines, and the lowest line is the common neutral. The difference

FIG. 28.

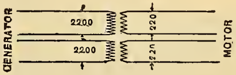


FIG. 29.

of potential between the main conductor is 200 volts, while that between either of them and the neutral is 115 volts. 200 volt-motors are joined to the mains, while 115 volt-lamps are connected between the mains and the neutral. The neutral is similar to the neutral wire in the Edison three-wire system, and only carries current when the lamp load is unbalanced.

The potential between the main conductors should be used in the formulæ, and the section of neutral wire should be made in the proportion to each of the main conductors that the lighting load is to the total load. When lights only are used, the neutral should be of the same size as either of the three main conductors. The copper then required in a four-wire three-phase system of secondary distribution to transmit a given power at a given loss is about 33.3%, as compared with a two-wire single-phase system, or a four-wire two-phase system having the same voltage across the lamps.

The connections of two transformers for supplying motors on the four-wire two-phase system are shown in Fig. 29. This system practically consists of two separate single-phase circuits, half the power being transmitted over each circuit when the load is balanced. The copper required, as compared with the three-phase system to transmit given power with given loss at the same voltage between lines, is 133⅓ % — that is, the same as with a single-phase system.

APPLICATIONS OF GENERAL WIRING FORMULÆ.

Continuous Current.

TWO-WIRE SYSTEM.

Example: 500 half ampere, 110 volt-lamps. Distance to lights, 1000 ft.; loss in line = 10% of delivered power.

$$\text{C.M} = \frac{2160 \times 1000 \times (500 \times .5 \times 110)}{10 \times 110^2} = 490{,}900 \text{ C.M.}$$

$$\text{Volts drop to lamp} = \frac{10 \times 110 \times 1}{100} = 11 \text{ volts.}$$

THREE-WIRE SYSTEM.

Example: 600 half-ampere, 110 volt-lamps. Distance to distribution point, 1500 ft. Volts between outside lines at distributing point, 220. Loss in line = 8% of delivered power.

Area of outside conductors =

$$\frac{2160 \times 1500 \times (600 \times .5 \times 110)}{8 \times 220^2} = 276{,}100 \text{ C.M.}$$

The area of the neutral feeder is 276,100 × $\frac{1}{3}$ = 92,030 C.M.

$$\text{Volts drop in circuit} = \frac{8 \times 220 \times 1}{100} = 17.6.$$

$220 + 17.6 = 237.6$ volts at station between outside lines; and 118.8 volts between outside wires and neutral.

Alternating Currents.

TWO-WIRE SINGLE-PHASE SYSTEM. 125 CYCLES.

Example: 1000, 16 c.p., 3.6 watt, 104 volt-lamps. 10 to 1 transformers Distance, 2000 ft. to generator. 2 volts less in secondary wiring. Drop in transformers for lighting is 3%. Loss in primary line to be equal to about 5% of power delivered at transformers. Efficiency of transformers, 97%.

Volts at transformer primaries $= 106 \times 10 \times 1.03 = 1091.8$. $1000 \times 16 \times 3.6 =$ 57,600 watts. $\frac{57{,}600}{.98 \times .97} =$ about 60,600 watts at transformer primaries.

$$\text{C.M.} = \frac{2000 \times 60{,}600}{5 \times 1091.8^2} \times 2400 = 48{,}800 \text{ C.M.}$$

No. 3 B. and S. = 52,633 C.M.

$$\frac{2000 \times 60{,}600 \times 2400}{52{,}633 \times 1091.8^2} = 4.64\% \text{ loss of delivered power, in primary wiring.}$$

Volts loss in primary lines =

$$\frac{4.64 \times 1091.8 \times 1.35}{100} = 68.4.$$

1091.8 + 68.4 = 1160.2 volts at generator.

TWO-WIRE SYSTEM. 60 CYCLES.

Example: The same load and losses as for the previous problem.
Volts at transformor primaries = 106 × 10 × 1.03 = 1091.8.
Load at transformer primaries = 60,600 watts.
No. 3 B. and S. wire gives 4.64% loss in primary wiring.
Volts loss in primary lines =

$$\frac{4.64 \times 1091.8 \times 1.14}{100} = 57.7.$$

1091.8 + 57.7 = 1149.5 volts at generator.

TWO-WIRE SYSTEM, WITH THREE-WIRE SECONDARIES. 60 OR 125 CYCLES.

The primary wiring is identical with that for the two-wire system. The secondary wiring is calculated, using the voltage between outside lines, and the three wires are made of the same cross-section. The drop in voltage on the secondary wiring as obtained by the formula is the drop between outside lines, and is twice the drop to each individual lamp.

Monocyclic System. 60 Cycles.

MOTOR AND LIGHTS ON SEPARATE TRANSFORMERS. (See Fig. 25.)

Example: 1500 half-ampere, 104 volt-lamps. One 25 H.P. 110 volt-induction motor; efficiency, 85%. Distance from generator to transformers, 3000 ft. Distance from transformers to motor, 100 ft. Loss in motor circuit, $2\frac{1}{2}$%. Loss of energy in transformers, 3%. Loss in primary circuit, 4%. Generator voltage, 1040 at no load.

$$\text{Input at motor} = \frac{25 \times 746}{.85} = 21{,}940 \text{ watts.}$$

$\text{C.M.} = \frac{100 \times 21{,}940}{2.5 \times 110^2} \times 3380 = 245{,}000.$ No. 0000 B. and S. wire = 211,600 C.M; but as two No. 0 B. and S. will give the same loss, and $\frac{1.49}{2.09} = 71.3\%$ as great a drop in voltage, they are preferable. Making each motor lead of two No. 0 B. and S. wires in parallel, then, $P = \frac{100 \times 21{,}940 \times 3380}{105{,}592 \times 2 \times 110^2} = 2.9\%.$

$$\text{Volts loss to motors} = \frac{2.9 \times 110 \times 1.49}{100} = 4.75.$$

Volts at primaries of transformers for motors = 1.05 × 9 × (110 + 4.75) = 1084.

$$\text{Volts on secondaries of lighting transformers} = \frac{1084}{1.03 \times 10} = 105.2.$$

Watts at primaries of motor transformers =

$$\frac{21{,}940 \times 1.029}{.97} = 23{,}200.$$

Watts at primaries of lighting transformers =

$$\frac{1500 \times .5 \times 105.2}{.97} = 81{,}340.$$

Total watts delivered at transformers = 23,200 + 81,340 = 104,540.
Power factor of load is

$$\frac{23{,}200 \times .80 + 81{,}340 \times .95}{104{,}540} = .91.$$

$$K = \frac{2160}{.91^2} = 2610.$$

$$\text{C.M.} = \frac{3000 \times 104{,}540}{4 \times 1076^2} \times 2610 = 175{,}750.$$

Taking No. 000 B. and S. wire = 167,805 C.M., then $P = \frac{3000 \times 104{,}540}{167{,}805 \times 1076^2} \times 2610 = 4.21\%$.

Drop in primary circuit =

$$\frac{4.21 \times 1076}{100} \times \frac{1.49 \times 80.8 + 1.62 \times 23.2}{104} = 68.5 \text{ volts.}$$

Voltage between outside lines at generator = 1076 + 68.5 = 1144.5 volts.

Current in main conductors $= \frac{104{,}540}{1076 \times .91} = 106.7$ amperes.

Primary teazer wire $= \frac{23{,}200}{104{,}540} \times 167{,}805 = 37{,}240$ C.M. required

Use No. 4 B. and S., with a section of 41,742 C.M.

THREE-WIRE SECONDARY FOR MOTORS AND LIGHTS. 60 CYCLES.

(See Fig. 26.)

Example: Distance from generator to transformers, 1000 ft. Ratio of main transformers, 9 to 1. The load consists of 1000 half-ampere, 110 volt-lamps, and four 10-H. P. induction-motors. The distance from transformers to motors is 200 ft., and the length of three-wire lighting feeders is 150 ft. The drop in lighting feeders and motor circuits to be about 10 volts. Loss in primary circuit to be 3%.

Lamp load = .5 × 110 × 1000 = 55,000 watts.

Assuming a per cent loss such that $\frac{P \times E \times M}{100}$ will be about 10 volts, then

$$\text{C.M.} = \frac{150 \times 55{,}000}{2.5 \times 220^2} \times 2400 = 163{,}600 \text{ C.M.}$$

Taking No. 000 B. and S. wire with an area of 167,805 C.M., we have $P = \frac{150 \times 55{,}000}{167{,}805 \times 220^2} \times 2400 = 2.44.$

$$\text{Volts loss in lighting feeders} = \frac{2.44 \times 220 \times 1.49}{100} = 8.$$

$$\text{Voltage at transformers} = 220 + 8 = 228.$$

Size of neutral feeder $= \frac{167{,}805}{3} = 55{,}935$ C.M., or about No. 2 B. and S. area, 66,373 C.M.

Input on each 10 H.P. motor at full-load with an efficiency of 84% is equal to $\frac{10 \times 746}{.84} = 8{,}881$ watts.

Assuming a per cent loss such that $\frac{P \times E \times M}{10}$ is about 8 volts, we have,

$$\text{C.M.} = \frac{200 \times 8881}{3.5 \times 220^2} = 3380 = 35{,}500 \text{ C.M.}$$

No. 5 B. and S. = 33,102 C.M. taken for section of motor leads.

$$P = \frac{200 \times 8881 \times 3380}{33{,}102 \times 220^2} = 3.75.$$

$$\text{Volt loss to motors} = \frac{3.75 \times 220 \times 1}{100} = 8.25.$$

The motor load is 4 × 8881 × 1.0375 = 36,800 watts.
The lighting load is 55,000 × 1.0244 = 56,340 watts.
56,340 + 36,800 = 93,140 watts.

Assuming transformer efficiencies of 97%, $\frac{93{,}140}{.97} = 96{,}000$ watts load on transformers.

The voltage at the transformer primaries, allowing 4% drop in transformers, is 228 × 9 × 1.04 = 2134.

$$\text{C.M.} = \frac{1000 \times 96{,}000}{3 \times 2134^2} \times \frac{56{,}340 \times 2400 + 36{,}800 \times 3380}{96{,}000} = 19{,}000 \text{ C.M.}$$

No. 7 B. and S. = 20,816 C.M.

$$P = \frac{19{,}000}{20{,}816} \times 3 = 2.74.$$

Volts loss in line $= \frac{2.74 \times 2134 \times 1}{100} = 58.5$. $2134 + 58.5 = 2192.5$ volts at generator. The section of the primary teazer wire would be $\frac{36.8}{93.4} \times 19{,}000 = 7500$ C.M., but this is too small for outside work, hence we would use two No. 7 wires, and one No. 8 wire for the primary circuit.

Three-Phase System. 60 Cycles.

THREE-WIRE TRANSMISSION. (See FIGS. 27 and 28.)

Example. — Required: the size of conductors and drop in line to transmit 5000 H.P. $3\frac{1}{2}$ miles, with a loss equal to about 10% of the delivered power. Voltage between lines at receiving end, 5000. Power factor of load, 85%.

$$\text{C.M.} = \frac{5280 \times 3.5 \times 5000 \times 746}{10 \times 5000^2} \times 1500 = 413{,}582 \text{ C.M.}$$

Two No. 0000 B. and S. wires per branch would answer; but the drop in voltage will be only $\frac{1.46}{1.99}$, or 73.3% as great for the same loss of power, if we take four No. 0 B. and S. wires in parallel, or a line of twelve No. 0 B. and S. wires in all. The loss will be $P = \frac{5280 \times 3.5 \times 5000 \times 746}{4 \times 105{,}592 \times 5000^2} \times 1500 = 9.79\%$ of delivered power, i.e., $.0979 \times 5000 = 489.5$ H.P. lost in line.

$$\text{Volts lost in line} = \frac{9.79 \times 5000 \times 1.46}{100} = 715 \text{ volts.}$$

$$\text{Voltage at generator} = 5000 + 715 = 5715 \text{ volts.}$$

$$\text{Current in line} = \frac{5000 \times 746}{5000} \times .659 = 506.5 \text{ amperes.}$$

FOUR-WIRE SECONDARY SYSTEM. (See FIG. 29.)

Example. — Required: the size of conductors from transformers to the distributing centre of a four-wire secondary system for lights and motors. The load consists of four 15 H.P., 200 volt-induction motors, and 750 half-ampere, 16 c.p., 115 volt-lamps. Length of secondary wiring from transformers to distribution centre, 600 ft. About 15 volts drop on lighting circuits from transformers to distributing centre. Efficiency of motors, 85%. 5 volts drop on circuits from distributing centre to motors. Voltage at distributing point between main lines is 205. Current in main lines for motors is $\frac{4 \times 15 \times 746 \times .725}{.85 \times 200} = 191$ amperes.

Current from transformers for lamps is

$$\frac{(750 \times .5 \times 115) \times .607}{200} = 131 \text{ amperes.}$$

Total current from transformers is $131 + 191 = 322$ amperes.

For motors, $191 = \frac{W}{205} \times .725$. $W = 54{,}000$.

For lamps, $131 = \frac{W}{205} \times .607$. $W = 44{,}240$. Total watts $= 98{,}240$.

Taking for trial two No. 0 B. and S. wires in parallel for each of the main conductors, as preferable to one No. 0000, then $P = \frac{600 \times 98,240}{2 \times 105,592 \times 205^2} \times$

$$\frac{1200 \times 44,240 + 1690 \times 54,000}{98,249} = 9.75.$$

$$\text{Volts loss in lines} = \frac{9.75 \times 205 \times 1.46}{100} = 29.2.$$

Volts at transformers between main lines = 231.4.

Actual drop between main conductors and neutral to distributing point = $29.2 \times \frac{115}{200} = 16.8$ volts.

The section of the neutral conductor should be about $\frac{131 \times 2 \times 105,592}{322} =$ 86,000 C.M. We may use one No. 1 B. and S. wire, with a section of 83,694 C.M. for the neutral.

Two-Phase System. 60 Cycles.

FOUR-WIRE TRANSMISSION. (See FIG. 29.)

Example. — Required: the size of conductors and drop in line to transmit 5000 H.P. 3½ miles, with a loss equal to about 10% of the delivered power. Voltage between lines at receiving end, 5000. Power factor of load is 85%.

$$\text{C.M.} = \frac{5280 \times 3.5 \times 5000 \times 746}{10 \times 5000^2} \times 1500 = 413,580 \text{ C.M.}$$

Taking four No. 0 B. and S. wires in parallel, the line will consist of sixteen No. 0 B. and S. wires in all. The loss will be $P = \frac{5280 \times 3.5 \times 5000 \times 746}{4 \times 105,592 \times 5000^2}$ $\times 1500 = 9.79\%$ of delivered power, or $.0979 \times 5000 = 489.5$ H.P. lost in the line.

Volts lost in line =

$$\frac{P \times E \times M}{100} = \frac{9.79 \times 5000 \times 1.46}{100} = 715 \text{ volts.}$$

Volts at generating end of line = 5715.

$$\text{Current in line} = \frac{5000 \times 746}{5000} \times .588 = 438.6 \text{ amperes.}$$

Alternating-Current Arcs.

Power factor is about .75. Calculate wire for *apparent* watts, not real watts.

Chart and Table for calculating Alternating-Current Lines.

RALPH D. MERSHON, in *American Electrician.*

The accompanying table, and chart on page 137 include everything necessary for calculating the copper of alternating-current lines.

The terms, resistance volts, resistance E.M.F., reactance volts, and reactance E.M.F., refer to the voltages for overcoming the back E.M.F.'s due to resistance and reactance respectively. The following examples illustrate the use of the chart and table.

PROBLEM. — Power to be delivered, 250 k.w.; E.M.F. to be delivered, 2000 volts; distance of transmission, 10,000 ft.; size of wire, No. 0; distance between wires, 18 inches; power factor of load, .8; alternations, 7200 per minute. Find the line loss and drop.

The power factor is that fraction by which the apparent power or volt-amperes must be multiplied to give the true power or watts. Therefore the apparent power to be delivered is $\frac{250 \text{ k.w.}}{.8} = 312.5$ apparent k.w., or 312,500 volt-amperes, or apparent watts. The current, therefore, at 2000 volts will be $\frac{312,500}{2000} = 156.25$ amperes. From the table of reactances, under the heading "18 inches," and corresponding to No. 0 wire, is obtained the constant, .228. Bearing the instructions of the table in mind, the reactance volts of this line are 156.25 (amperes) × 10 (thousands of feet) × .228 = 356.3 volts, which are 17.8 per cent of the 2000 volts to be delivered.

From the column headed "Resistance Volts," and corresponding to No. 0 wire, is obtained the constant .197. The resistance volts of the line are, therefore, 156.25 (amperes) × 10 (thousands of feet) × .197 = 307.8 volts, which are 15.4 per cent of the 2000 volts to be delivered.

Starting, in accordance with the instructions of the sheet, from the point where the vertical line, which at the bottom of the sheet is marked "Load Power Factor .8," intersects the inner or smallest circle, lay off horizontally and to the right the resistance E.M.F. in per cent (15.4), and "from the point thus obtained," lay off vertically the reactance E.M.F. in per cent (17.8). The last point falls at about 23 per cent, as given by the circular arcs. This, then, is the drop in per cent of the *E.M.F. delivered.* The drop in per cent of the *generator* E.M.F. is, of course, $\frac{23}{100 + 23} = 18.7$ per cent.

The resistance volts in this case being 307.8, and the current 156.25 amperes, the energy loss is $307.8 \times 156.25 = 48.1$ k.w. The percentage loss is $\frac{48.1}{250 + 48.1} = 16.1$. Therefore, for the problem taken, the drop is 18.7 per cent, and the energy loss is 16.1 per cent.

If the problem be to find the size of wire for a given drop, it must be solved by trial. Assume a size of wire, and calculate the drop in the manner above indicated; the result in connection with the table will show the direction and extent of the change necessary in the size of wire to give the required drop.

The table is made out for 7200 alternations per minute, but will answer for any other number. For instance, for 16,000 alternations, multiply the reactances by $16000 \div 7200 = 2.22$.

As an illustration of the method of calculating the drop in a line and transformer, and also of the use of the table and chart in calculating low-voltage mains, the following example is given: —

Problem. — A single-phase, induction motor is to be supplied with 20 amperes at 200 volts; alternations, 7200 per minute; power factor, .78. The distance from transformer to motor is 150 ft., and the line is No. 5 wire, 6 inches between centres of conductors. The transformer reduces in the ratio 2000 : 200, and has a capacity of 25 amperes at 200 volts; when delivering this current and voltage, its resistance E.M.F. is as 2.5 per cent, and its reactance E.M.F. 5 per cent, both of these constants being furnished by the makers. Find the drop.

The reactance of 1000 ft. of circuit, consisting of two No. 5 wires, 6 inches apart, is .204. The reactance-volts, therefore, are $.204 \times \frac{150}{1000} \times 20 = .61$ volts. The resistance-volts are $.627 \times \frac{150}{1000} \times 20 = 1.88$ volts. At 25 amperes, the resistance-volts of the transformers are 2.5 per cent of 200, or 5 volts. At 20 amperes they are $\frac{20}{25}$ of this, or 4 volts. Similarly, the transformer reactance volts at 25 amperes are 10, and at 20 amperes are 8 volts. The combined reactance-volts of transformer and line are $8 + .61 = 8.61$, which is 4.3 per cent of the 200 volts to be delivered. The combined resistance-volts are $1.88 + 4$, or 5.88, which is 2.94 per cent of the E.M.F. to be delivered. Combining these quantities on the chart with a power factor of .78, the drop is 5 per cent of the delivered E.M.F., or $\frac{5}{105} = 4.8$ per cent of the impressed E.M.F. The transformer must therefore be supplied with $2000 \div .952 = 2100$ volts, in order that 200 volts shall be delivered to the motor.

To calculate a four-wire, two-phased transmission circuit, compute, as above, the single-phased circuit required to transmit one-half the power at the same voltage. The two-phase transmission will require two such circuits.

To calculate a three-phase transmission, compute, as above, a single-phase circuit to carry one-half the load at the same voltage. The three-phase transmission will require three wires of the size obtained for the single-phase circuit, and with the same distance (triangular) between centres.

By means of the table calculate the *Resistance-Volts* and the *Reactance-*

Volts in the line, and find what per cent each is of the E.M.F. delivered at the end of the line. Starting from the point on the chart where the vertical line corresponding with power factor of the load intersects the smallest circle, lay off in per cent the resistance E.M.F. horizontally and to the right; from the point thus obtained lay off upward in per cent the reactance E.M.F. The circle on which the last point falls gives the drop in per cent of the E.M.F. delivered at the end of the line. Every tenth circle-arc is marked with the per cent drop to which it corresponds.

Size of Wire B.&S.	Weight-Pounds per 1000 ft. Single Wire.	Resistance-Volts in 1000 ft. of Line (2000 ft. of wire) for One Ampere ($\sqrt{\text{Mean Square}}$.)	Reactance-Volts in 1000 ft. of Line (=2000 ft. of Wire) for One Ampere ($\sqrt{\text{Mean Square}}$) at 7200 Alternations per Minute for the Distance given between Centres of Conductors.										
			½″	1″	2″	3″	6″	9″	12″	18″	24″	30″	36″
0000	639	.098	.046	.079	.111	.130	.161	.180	.193	.212	.225	.235	.244
000	507	.124	.052	.085	.116	.135	.167	.185	.199	.217	.230	.241	.249
00	402	.156	.057	.090	.121	.140	.172	.190	.204	.222	.236	.246	.254
0	319	.197	.063	.095	.127	.145	.177	.196	.209	.228	.241	.251	.259
1	253	.248	.068	.101	.132	.151	.183	.201	.214	.233	.246	.256	.265
2	201	.313	.074	.106	.138	.156	.188	.206	.220	.238	.252	.262	.270
3	159	.394	.079	.112	.143	.162	.193	.212	.225	.244	.257	.267	.275
4	126	.497	.085	.117	.149	.167	.199	.217	.230	.249	.262	.272	.281
5	100	.627	.090	.121	.154	.172	.204	.223	.236	.254	.268	.278	.286
6	79	.791	.095	.127	.158	.178	.209	.228	.241	.260	.272	.283	.291
7	63	.997	.101	.132	.164	.183	.214	.233	.246	.265	.278	.288	.296
8	50	1.260	.106	.138	.169	.188	.220	.238	.252	.270	.284	.293	.302

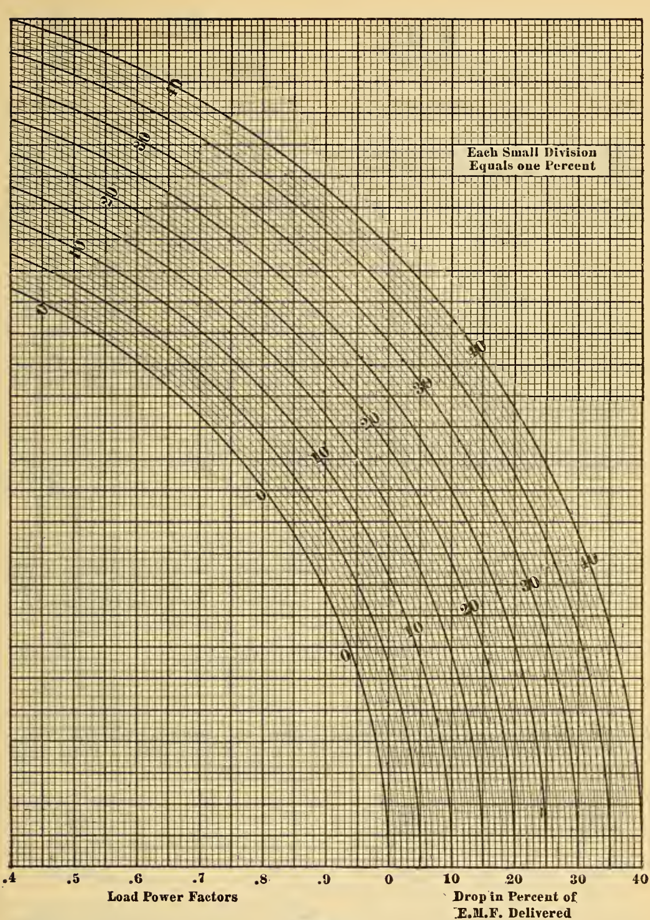


FIG. 30.

BELL WIRING.

The following diagrams show various methods of connecting up-call bells for different purposes, and will indicate ways in which incandescent lamps may also be connected to accomplish different results.

FIG. 31. One Bell, operated by one Push.

FIG 32. One Bell, operated by Two Pushes.

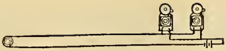


FIG. 33. Two Bells, operated by One Push.

FIG. 34. Two Bells, operated by Two Pushes.

When two or more bells are required to ring from one push, the common practice is to connect them in series, i.e., wire from one directly to the next, and to make all but one single-stroke ends. Bells connected in multiple arc, as in diagram No. 24, give better satisfaction, although requiring more wire.

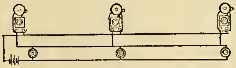


FIG. 35. Three-line Factory Call. A number of Bells operated by any number of pushes. All bells rung by each push.

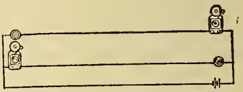


FIG. 36. Simple button, Three-line Return Call. One set of battery.

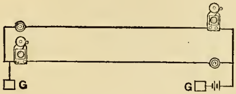


FIG. 37. Simple Button, Two-Line and Ground Return Call. One set of Battery.

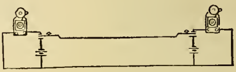


FIG. 38. Two-Line Return Call. Illustrating use of Return Call Button. Bells ring separately.

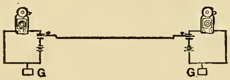


FIG. 39. One-Line and Ground Return Call. Illustrating use of Return Call-Button. Bells ring separately.

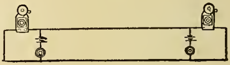


FIG. 40. Simple Button, Two-Line Return Call. Bells ring together.

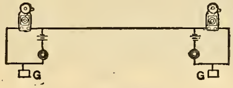


FIG. 41. Simple-Button, One-Line and Ground Return Call. Bells ring together. The use of complete metallic circuit in place of ground connection is advised in all cases where expense of wire is not considerable.

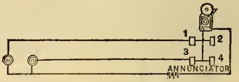


FIG. 42. Four Indication Annunciator. Connections drawn for two buttons only. A burglar alarm circuit is similar to the above, but with one extra wire running from door or window-spring side of battery to burglar alarm in order to operate continuous ringing attachment.

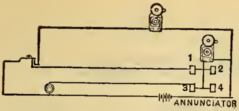


FIG. 43. Four Indication Annunciator, with extra Bell to ring from one Push only. Illustrating use of three-point button.

FIG. 44. Acoustic Telephone with Magneto Bell Return Call. Extension Bell at one end of line.

In running lines between any two points, use care to place the battery, if possible, near the push-button end of the line, as a slight leakage in the circuit will not then weaken the battery.

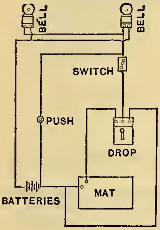


FIG. 45. Diagram of Burglar-Alarm Mat, two Bells, one Push and Automatic Drop; all operated by one battery. Both bells ring from one push or mat, as desired, by changing the switch.

When mat is to be used, throw it into the circuit by the switch, so that when the circuit is closed by a person stepping on the mat, the automatic drop will keep it closed, and both bells will continue to ring until the drop is hooked up again.

GAS-LIGHT WIRING.

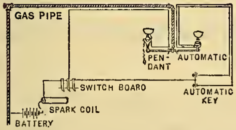


FIG. 46. Pendent and Automatic Gas-Lighting Circuit, with Switch-board.

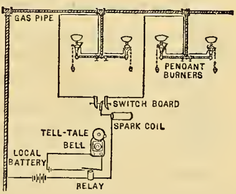


FIG. 47. Pendent Gas-Lighting Circuit, with Switch-board, Relay, and Tell-Tale Bell.

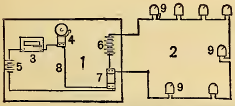


FIG. 48. Diagram showing arrangement of circuits for Fire-Alarm or District-Messenger Service.

Fig. 1 represents the engine-house or central station containing the local or open circuit (8).

2 Represents the main or closed circuit on which is located the fire-alarm or messenger boxes (9).

3 Is the automatic register and winder.

4 Is the electro-mechanical gong.

5 Is the battery of open-circuit cells.

6 Is the battery of closed-circuit cells.

7 Is the relay and relay bell.

Instead of, or in addition to, the gong (4), may be used a mechanical tower strike.

PROPERTIES OF CONDUCTORS.

Pure and Soft Copper.

Specific gravity, pure annealed, at 60° F.	8.89 lbs.
Cubic foot weighs	555 lbs.
Cubic inch weighs	.32 lbs.
1,000 foot 1 inch square rod weighs	3,851 lbs.
Tensile strength at 100° F. per square inch	23,366 lbs.
Specific resistance 1 cubic centimeter 0° C.	.000001594 ohm.
Resistance 1 cubic inch 15.5° C. or 60° F.	.0000006774 ohm.
Resistance 1 foot of 1 square inch section 20° C.	.000008128 ohm.
Resistance 1 mil-foot 0° C.	9.59 ohms.

Weight per mile of copper wire is

$$\frac{(\text{dia. in mils})^2}{62.5}$$

Resistance per mile in ohms, of pure copper at 60° F., is

$$\frac{54{,}892}{(\text{dia. in mils})^2}$$

Specific conductivity of pure copper is 100, commercial copper runs from 96 to 102 per cent of the standard.

Percentage of conductivity is found by measuring the resistance of a sample of the same length and weight as the standard, and at the same temperature, then if $R =$ resistance of standard, and $r =$ the resistance of sample, $\frac{100 \times R}{r} =$ per cent conductivity.

Percentage Conductivity of any Sample.

The percentage conductivity of any sample of a conductor, as referred to a standard, can be determined as follows: —

Let $R =$ resistance of a unit weight and length of the standard, at temperature t, from tables.

$l =$ length of wire to be tested,

$w =$ weight of wire to be tested,

$r =$ computed resistance of a pure standard copper wire of the same dimensions and temperature as the test sample.

$r_1 =$ observed resistance at temperature t of the wire under test in ohms.

Then as the resistance of a conductor is directly proportional to its length, and inversely proportional to its weight per unit of length (its cross-section),

$$r = \frac{R\,l^2}{w} \text{ ohms.}$$

By actual test, the resistance of the wire having been found to be r' at temperature t, then

$$r' : r :: 100 : x$$

and the percentage of conductivity of the wire is

$$x = \frac{100\,r}{r'}.$$

Rise of Resistance with Temperature.

The resistance of conductors is not a linear function of the temperature, and hence its variation with the temperature must, for very precise work, be represented in the ordinary formula: —

$$R = r\,(1 + a\,t \pm b\,t^2)$$

Where R = resistance at the temperature t,
r = resistance at 0° C.,
t = temperature in degrees C.,
a and b = numerical constants from table below.

The following values of the constants have been found, but they are really applicable to the original samples under test only:—

	a	b
Metals (very pure)	.00382	+.0000126
Mercury	.000882	—.000000362
German silver (Cu 60 — Zn 26 — Ni 14)	.000443	+.000000152
Platinum silver (Pt 67 — Ag 33)	.00031	"
Platinoid (Cu 59 — Zn 25.5 — Ni 14 — W 55)	.00021	"
Silver gold	.0006999	—.000000062

For ordinary calculations the formula may be written and used as follows:—

$$R = r\,(1 + at)$$

the values of a being given in the following table:—

METAL.	a
Silver	.00377
Copper	.00388
Gold	.00365
Aluminum	.00390
Platinum	.00247
Iron	.00453
Tin	.00365
Lead	.00387
Antimony	.00389
Bismuth	.00354
Mercury	.00088
German silver	.00028 to .00044

The following table gives the value of the principal practical units of resistance which existed previous to the establishment of the International Units.

UNIT	INTERNATIONAL OHM.	B.A. OHM.	LEGAL OHM 1884.	SIEMENS'S OHM.
International ohm	1.	1.0136	1.0028	1.0630
B. A. ohm	0.9866	1.	0.9894	1.0488
Legal ohm	0.9972	1.0107	1.	1.0600
Siemens's ohm	0.9407	0.9535	0.9434	1.

Thus to reduce British Association ohms to international ohms we divide by 1.0136, or multiply by 0.9866; and to reduce legal ohms to international ohms we divide by 1.0028, or multiply by 0.9972, etc.

COPPER WIRE TABLE OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Giving weights and lengths of cool, warm, and hot wires, of Matthiessen's standard of conductivity.

A.W.G.	Diameter.	Area.		Lbs. per foot.	Lbs. per ohm.			Feet per lb.	Feet per ohm.		
B. & S.	Inches.	Circular mils.	Sq. in. Sq. mils.		@ 20° C.	@ 50° C.	@ 80° C.		@ 20° C.	@ 50° C.	@ 80° C.
0000	0.460	211,600	166,190	0.6405	13,090	11,720	10,570	1.561	20,440	18,290	16,510
000	0.4096	167,800	131,790	0.5080	8,232	7,369	6,647	1.969	16,210	14,510	13,090
00	0.3648	133,100	104,518	0.4028	5,177	4,634	4,182	2.482	12,850	11,500	10,380
0	0.3249	105,500	82,887	0.3195	3,256	2,914	2,630	3.130	10,190	9,123	8,232
1	0.2893	83,690	65,732	0.2533	2,048	1,833	1,654	3.947	8,083	7,235	6,528
2	0.2576	66,370	52,128	0.2009	1,288	1,153	1,040	4.977	6,410	5,738	5,177
3	0.2294	52,630	41,339	0.1593	810.0	725.0	654.2	6.276	5,084	4,550	4,106
4	0.2043	41,740	32,784	0.1264	509.4	455.9	411.4	7.914	4,031	3,608	3,256
5	0.1819	33,100	25,999	0.1002	320.4	286.7	258.7	9.980	3,197	2,862	2,582
6	0.1620	26,250	20,618	0.07946	201.5	180.3	162.7	12.58	2,535	2,269	2,048
7	0.1443	20,820	16,351	0.6302	126.7	113.4	102.3	15.87	2,011	1,800	1,624
8	0.1285	16,510	12,967	0.04998	79.69	71.33	64.36	20.01	1,595	1,427	1,288
9	0.1144	13,090	10,283	0.03963	50.12	44.86	40.48	25.23	1,265	1,132	1,021
10	0.1019	10,380	8,155	0.03143	31.52	28.21	25.46	31.82	1,003	897.6	809.9
11	0.09074	8,234	6,467	0.02493	19.82	17.74	16.01	40.12	795.3	711.8	642.3
12	0.08081	6,530	5,129	0.01977	12.47	11.16	10.07	50.59	630.7	564.5	509.4
13	0.07196	5,178	4,067	0.01568	7.840	7.017	6.332	63.79	500.1	447.7	404.0
14	0.06408	4,107	3,225	0.01243	4.931	4.413	3.982	80.44	396.6	355.0	320.3
15	0.05707	3,257	2,558	0.009858	3.101	2.776	2.504	101.4	314.5	281.5	254.0
16	0.05082	2,583	2,029	0.007818	1.950	1.746	1.575	127.9	249.4	223.3	201.5
17	0.04526	2,048	1,609	0.006200	1.226	1.098	0.9906	161.3	197.8	177.1	159.8
18	0.04030	1,624	1,276	0.004917	0.7713	0.6904	0.6230	203.4	156.9	140.4	126.7
19	0.03589	1,288	1,012	0.003899	0.4851	0.4342	0.3918	256.5	124.4	111.4	100.5
20	0.03196	1,022	802	0.003092	0.3051	0.2731	0.2464	323.4	98.66	88.31	79.68
21	0.02846	810.1	636.3	0.002452	0.1919	0.1717	0.1550	407.8	78.24	70.03	63.19

22	0.02535	642.4	504.6	0.001945	0.1207	0.1080	0.09746	514.2	62.05	55.54	50.11
23	0.02257	509.5	400.2	0.001542	0.07589	0.06793	0.06129	648.4	49.21	44.04	39.74
24	0.02010	404.0	317.3	0.001223	0.04773	0.04272	0.03855	817.6	39.02	34.93	31.52
25	0.01790	320.4	251.7	0.0009699	0.03002	0.02687	0.02424	1,031	30.95	27.70	24.99
26	0.01594	254.1	199.6	0.0007692	0.01888	0.01690	0.01525	1,300	24.54	21.97	19.82
27	0.0142	201.5	158.3	0.0006100	0.01187	0.01063	0.009588	1,639	19.46	17.42	15.72
28	0.01264	159.8	125.5	0.0004837	0.007466	0.006683	0.006030	2,067	15.43	13.82	12.47
29	0.01126	126.7	99.53	0.0003836	0.004696	0.004203	0.003792	2,607	12.24	10.96	9.886
30	0.01003	100.5	78.94	0.0003042	0.002953	0.002643	0.002385	3,287	9.707	8.688	7.840
31	0.008928	79.70	62.60	0.0002413	0.001857	0.001662	0.001500	4,145	7.698	6.890	6.217
32	0.007950	63.21	49.64	0.0001913	0.001168	0.001045	0.0009436	5,227	6.105	5.464	4.930
33	0.007080	50.13	39.37	0.0001517	0.0007346	0.0006575	0.0005933	6,591	4.841	4.333	3.910
34	0.006305	39.75	31.22	0.0001203	0.0004620	0.0004135	0.0003731	8,311	3.839	3.436	3.101
35	0.005615	31.52	24.76	0.00009543	0.0002905	0.0002601	0.0002347	10,480	3.045	2.725	2.459
36	0.0050	25.0	19.64	0.00007568	0.0001827	0.0001636	0.0001476	13,210	2.414	2.161	1.950
37	0.004453	19.83	15.57	0.00006001	0.0001149	0.0001029	0.00009281	16,660	1.915	1.714	1.547
38	0.003965	15.72	12.35	0.00004759	0.00007210	0.00006454	0.00005824	21,010	1.519	1.359	1.226
39	0.003531	12.47	9.79	0.00003774	0.00004545	0.00004068	0.00003671	26,500	1.204	1.078	0.9726
40	0.003145	9.888	7.77	0.00002993	0.00002858	0.00002559	0.00002309	33,410	0.9550	0.8548	0.7713

The data from which this table has been computed are as follows: Matthiessen's standard resistivity, Matthiessen's temperature coefficient, specific gravity of copper = 8.89. Resistance in terms of the international ohm.

Matthiessen's standard 1 meter gramme of hard drawn copper = 0.1469 B.A.U. @ 0° C. Ratio of resistivity hard to soft copper 1.0226.
1 " soft " = 0.14365 B. A. U. @ 0° C. One B. A. U. = 0.9866 international ohms.
1 " soft " = 0.141729 international ohms at 0° C.

Temperature coefficients of resistance for 20° C., 50° C., and 80° C., 1.07968, 1.20625 and 1.33681 respectively. 1 foot = 0.3048028 meter, 1 pound = 453.59256 grammes.

Although the entries in the table are carried to the fourth significant digit, the computations have been carried to at least five figures. The last digit is therefore correct to within half a unit, representing an arithmetical degree of accuracy of at least one part in two thousand. The diameters of the B. & S. or A. W. G. wires are obtained from the geometrical series in which No. 0000 = 0.4600 inch and No. 36 = 0.005 inch, the nearest fourth significant digit being retained in the areas and diameters so deduced.

It is to be observed that while Matthiessen's standard of resistivity may be permanently recognized, the temperature coefficient of its variation which he introduced, and which is here used, may in future undergo slight revision.

F. B. CROCKER, W. E. GEYER, } Committee on
G. A. HAMILTON, A. E. KENNELLY, Chairman, } "Units and Standards."

Copper Wire Table.—*Continued.*

Giving resistances of cool, warm, and hot wires, of Matthiessen's standard conductivity, for Brown & Sharp Gauge. Am. Inst. E. E.

GAUGES.	RESISTANCE.					
A. W. G.	Ohms per lb.			Ohms per foot.		
B. & S.	@ 20° C.	@ 50° C.	@ 80° C.	@ 20° C.	@ 50° C.	@ 80° C.
0000	0.00007639	0.00008535	0.00009459	0.00004893	0.00005467	0.00006058
000	0.0001215	0.0001357	0.0001504	0.00006170	0.00006893	0.00007640
00	0.0001931	0.0002158	0.0002391	0.00007780	0.00008692	0.00009633
0	0.0003071	0.0003431	0.0003803	0.00009811	0.0001096	0.0001215
1	0.0004883	0.0005456	0.0006046	0.0001237	0.0001382	0.0001532
2	0.0007765	0.0008675	0.0009614	0.0001560	0.0001743	0.0001932
3	0.001235	0.001379	0.001529	0.0001967	0.0002198	0.0002435
4	0.001963	0.002193	0.002431	0.0002480	0.0002771	0.0003071
5	0.003122	0.003487	0.003865	0.0003128	0.0003495	0.0003873
6	0.004963	0.005545	0.006145	0.0003944	0.0004406	0.0004883
7	0.007892	0.008817	0.009772	0.0004973	0.0005556	0.0006158
8	0.01255	0.01402	0.01554	0.0006271	0.0007007	0.0007765
9	0.01995	0.02229	0.02471	0.0007908	0.0008835	0.0009791

10	0.03173	0.03545	0.03928	0.0009972	0.001114	0.001235
11	0.05045	0.05636	0.06246	0.001257	0.001405	0.001557
12	0.08022	0.08962	0.09932	0.001586	0.001771	0.001963
13	0.1276	0.1425	0.1579	0.001999	0.002234	0.002476
14	0.2028	0.2266	0.2511	0.002521	0.002817	0.003122
15	0.3225	0.3603	9.3993	0.003179	0.003552	0.003936
16	0.5128	0.5729	0.6349	0.004009	0.004479	0.004964
17	0.8153	0.9109	1.010	0.005055	0.005648	0.006259
18	1.296	1.448	1.605	0.006374	0.007122	0.007892
19	2.061	2.303	2.552	0.008038	0.008980	0.009952
20	3.278	3.662	4.058	0.01014	0.01132	0.01255
21	5.212	5.823	6.453	0.01278	0.01428	0.01583
22	8.287	9.259	10.26	0.01612	0.01801	0.01996
23	13.18	14.72	16.32	0.02032	0.02271	0.02516
24	20.95	23.41	25.94	0.02563	0.02863	0.03173
25	33.32	37.22	41.25	0.03231	0.03610	0.04001
26	52.97	59.18	65.59	0.04075	0.04552	0.05045
27	84.23	94.11	104.3	0.05138	0.05740	0.06362
28	133.9	149.6	165.8	0.06479	0.07239	0.08022
29	213.0	237.9	263.7	0.08170	0.09128	0.1012
30	338.6	378.3	419.3	0.1030	0.1151	0.1276
31	538.4	601.6	666.7	0.1299	0.1451	0.1608
32	856.2	956.5	1,060	0.1638	0.1830	0.2028
33	1,361	1,521	1,685	0.2066	0.2308	0.2558
34	2,165	2,418	2,680	0.2605	0.2910	0.3225
35	3,441	3,845	4,262	0.3284	0.3669	0.4067
36	5,473	6,114	6,776	0.4142	0.4627	0.5129
37	8,702	9,722	10,770	0.5222	0.5835	0.6466
38	13,870	15,490	17,170	0.6585	0.7357	0.8154
39	22,000	24,580	27,240	0.8304	0.9277	1.028
40	34,980	39,080	43,320	1.047	1.170	1.296

Copper Wire Table. — *Continued.*

Giving weights and lengths of cool, warm, and hot wires, of Matthiessen's standard conductivity, for B. W. Gauge.

Am. Inst. E. E.

GAUGES. To the nearest fourth significant digit.				WEIGHT.				LENGTH.			
B.W.G.	Dia-meter.	Area.		Lbs. per. foot	Lbs. per ohm.			Feet per lb.	Feet per ohm.		
Stub's.	Inches.	Circular mils.	Sq. in. Sq. mils.		@ 20° C.	@ 50° C.	@ 80° C.		@ 20° C.	@ 50° C.	@ 80° C.
0000	0.454	206,100	161,883	0.6239	12,420	11,120	10,030	1.603	19,910	17,820	16,080
000	0.425	180,600	141,863	0.5468	9,538	8,537	7,704	1.829	17,450	15,620	14,090
00	0.380	144,400	113,411	0.4371	6,096	5,456	4,924	2.288	13,950	12,480	11,260
0	0.340	115,600	90,792	0.3499	3,907	3,497	3,155	2.858	11,160	9,993	9,017
1	0.3000	90,000	70,686	0.2724	2,368	2,120	1,913	3.671	8,692	7,780	7,020
2	0.2840	80,660	63,347	0.2441	1,902	1,702	1,536	4.096	7,790	6,973	6,292
3	0.2590	67,080	52,685	0.2031	1,316	1,178	1,063	4.925	6,479	5,799	5,233
4	0.2380	56,640	44,488	0.1715	938.0	839.6	757.6	5.832	5,471	4,897	4,419
5	0.2200	48,400	38,013	0.1465	684.9	613.0	553.1	6.826	4,675	4,184	3,775
6	0.2030	41,210	32,365	0.1247	496.5	444.4	401.0	8.017	3,980	3,562	3,215

7	0.1800	32,400	25,447	0.09808	306.9	274.7	247.9	10.20	3,129	2,801	2,527
8	0.1650	27,230	21,382	0.08241	216.7	194.0	175.0	12.13	2,629	2,354	2,124
9	0.1480	21,900	17,203	0.06630	140.3	125.6	113.3	15.08	2,116	1,894	1,709
10	0.1340	17,960	14,103	0.05435	94.26	84.37	76.13	18.40	1,734	1,552	1,401
11	0.1200	14,400	11,310	0.04359	60.62	54.26	48.96	22.94	1,391	1,245	1,123
12	0.1090	11,880	9,331	0.03596	41.27	36.94	33.33	27.81	1,147	1,027	926.9
13	0.0950	9,025	7,088	0.02732	23.81	21.31	19.23	36.60	871.7	780.2	704.0
14	0.08300	6,889	5,411	0.02085	13.87	12.42	11.21	47.95	665.4	595.5	537.4
15	0.07200	5,184	4,072	0.01569	7.857	7.032	6.346	63.73	500.7	448.1	404.4
16	0.06500	4,225	3,318	0.01279	5.219	4.671	4.215	78.19	408.1	365.2	329.6
17	0.0580	3,364	2,642	0.01018	3.308	2.961	2.672	98.23	324.9	290.8	262.4
18	0.04900	2,401	1,886	0.007268	1.685	1.509	1.361	137.6	231.9	207.6	187.3
19	0.04200	1,764	1,385	0.005340	0.9097	0.8143	0.7347	187.3	170.4	152.5	137.6
20	0.03500	1,225	962	0.003708	0.4387	0.3927	0.3543	269.7	118.3	105.9	95.56
21	0.03200	1,024	804.2	0.003100	0.3066	0.2744	0.2476	322.6	98.90	88.52	79.88
22	0.02800	784.0	615.8	0.002373	0.1797	0.1608	0.1451	421.4	75.72	67.78	61.16
23	0.0250	625.0	490.9	0.001892	0.1142	0.1022	0.09224	528.6	60.36	54.03	48.75
24	0.0220	484.0	380.1	0.001465	0.06849	0.06130	0.05531	682.6	46.75	41.84	37.75
25	0.0200	400.0	314.2	0.001211	0.04678	0.04187	0.03778	825.9	38.63	34.58	31.20
26	0.0180	324.0	254.5	0.0009808	0.03069	0.02747	0.02479	1,020	31.29	28.01	25.27
27	0.0160	256.0	201.1	0.0007749	0.01916	0.01715	0.01548	1,290	24.73	22.13	19.97
28	0.0140	196.0	153.9	0.0005933	0.01123	0.01005	0.009071	1,685	18.93	16.94	15.29
29	0.0130	169.0	132.7	0.0005116	0.008350	0.007474	0.006744	1,955	16.32	14.61	13.18
30	0.0120	144.0	113.1	0.0004359	0.006062	0.005426	0.004896	2,294	13.91	12.45	11.23
31	0.0100	100.0	78.54	0.0003027	0.002924	0.002617	0.002361	3,304	9.658	8.645	7.800
32	0.0090	81.0	63.62	0.0002452	0.001918	0.001717	0.001549	4,078	7.823	7.002	6.318
33	0.0080	64.0	50.27	0.0001937	0.001197	0.001072	0.0009672	5,162	61.81	5.533	4.992
34	0.0070	49.0	38.48	0.0001483	0.0007019	0.0006283	0.0005669	6,742	47.33	4.236	3.822
35	0.0050	25.0	19.64	0.00007568	0.0001827	0.0001636	0.0001476	13,210	2.414	2.161	1.950
36	0.0040	16.	12.57	0.00004843	0.00007484	0.00006699	0.00006045	20,650	1.545	1.383	1.248

Copper Wire Table. — *Continued.*

Giving resistances of cool warm, and hot wires, of Matthiessen's standard conductivity, for B. W. Gauge.
Am. Inst. E. E.

GAUGES.	RESISTANCE.					
B. W. G.	Ohms per pound.			Ohms per foot.		
Stub's.	@ 20° C.	@ 50° C.	@ 80° C.	@ 20° C.	@ 50° C.	@ 80° C.
0000	0.00008051	0.00008996	0.00009969	0.00005023	0.00005612	0.00006220
000	0.0001048	0.0001171	0.0001298	0.00005732	0.00006404	0.00007097
00	0.0001640	0.0001833	0.0002031	0.00007170	0.00008011	0.00008878
0	0.0002560	0.0002860	0.0003169	0.00008957	0.0001001	0.0001109
1	0.0004223	0.0004718	0.0005228	0.0001150	0.0001285	0.0001424
2	0.0005258	0.0005874	0.0006510	0.0001284	0.0001434	0.0001589
3	0.0007601	0.0008492	0.0009412	0.0001543	0.0001724	0.0001911
4	0.001066	0.001191	0.001320	0.0001828	0.0002042	0.0002263
5	0.001460	0.001631	0.001808	0.0002139	0.0002390	0.0002649
6	0.002014	0.002250	0.002494	0.0002513	0.0002807	0.0003111
7	0.003258	0.003640	0.004034	0.0003196	0.0003570	0.0003957
8	0.004615	0.005156	0.005714	0.0003803	0.0004249	0.0004709
9	0.007129	0.007965	0.008827	0.0004727	0.0005281	0.0005853

10	0.01061	0.01185	0.01314	0.0005766	0.0006442	0.0007140
11	0.01650	0.01843	0.02042	0.0007190	0.0008033	0.0008903
12	0.02423	0.02707	0.03000	0.0008715	0.0009736	0.001079
13	0.04199	0.04692	0.05200	0.001147	0.001282	0.001420
14	0.07207	0.08052	0.08924	0.001503	0.001679	0.001861
15	0.1273	0.1422	0.1576	0.001997	0.002231	0.002473
16	0.1916	0.2141	0.2373	0.002451	0.002738	0.003034
17	0.3023	0.3377	0.3742	0.003078	0.003439	0.003811
18	0.5933	0.6629	0.7346	0.004312	0.004818	0.005339
19	1.099	1.228	1.361	0.005870	0.006558	0.007267
20	2.279	2.547	2.822	0.008452	0.009443	0.01047
21	3.262	3.644	4.039	0.01011	0.01130	0.01252
22	5.565	6.217	6.890	0.01321	0.01475	0.01635
23	8.756	9.783	10.84	0.01657	0.01851	0.02051
24	14.60	16.31	18.08	0.02139	0.02390	0.02649
25	21.38	23.88	26.47	0.02588	0.02892	0.03205
26	32.58	36.40	40.34	0.03196	0.03570	0.03957
27	52.19	58.31	64.62	0.04045	0.04519	0.05008
28	89.04	99.48	110.2	0.05283	0.05902	0.06541
29	119.08	133.8	148.3	0.06127	0.06845	0.07586
30	165.0	184.3	204.2	0.07190	0.08033	0.08903
31	342.0	382.1	423.5	0.1035	0.1157	0.1282
32	521.3	582.5	645.5	0.1278	0.1428	0.1583
33	835.1	933.0	1,034	0.1618	0.1807	0.2003
34	1,425	1,592	1,764	0.2113	0.2361	0.2616
35	5,473	6,114	6,776	0.4142	0.4627	0.5129
36	13,360	14,930	16,540	0.6471	0.7230	0.8011

HARD-DRAWN COPPER TELEGRAPH WIRE.

(J. A. Roebling's Sons Co.)

Furnished in half-mile coils, either bare or insulated.

Size B. & S. Gauge.	Resistance in Ohms per Mile.	Breaking Strength. Pounds.	Weight per Mile.	Approximate Size of E. B. B. Iron Wire equal to Copper.	
9	4.30	625	209	2	Iron-wire Gauge.
10	5.40	525	166	3	
11	6.90	420	131	4	
12	8.70	330	104	6	
13	10.90	270	83	6½	
14	13.70	213	66	8	
15	17.40	170	52	9	
16	22.10	130	41	10	

In handling this wire the greatest care should be observed to avoid kinks, binds, scratches, or cuts. Joints should be made only with McIntire Connectors.

On account of its conductivity being about five times that of Ex. B. B. Iron Wire, and its breaking strength over three times its weight per mile, copper may be used of which the section is smaller and the weight less than an equivalent iron wire, allowing a greater number of wires to be strung on the poles.

Besides this advantage, the reduction of section materially decreases the electrostatic capacity, while its non-magnetic character lessens the self-induction of the line, both of which features tend to increase the possible speed of signalling in telegraphing, and to give greater clearness of enunciation over telephone lines, especially those of great length.

LEAD-ENCASED ANTI-INDUCTION TELEPHONE AND TELEGRAPH CABLES.

(Roebling's.)

Plain Cables, Lead Encased.		For Metallic Circuit.		For Telegraph Circuits.	
No. of Wires.	Size Wire B. & S. Gauge.	No. of Pairs.	Size Wire B. & S. Gauge.	No. of Wires.	Size Wire B. & S. Gauge.
4	18	5	18	3	14
7	18	15	18	4	14
10	18	25	18	7	14
50	18	50	18	10	14
100	18	75	18	20	14
				50	14
				100	14

TABLE OF DIMENSIONS. WEIGHT, AND RESISTANCE OF PURE COPPER WIRE.

(Edison or Circular Mil Gauge.)

E. S. G. Gauge Number.	Circular mils.	Maximum Amperes. $\sqrt[4]{\left(\frac{C.M.}{10^4}\right)^3}$	Diameter in mils. Mil = .001 in.	Weight. Sp. gr. 8.889.	
				Lbs. per foot.	Lbs. per ohm.
3	3,000	12.5	54.78	.009084	2.597
5	5,000	18.3	70.72	.015139	7.214
8	8,000	26.0	89.45	.024220	18.464
12	12,000	35.2	109.55	.036328	41.538
15	15,000	41.6	122.48	.045410	64.902
20	20,000	51.6	141.43	.060548	115.372
25	25,000	61.0	158.12	.075682	180.278
30	30,000	70.0	173.21	.090817	259.722
35	35,000	78.6	187.09	.105955	353.340
40	40,000	86.8	200.00	.121082	461.440
45	45,000	94.9	212.14	.136227	584.098
50	50,000	102.7	223.61	.151357	721.026
55	55,000	110.3	234.53	.166501	872.547
60	60,000	117.7	244.95	.181625	1,038.258
65	65,000	125.0	254.96	.196772	1,218.586
70	70,000	132.1	264.58	.211901	1,413.264
75	75,000	139.1	273.87	.227043	1,622.457
80	80,000	146.0	282.85	.242176	1,845.952
85	85,000	152.8	291.55	.257303	2,083.759
90	90,000	159.5	300.00	.272434	2,336.405
95	95,000	166.1	308.23	.287587	2,603.046
100	100,000	172.6	316.23	.302709	2,884.082
110	110,000	185.4	331.67	.332991	3,489.958
120	120,000	198.0	346.42	.363267	4,153.433
130	130,000	210.2	360.56	.393527	4,874.226
140	140,000	222.2	374.17	.423797	5,652.899
150	150,000	234.0	387.30	.454061	6,484.573
160	160,000	245.6	400.00	.484328	7,383.042
170	170,000	257.0	412.32	.514622	8,335.525
180	180,000	268.3	424.27	.544884	9,344.686
190	190,000	279.4	435.89	.575140	10,411.241
200	200,000	290.4	447.22	.605427	11,536.681
220	220,000	312.0	469.05	.665975	13,959.567
240	240,000	333.0	489.90	.726498	16,612.114
260	260,000	353.5	509.91	.787058	19,496.997
280	280,000	373.7	529.16	.847605	22,612.233
300	300,000	393.6	547.73	.908140	25,957.464
320	320,000	413.1	565.69	.968672	29,533.696
340	340,000	432.3	583.10	1.029214	33,340.181
360	360,000	451.3	600.00	1.089738	37,376.652

1 Mil Foot = 9.718 B. A. Units @ 0° C. (Dr. Matthiessen.)

TABLE OF DIMENSIONS, WEIGHT, AND RESISTANCE OF PURE COPPER WIRE—*Continued.*

(Edison or Circular Mil Gauge.)

Length.		Resistance. Legal ohms at 75° Fahr.		E. S. G. Gauge Number.
Feet per lb.	Feet per ohm.	Ohms per lb.	Ohms per ft.	
110.087	285.9	.3850405	.003497600	3
66.054	476.5	.1386225	.002098640	5
41.288	762.3	.0651602	.001311780	8
27.527	1,143.4	.0240743	.000874578	12
22.022	1,429.2	.0154178	.000699663	15
16.516	1,905.7	.0086664	.000524745	20
13.213	2,382.0	.0055470	.000419807	25
11.011	2,859.9	.0038522	.000349840	30
9.4381	3,334.9	.0028301	.000299863	35
8.2589	3,811.0	.0021671	.000262400	40
7.3407	4,287.7	.0017120	.000233227	45
6.6069	4,763.8	.0013868	.000209914	50
6.0060	5,240.5	.0011467	.000190821	55
5.5059	5,716.5	.00096315	.000174931	60
5.0820	6,192.9	.00082057	.000161465	65
4.7192	6,669.4	.00070758	.000149937	70
4.4044	7,146.0	.00061635	.009139938	75
4.1282	7,622.3	.00054172	.000131193	80
3.8865	8,098.4	.00047990	.000123480	85
3.6706	8,574.7	.00042807	.000116622	90
3.4773	9,051.6	.00038415	.000110477	95
3.3035	9,527.6	.00034673	.000104960	100
3.0031	10,480.6	.00028656	.000095410	110
2.7528	11,433.6	.00024070	.000084460	120
2.5411	12,386.0	.00020514	.000080730	130
2.3596	13,338.7	.00017690	.000074970	140
2.2023	14,291.3	.00015409	.000069997	150
2.0647	15,243.9	·00013544	.000065600	160
1.9432	16,197.4	.00011995	.000061735	170
1.8353	17,149.9	.00010701	.000058309	180
1.7387	18,102.1	.00009604	.000055242	190
1.6517	19,055.4	.00008667	.000052478	200
1.5016	20,961.1	.00007163	.000047707	220
1.3765	22,866.0	.00006019	.000043733	240
1.2706	24,772.1	.00005129	.000040368	260
1.1798	26,677.8	.00004422	.000037484	280
1.1012	28,583.1	.00003852	.000034986	300
1.0323	30,488.3	.00003386	.000032799	320
.9716	32,393.8	.00002999	.000030870	340
.9177	34,298.7	.00002675	.000029155	360

1 Mil Foot = 9.718 B. A. Units @ 0° C. (Dr. Matthiessen.)

SAFE CARRYING CAPACITY OF COPPER WIRES.

Below will be found the formulæ of Forbes and Kennelly for safe carrying capacity of copper conductors. The results, which would be obtained by using these formulæ, have been somewhat modified in practice, and the reader is referred to the tables in the "National Code" for capacities recommended by the underwriters.

Size of Conductors.

(Prof. G. Forbes.)

Bare Overhead Wires.—The relation between the diameter of a conductor and the current it can safely carry without over-heating is

$$I=\sqrt{D^3t\frac{\pi^2 H}{4R\times .24}}.$$

Where $I=$ Current in amperes.
$D=$ Diameter of wire in centimeters.
$t=$ Excess of temperature C. of wire over the air.
$H=$ Coefficient of radiation and convection $=.0003$.
$R=$ Specific electrical resistance of material per c. cm. at the limiting temp.
$.24=$ Calories in a Joule.

Insulated Overhead Wires.—For gutta-percha and india-rubber insulation,

$$I=\sqrt{\left\{\frac{\pi_2 kD_1^2}{.48\,R}\times t\times\frac{3D_2}{10+3D_2\log_\epsilon\dfrac{D_2}{D_1}}\right\}}$$

Where $D_1=$ Diameter of conductor.
$D_2=$ Diameter of insulated cable.
$t=$ Excess of temperature of conductor over air.
$k=$ Heat conductivity of insulator; for G.-P. $=.00048$; for I.-R. $=.00041$.

Kennelly's Rule for the Safe Diameter of an Insulated Paneled Wire.

If the limiting safe diameter of an insulated paneled wire be such that twice the proposed full load upon it shall only raise its temperature 40° C., then the best formula is

$$d=.0147\,I^{\frac{2}{3}},$$

d being in inches and I in amperes; or approximately

$$d=\frac{I^{\frac{2}{3}}}{70}.$$

Heating of Bare Conductors by a Current.

The temperature to which a bare copper wire freely suspended in still air will be raised when traversed by a current is approximately

$$T^\circ=\frac{I^2}{d^3}\times 90{,}000+t^\circ,$$

where

$T^\circ=$ temperature of wire in F°.
$t^\circ=$ temperature of air in F°.
$I=$ current in amperes.
$d=$ diameter of wire in mils.

For a given presumable maximum elevation of temperature the requisite diameter is approximately

$$d=45\sqrt[3]{\frac{I^2}{T^\circ-t^\circ}}$$

IRON WIRE.

Iron.

Specific gravity	7.7
Cubic foot weighs	480 lbs.
Cubic inch weighs	.2779 lb.
Tensile strength per square inch	50,000 to 60,000 lbs.
Specific resistance 1 cubic centimeter at 0° C.	.0000095 ohms.
Resistance per mil foot	58 ohms.

Steel.

Specific gravity	7.932
Cubic foot weighs	490 lbs.
Cubic inch weighs	.2834 lb.
Tensile strength per square inch	55,000 to 80,000 lbs.
Specific resistance 1 cubic centimeter at 0° C.	.0000133 ohms.
Resistance per mil foot	82 ohms

The above items are for the metals as metals, and not when in wire. Resistance of iron wire varies so much, by reason of drawing and hardening, that it is not practicable to state specific resistances, weights, and strengths. The following tables give approximate averages.

GALVANIZED IRON WIRE FOR TELEGRAPH AND TELEPHONE LINES.

(Trenton Iron Co.)

Weight per Mile-Ohm.—This term is to be understood as distinguishing the *resistance of material* only, and means the weight of such material required per mile to give the resistance of one ohm. To ascertain the mileage resistance of any wire, divide the "weight per mile-ohm" by the weight of the wire per mile. Thus in a grade of Extra Best Best, of which the weight per mile-ohm is 5,000, the mileage resistance of No. 6 (weight per mile 525 lbs.) would be about 9½ ohms; and No. 14 steel wire, 8500 lbs weight per mile-ohm (95 lbs. weight per mile), would show about 69 ohms.

Sizes of Wire used in Telegraph and Telephone Lines.

No. 4. Has not been much used until recently; is now used on important lines where the multiplex systems are applied.

No. 5. Little used in the United States.

No. 6. Used for important circuits between cities.

No. 8. Medium size for circuits of 400 miles or less.

No. 9. For similar locations to No. 8, but on somewhat shorter circuits; until lately was the size most largely used in this country.

Nos. 10, 11. For shorter circuits, railway telegraphs, private lines, police and fire alarm lines, etc.

No. 12. For telephone lines, police and fire alarm lines, etc.

Nos. 13, 14. For telephone lines, and short private lines; steel wire is used most generally in these sizes.

The coating of telegraph wire with zinc as a protection against oxidation is now generally admitted to be the most efficacious method.

The grades of line wire are generally known to the trade as "Extra Best Best" (E. B. B.), "Best Best" (B. B.), and "Steel."

"Extra Best Best" is made of the very best iron, as nearly pure as any commercial iron, soft, tough, uniform, and of very high conductivity, its weight per mile-ohm being about 5,000 lbs.

The "Best Best" is of iron, showing in mechanical tests almost as good results as the E. B. B., but not quite as soft, and being somewhat lower in conductivity; weight per mile-ohm about 5,700 lbs.

The Trenton "Steel" wire is well suited for telephone or short telegraph lines, and the weight per mile-ohm is about 6,500 lbs.

The following are (approximately) the weights per mile of various sizes of galvanized telegraph wire, drawn by Trenton Iron Co.'s gauge:

No.	4,	5.	6,	7,	8,	9,	10,	11,	12,	13,	14,
Lbs.	720.	610.	525.	450.	375.	310 .	250.	200.	160.	125.	95.

TESTS OF TELEGRAPH WIRE.

The following data are taken from a table given by Mr. Prescott relating to tests of E. B. B. galvanized wire furnished the Western Union Telegraph Co.:

Size of wire.	Diam. Parts of One Inch.	Weight.		Length. Feet per pound.	Resistance. Temp. 75.8° Fahr.		Ratio of Breaking Weight to Weight per mile.
		Grains per foot.	Pounds per mile.		Feet per ohm.	Ohms per mile.	
4	.238	1,043.2	886.6	6.00	958	5.51	
5	.220	891.3	673.0	7.85	727	7.26	
6	.203	758.9	572.2	9.20	618	8.54	3.05
7	.180	596.7	449.9	11.70	578	10.86	3.40
8	.165	501.4	378.1	14.00	409	12.92	3.07
9	.148	403.4	304.2	17.4	328	16.10	3.38
10	.134	330.7	249.4	21.2	269	19.60	3.37
11	.120	265.2	200.0	26.4	216	24.42	2.97
12	.109	218.8	165.0	32.0	179	29.60	3.43
14	.083	126.9	95.7	55.2	104	51.00	3.05

Joints in Telegraph Wires.—The fewer the joints in a line the better. All joints should be carefully made and well soldered over, for a bad joint may cause as much resistance to the electric current as several miles of wire.

WEIGHT AND RESISTANCE OF GALVANIZED IRON WIRE PER MILE.

(Roebling.)

Gauge. B. & S.	Weight per Mile.	Resistance. Ohms.	Gauge. B. & S.	Weight per Mile.	Resistance. Ohms.
6	550	10	11	216	20
7	470	12.1	12	170	32.7
8	385	14.1	14	100	52.8
9	330	16.4	16	62	91.6
10	268	20			

SIZE, WEIGHT, LENGTH AND STRENGTH OF IRON WIRE.

(Trenton Iron Co.)

No. by Trenton Wire Gauge.	Diam. in Decimals of one inch.	Area of section in Decimals of One Inch.	Feet to the Pound.	Weight of one Mile in Pounds.	Tensile Strength (Approximately) of Charcoal Iron Wire in Pounds.	
					Bright.	Annealed.
00000	.450	.15904	1.863	2,833.248	12,598	9,449
0000	.400	.12566	2.358	2,238.878	9,955	7,466
000	.360	.10179	2.911	1,813.574	8,124	6,091
00	.330	.08553	3.465	1,523.861	6,880	5,160
0	.305	.07306	4.057	1,301.678	5,926	4,445
1	.285	.06379	4.645	1,136.678	5,226	3,920
2	.265	.05515	5.374	982.555	4,570	3,425
3	.245	.04714	6.286	839.942	3,948	2,960
4	.225	.03976	7.454	708.365	3,374	2,530
5	.205	.03301	8.976	588.139	2,839	2,130
6	.190	.02835	10.453	505.084	2,476	1,860
7	.175	.02405	12.322	428.472	2,136	1,600
8	.160	.02011	14.736	358.3008	1,813	1,360
9	.145	.01651	17.950	294.1488	1,507	1,130
10	.130	.01327	22.333	236.4384	1,233	925
11	.1175	.01084	27.340	193.1424	1,010	758
12	.105	.00866	34.219	154.2816	810	607
13	.0925	.00672	44.092	119.7504	631	473
14	.080	.00503	58.916	89.6016	474	356
15	.070	.00385	76.984	68.5872	372	280
16	.061	.00292	101.488	52.0080	292	220
17	.0525	.00216	137.174	38.4912	222	165
18	.045	.00159	186.335	28.3378	169	127
19	.040	.0012566	235.084	22.3872	137	103
20	.035	.0009621	308.079	17.1389	107	80
21	.031	.0007547	392.772	13.4429		
22	.028	.0006157	481.234	10.9718		
23	.025	.0004909	603.863	8.7437		
24	.0225	.0003976	745.710	7.0805		
25	.020	.0003142	943.396	5.5968		
26	.018	.0002545	1,164.689	4.5334		
27	.017	.0002270	1,305.670	4.0439		
28	.016	.0002011	1,476.869	3.5819		
29	.015	.0001767	1,676.989	3.1485		
30	.014	.0001539	1,925.321	2.7424		
31	.013	.0001327	2,232.653	2.3649		
32	.012	.0001131	2,620.607	2.0148		
33	.011	.0000950	3,119.092	1.6928		
34	.010	.00007854	3,773.584	1.3992		
35	.0095	.00007088	4,182.508	1.2624		
36	.009	.00006362	4,657.728	1.1336		
37	.0085	.00005675	5,222.035	1.0111		
38	.008	.00005027	5,896.147	.89549		
39	.0075	.00004418	6,724.291	.78672		
40	.007	.00003848	7,698.253	.68587		

The above figures on tensile strength are based upon tests made with good charcoal-iron wire from Trenton blooms.
The tensile strength of wire made of —
Good refined iron is about 15% less.
Swedish charcoal iron is about 10 "
Mild Bessemer steel is about 10 more.
Ordinary crucible steel is about 25 "
Special crucible steel is from 30 to 120 "
than that of charcoal iron wire.

WEIGHTS OF IRON AND STEEL WIRE.

No. B. & S.	Diameter in Mils.	Weight per 1000′.	
		Wrought Iron.	Steel.
0000	460	561	566
000	409.64	445	449
00	364.8	353	356
0	324.86	280	282
1	289.3	222	224
2	257.63	176	178
3	229.42	139	141
4	204.31	111	112
5	181.94	87.7	88.5
6	162.02	69.6	70.2
7	144.28	55.2	55.7
8	128.49	43.8	44.1
9	114.43	34.7	35
10	101.89	27.5	27.8
11	90.74	21.8	22
12	80.81	17.3	17.5

GALVANIZED SIGNAL STRAND. SEVEN WIRES.

Diameter, Inches.	Weight per 1000′.			Estimated Breaking Weight.
	Bare Strand.	Double Braid W. P.	Triple Braid W. P.	
1-2	520	616	677	8,320
15-32	420	510	561	6,720
7-16	360	444	488	5,720
3-8	290	362	398	4,640
5-16	210	270	297	3,360
9-32	160	214	235	2,560
17-64	120	171	188	1,920
1-4	100	148	163	1,600
7-32	80	122	134	1,280
3-16	60	96	105	960
11-64	43	76	84	688
9-64	33	60	66	528
1-8	24	48	53	384
3-32	20	38	42	320

STRANDED WIRE CABLES.

(Everett.)

Ratio of area of copper to area of circular or available space

$$= \frac{\text{copper area}}{\text{available area.}}$$

If $n =$ number of concentric layers around one central strand,

then
$$\frac{3\,(n^2 + n) + 1}{(2\,n + 1)^2} = \text{Ratio.}$$

The number of wires that will strand will be $3n\,(n + 1) + 1$.

Number of Strands.	$\frac{\text{copper area}}{\text{available area}} = \text{ratio.}$
1	1.000
7	.778
19	.760
37	.755
61	.753
91	.752

Sheathing Core. — The number, N, of sheathing wires having a diameter, d, which will cover a core having a diameter, D, is

$$N = \pi\,\frac{D + d}{d}.$$

DATA ON CABLES.

Below is given a table showing the actual circular mils, the diameter bare inches, and the number and size of strands (wires) generally used in the manufacture of cables.

(General Electric Company.)

Size of Cable.	Actual Circular Mils.	Diam. Bare Inches.	Make up.		Approx. Weight of Copper per 1000 feet.
			No. Wires.	Size wire.	
8 B. & S.	18,000	.147	7	16 B. & S.	57
6 B. & S.	28,600	.180	1	15 B. & S.	85
			6	16 B. W. G.	
5 B. & S.	35,300	.209	1	16 B. W. G.	112
			6	15 B. W. G.	
4 B. & S.	44,300	.234	1	15 B. W. G.	140
			6	12 B. W. G.	
3 B. & S.	55,900	.263	1	12 B. & S.	178
			6	11 B. & S.	
2 B. & S.	70,600	.295	1	11 B. & S.	224
			6	10 B. & S.	
1 B. & S.	80,275	.325	19	16 B. W. G.	255
0 B. & S.	106,500	.378	1	15 B. W. G.	338
			6	12 B. & S.	
			12	15 B. W. G.	
00 B. & S.	134,200	.425	1	12 B. & S.	426
			6	11 B. & S.	
			12	12 B. & S.	
000 B. & S.	167,500	.475	5	11 B. & S.	532
			14	13 B. W. G.	
0000 B. & S.	216,900	.524	1	10 B. & S.	650
			6	12 B. W. G.	
			13	10 B. & S.	

DATA ON CABLES — *Continued.*

Size of Cable.	Actual Circular Mils.	Diam. Bare. Inches.	Make up.		Approx. Weight of Copper per 1000 feet.
			No. Wires.	Size Wire.	
250,000 C. M.	250,200	.568	7	.117 inch.	790
			13	12 B. W. G.	
300,000 C. M.	304,600	.637	37	11 B. & S.	949
350,000 C. M.	350,400	.680	12	10 B. & S.	1,092
			25	13 B. W. G.	
400,000 C. M.	402,600	.735	7	10 B. & S.	1,224
			12	12 B. W. G.	
			18	10 B. & S.	
500,000 C. M.	506,400	.820	37	.117 inch.	1,550
600,000 C. M.	601,500	.900	37	10 B. & S.	1,874
			24	13 B. W. G.	
750,000 C. M.	751,800	1.020	15	.117 inch.	2,331
			46	12 B. W. G.	
800,000 C. M.	800,600	1.037	42	.117 inch.	2,462
			19	12 B. W. G.	
900,000 C. M.	903,700	1.096	12	8 B. & S.	2,815
			49	11 B. W. G.	
1,000,000 C. M.	1,007,000	1.157	61	8 B. & S.	3,138
1,250,000 C. M.	1,250,600	1.296	7	11 B. W. G.	3,831
			84	.117 inch.	
1,500,000 C. M.	1,512,300	1.412	91	8 B. & S.	4,681
2,000,000 C. M.	2,001,700	1.652	82	8 B. & S.	6,237
			45	11 B. W. G.	

NAVY STANDARD WIRES.

In the following table are given sizes and prices of Navy Standard Wires as per specifications issued by the Navy Department in March, 1897.

Actual C. M.	No Wires in Strand.	Size of Wire B. & S.	Diameter Inches.		Diameter in 32ds of an inch.			Approx. Weight per 1000 feet.	List price per 1000 feet.
			Over copper.	Over Para rubber.	Over vulc. rubber.	Over tape.	Over braid.		
4,107	1	14	.06408	.0953	7	9	11	56.9	$60.00
9,016	7	19	.10767	.1389	10	12	14	103	110.00
11,368	7	18	.12090	.1522	10	12	14	108.5	110.00
14,336	7	17	.13578	.1670	10	12	14	115.5	110.00
18,081	7	16	.15225	.1837	11	13	15	140	130.00
22,799	7	15	.17121	.2025	12	14	16	165¼	150.00
30,856	19	18	.20150	.2328	12	14	16	184	165.00
33,912	19	17	.22630	.2576	13	15	17	218	190.00
49,077	19	16	.25410	.2854	14	16	18	260¼	210.00
60,088	37	18	.28210	.3134	15	17	19	314	260.00
75,776	37	17	.31682	.3481	16	18	20	371	290.00
99,064	61	18	.36270	.3940	18	20	22	463	385.00
124,928	61	17	.40734	.4386	19	21	23	557	415.00
157,563	61	16	.45738	.4885	20	22	24	647	460.00
198,677	61	15	.51363	.5449	22	24	26	794	535.00
250,527	61	14	.57672	.6080	24	26	28	970	615.00
296,387	91	15	.62777	.6590	26	28	30	1,138	750.00
373,737	91	14	.70488	.7361	29	31	33	1,420	900.00
413,639	127	15	.74191	.7732	30	32	34	1,553	1,000.00
Double Conductor, Plain, 2–7–22 B. & S.								181.5	260.00
Double Conductor, Silk, 2–7–25 B. & S.								28	110.00
Double Conductor, Diving Lamp, 2–7–20 B. & S.								218.3	335.00
Bell Cord, 1–16 B. & S.								29.7	32.50

SPECIAL CABLES FOR STREET-CAR WIRING.

Car wiring cables have a wrapping between the wire and rubber to facilitate stripping for soldering. The 7–14 single braid is adapted for ordinary car wiring for two 25 h.p. motors. The triple braid is recommended for taps to motors, as it will stand abrasion and is more durable than rubber tubing. The 75–25 braided to .500″ diameter is standard for field leads of the GE–800 motor, and fits the rubber bushings in the motor frame. The 49–22 braided to .625″ diameter is standard for armature leads of the GE–800, and for all leads of the GE–1000 motors. These cables are also well adapted for leads for suspending arc lamps.

(General Electric Company.)

No. wires in strand.	Size of wires B. & S.	Equivalent single wire.	Diameter Bare.	Max. diam. Single braid.	Max. diam. Triple braid.	Thickness of rubber.	List price.	
							Single braid.	Triple braid.
*7	14	6	.192	.385	.500	.062	$73.50	$89.00
49	23	6	.200	.393	.500	.062	116.50	131.50
*75	25	6	.216	.410	.500	.062	120.00	135.00
*7	12	4	.243	.433	.553	.062	108.50	127.50
*49	22	4	.228	.418	.625	.062	139.50	160.00

* Carried in stock.

STANDARD RUBBER COVERED WHITE CORE WIRES AND CABLES.

(Made by General Electric Company.)

Rubber covered wires and cables are insulated with two or more coats of rubber, the inner coat in all cases being free from sulphur or other substance liable to corrode the copper, the best grade of fine Para being employed. All conductors are heavily and evenly tinned.

Five distinct finishes can be furnished as follows:— White or black braid, plain lead jacket, lead jacket protected by a double wrap of asphalted jute, lead jacket armored with a special steel tape, white armored, for submarine use.

For use in conduits the plain lead covering is recommended, or if corrosion is especially to be feared, the lead and asphalt. For use where no conduit is available, the band steel armored cable is best, as it combines moderate flexibility with great mechanical strength, enabling it to resist treatment which would destroy an unarmored cable.

In addition to the ordinary galvanometer tests, wires and cables are tested with an alternating current (as specified in table) before shipping. Are also prepared to quote promptly on wire armored cables for subaqueous circuits, but as the conditions and requirements of the weight of armor vary greatly, do not list them. Inquiries for quotations on these cables should state the length and size of cable, depth of water, character of bottom and current, in order that a proper weight of armor may be selected.

The tables following give list prices, dimensions, insulation resistance per mile, test pressure, and break-down pressure on all sizes of wires and cables in ordinary use. For underground and submarine work it is recommended that cables be not worked at more than one-half the pressure with which they are tested. If wires or cables are run on insulators in dry places they may be safely worked at test pressure.

Cables will be leaded according to the table given below, unless otherwise specified. Cables with any thickness of lead required can be supplied.

Cables up to $\frac{1}{4}$″ diameter over insulation, lead $\frac{3}{64}$″ thick.
" over $\frac{1}{4}$″ to $\frac{5}{8}$″ diameter over insulation, lead $\frac{7}{16}$″ thick.
" " $\frac{5}{8}$″ to $1\frac{1}{4}$″ " " " " $\frac{3}{32}$″ "
" " $1\frac{1}{4}$″ to $1\frac{5}{8}$″ " " " " $\frac{1}{10}$″ "
" " larger than $1\frac{5}{8}$″ " " " " $\frac{1}{8}$″ "

WHITE CORE RUBBER INSULATED WIRES AND CABLES.

Table of Resistances and Diameters.

(General Electric Company.)

Thickness of Rubber.	$\frac{3}{64}''$.		$\frac{2}{32}''$		$\frac{3}{32}''$		$\frac{4}{32}''$		$\frac{5}{32}''$		$\frac{6}{32}''$	
Voltage Test Pressure.	1,500		3,000		6,000		10,000		13,000		16,000	
Voltage Minimum Puncturing Pressure one minute.	6,000		9,000		14,000		19,000		24,000		30,000	
Size Conductor.	Insulation Resistance per Mile. Megohms.	Diameter Braided. Inches.	Insulation Resistance per Mile. Megohms.	Diameter Braided. Inches.	Insulation Resistance per Mile. Megohms.	Diameter Braided. Inches.	Insulation Resistance per Mile. Megohms.	Diameter Braided. Inches.	Insulation Resistance per Mile. Megohms.	Diameter Braided. Inches.	Insulation Re-sistance per Mile. Megohms.	Diameter Braided. Inches.
18 B. & S. Solid	750	.160	1,000	.204	1,200	.266	1,400	.354	1,800	.417	2,200	.479
16 " "	750	.185	1,000	.215	1,200	.289	1,400	.365	1,800	.428	2,200	.490
14 " "	700	.198	1,000	.229	1,200	.312	1,400	.374	1,800	.437	2,000	.499
12 " "	500	.215	1,000	.246	1,200	.329	1,400	.391	1,800	.454	2,000	.516
10 " "	400	.236	1,000	.267	1,200	.350	1,200	.412	1,400	.475	1,800	.537
8 " "	300	.262	750	.313	1,000	.376	1,200	.438	1,400	.521	1,800	.593
6 " "	Too heavy for $\frac{3}{64}''$ insulation.	. . .	750	.347	1,000	.409	1,200	.502	1,400	.565	1,500	.627
5 " "		. . .	750	.366	1,000	.428	1,200	.521	1,200	.584	1,500	.646
4 " "		. . .	500	.389	1,000	.451	1,200	.544	1,200	.607	1,500	.669
3 " "		. . .	500	.413	1,000	.475	1,200	.569	1,200	.632	1,300	.694
2 " "		. . .	500	.443	750	.505	1,000	.598	1,200	.661	1,300	.723
1 " "		. . .	500	.474	750	.536	1,000	.629	1,200	.692	1,300	.754
0 " "		. . .	500	.510	750	.572	1,000	.665	1,200	.728	1,300	.790

WHITE CORE RUBBER INSULATED WIRES AND CABLES.

Table of Resistances and Diameters. — *Continued.*

(General Electric Company.)

16 B. & S. Stranded	750	.204	1,000	.225	1,200	.298	1,400	.370	1,800	.463	2,200	.525
14 " "	700	.214	1,000	.245	1,200	.318	1,400	.380	1,800	.473	2,000	.535
12 " "	500	.234	1,000	.265	1,200	.338	1,400	.400	1,800	.493	2,000	.555
10 " "	400	.256	1,000	.287	1,200	.360	1,200	.422	1,500	.515	1,800	.577
8 " "	300	.291	750	.332	1,000	.395	1,200	.457	1,500	.550	1,800	.612
6 " "	. . .	. . .	750	.365	1,000	.427	1,200	.490	1,500	.583	1,500	.645
5 " "	. . .	. . .	750	.394	1,000	.456	1,200	.519	1,200	.612	1,500	.674
4 " "	. . .	. . .	500	.419	1,000	.481	1,200	.544	1,200	.637	1,500	.699
3 " "	. . .	. . .	500	.448	1,000	.510	1,200	.573	1,200	.666	1,300	.728
2 " "	. . .	. . .	500	.480	750	.542	1,000	.605	1,200	.698	1,300	.760
1 " "	. . .	. . .	500	.510	750	.572	1,000	.635	1,200	.728	1,300	.790
0 " "	. . .	. . .	500	.563	750	.625	1,000	.688	1,200	.781	1,300	.878
00 " "	. . .	. . .	400	.610	750	.672	1,000	.735	1,200	.828	1,300	.925
000 " "	. . .	. . .	400	.660	750	.722	1,000	.785	1,200	.908	1,300	.975
0000 " "		. . .	400	.709	500	.771	1,000	.864	1,200	.961	1,300	1.024
250,000 C. M. "	Too heavy for $\frac{3}{64}''$ insulation.	. . .	. . .	. . .	500	.875	750	.938	1.000	1.005	1,200	1.068
300,000 " "		. . .	. . .	. . .	500	.945	750	1.007	1,000	1.074	1,200	1.137
350,000 " "		. . .	. . .	. . .	500	.988	750	1.050	1,000	1.117	1,200	1.180
400,000 " "		. . .	Too heavy for $\frac{2}{32}''$ insulation.	. . .	500	1.048	750	1.105	1,000	1.172	1,200	1.235
500,000 " "		. . .		. . .	500	1.133	750	1.190	1,000	1.257	1,200	1.320
600,000 " "		. . .		. . .	500	1.213	500	1.270	750	1.337	1,000	1.400
750,000 " "	. . .	. . .		. . .	Too heavy for $\frac{3}{32}''$ insulation.	. . .	500	1.390	750	1.457	1,000	1.520
800,000 " "	. . .	. . .		. . .		. . .	500	1.407	750	1.474	1,000	1.537
900,000 " "	. . .	. . .		. . .		. . .	500	1.466	750	1.533	1,000	1.596
1,000,000 " "	. . .	. . .		. . .		. . .	500	1.527	750	1.594	1,000	1.657
1,250,000 " "	. . .	. . .	. . .	. . .		. . .	400	1.666	500	1.729	750	1.791
1,500,000 " "	. . .	. . .	. . .	. . .		. . .	300	1.782	400	1.845	600	1.907
2,000,000 " "	. . .	. . .	. . .	. . .		. . .	250	2.022	300	2.089	500	2.152

WHITE CORE. RUBBER INSULATED WIRES AND CABLES.

Table of Weights and Prices.

(General Electric Company.)

Thickness of Rubber.	$\frac{3}{64}''$		$\frac{2}{32}''$		$\frac{3}{32}''$		$\frac{4}{32}'$.		$\frac{5}{32}''$		$\frac{6}{32}''$	
Voltage Test Pressure.	1,500		3,000		6,000		10,000		13,000		16,000	
Voltage Minimum Puncturing Pressure one minute.	6,000		9,000		14,000		19,000		24,000		30,000	
Size Conductor.	Approx. Weight per 1,000 ft.	List price per 1,000 ft.	Approx. Weight per 1,000 ft.	List price per 1,000 ft.	Approx. Weight per 1,000 ft.	List price per 1,000 ft.	Approx. Weight per 1,000 ft.	List price per 1,000 ft.	Approx. Weight per 1,000 ft.	List price per 1,000 ft.	Approx. Weight per 1,000 ft.	List price per 1,000 ft.
18 B. & S. Solid.	19.8	$18.00	27.9	$24.50	46.9	$43.50	79.9	$68.50	107.9	$98.00	140.2	$132.00
16 " "	26.2	19.50	33.4	27.50	54	48.00	88.6	75.00	117.3	105.00	149.8	137.50
14 " "	32.11	23.50	40.3	31.50	68.6	55.00	97.2	80.00	127.2	112.00	161	145.50
12 " "	41.9	29.00	52.6	38.50	81.5	62.50	110.3	89.50	143	123.00	176	157.50
10 " "	57.8	39.00	68.7	48.50	98.7	73.00	128.8	103.00	163	136.50	199	174.00
8 " "	82.4	50.00	94.6	61.00	126	87.50	158	120.00	191	155.00	231	195.00
6 " "	...	...	125	80.00	165	110.00	198	145.00	236	183.00	278	225.00
5 " "	...	...	161	93.00	192	125.00	226	160.00	265	200.00	308	245.00
4 " "	...	...	192	107.50	225	142.00	261	180.00	300	225.00	346	267.50
3 " "	...	...	231	127.00	264	162.00	302	202.50	343	245.00	392	295.00
2 " "	...	..	278	150.00	315	187.00	353	230.00	398	275.00	448	327.50
1 " "	...	...	337	178.00	375	217.50	417	262.50	464	312.50	515	365.00
0 " "	...	...	410	210.00	449	252.50	495	300.00	544	352.50	598	410.00

WHITE CORE RUBBER INSULATED WIRES AND CABLES.

Table of Weights and Prices. — *Continued.*

(General Electric Company.)

16 B. &. S. Stranded.	27.1	25.00	34.7	32.50	61	55.50	90.5	81.50	128.3	115.00	162.8	150.00
14 " "	34.4	30.00	42.2	37.50	70.9	62.00	100.2	90.00	138.9	122.50	174.4	160.00
12 " "	47.3	38.00	58.5	46.50	86.9	72.00	115.4	100.00	155.9	136.00	192.4	173.50
10 " "	64.8	47.50	75.1	57.50	105.3	83.00	133.8	114.00	176.5	151.00	216.3	191.50
8 " "	96.1	63.00	106.1	74.00	139.9	103.50	170.9	137.00	215.9	176.50	258.4	220.00
6 " "	. . .	. . .	139.6	91.50	176	125.00	209.5	160.00	258	203.50	304.5	250.00
5 " "	. . .	. . .	172	108.00	210.6	143.00	246	181.00	299	228.50	347	276.50
4 " "	. . .	. . .	205	125.00	246.2	160.00	284	201.50	340	250.00	389	301.50
3 " "	. . .	. . .	251	147.00	292	185.00	332	227.50	390	280.00	441	333.50
2 " "	. . .	. . .	304	173.00	347	213.50	391	260.00	451	315.00	503	370.00
1 " "	. . .	. . .	342	200.00	386.3	241.50	431	290.00	494	350.00	550	417.50
0 " "	. . .	. . .	435	240.00	484	290.00	532	340.00	601	405.00	692	475.00
00 " "	. . .	. . .	532	285.00	584	336.00	636	392.50	721	462.50	804	533.00
000 " "	. . .	. . .	648	340.00	702	395.00	760	455.00	869	535.00	938	605.00
0000 " "	. . .	. . .	775	400.00	835	456.00	925	525.00	1,009	603.50	1,081	677.50
250,000 C. M. "	. . .	. . .	. . .	. . .	1,032	542.00	1,098	610.00	1.171	690.00	1,246	765.00
300,000 " "	. . .	. . .	. . .	. . .	1,211	633.00	1,282	705.00	1,360	790.00	1,442	875.00
350,000 " "	. . .	. . .	. . .	. . .	1,368	703.50	1,442	780.00	1,523	866.50	1,611	960.00
400,000 " "	. . .	. . .	. . .	. . .	1,575	775.00	1,593	852.50	1,681	950.00	1,770	1,037.50
500,000 " "	. . .	. . .	. . .	. . .	1,866	935.00	1,948	1,016.50	2,046	1,115.00	2,156	1,227.50
600,000 " "	. . .	. . .	. . .	. . .	2,213	1,100.00	2,305	1,190.00	2,408	1,295.00	2,525	1,425.00
750,000 " "	. . .	. . .	. . .	. . .	. . .	. . .	2,819	1,425.00	2,922	1,536.50	3,048	1,666.00
800,000 " "	. . .	. . .	. . .	. . .	. . .	. . .	2,958	1,485.00	3,074	1,610.00	3,187	1,726.50
900,000 " "	. . .	. . .	. . .	. . .	. . .	. . .	3,333	1,645.00	3,456	1,780.00	3,573	1,910.00
1,000,000 " "	. . .	. . .	. . .	. . .	. . .	. . .	3,678	1,770.00	3,810	1,910.00	3,930	2,065.00
1,250,000 " "	. . .	. . .	. . .	. . .	. . .	. . .	4,427	2,180.00	4,567	2,330.00	4,704	2,470.00
1,500,000 " "	. . .	. . .	. . .	. . .	. . .	. . .	5,324	2,520.00	5,478	2,680.00	5,620	2,830.00
2,000,000 " "	. . .	. . .	. . .	. . .	. . .	. . .	6,967	3,265.00	7,145	3,450.00	7,302	3,620.00

Below is a table of prices at which special finishes for any of the foregoing wires and cables can be furnished.

C. L. Plain lead cover over the rubber.
C. L. A. Lead cover with jute and asphalt over the lead.
C. L. A. I. Lead cover, jute and asphalt and band iron armored.

To obtain the price of the cable desired, add to the list price of the rubber covered cable braided, the list price of the finish desired for the diameter nearest to that of the braided cable.

A cable having a lead cover, jute and asphalt over the lead, and wire armored (C. L. A. W.), in addition to the above special finishes can also be furnished. Prices on application.

To obtain approximate weight of cable having special finish, add to the weight of the cable the weight of the special finish as given below.

SPECIAL FINISHES.

(General Electric Company.)

Diameter of Braided Cable. Inches.	C. L.		C. L. A.		C. L. A. I.	
	Approx. Weight per 1000 feet.	List price per 1000 feet.	Approx. Weight per 1000 feet.	List price per 1000 feet.	Approx. Weight per 1000 feet.	List price per 1000 feet.
.200	157	$30.00	252	$60.00	. . .	. . .
.225	170	31.50	268	62.50	. . .	. . .
.250	191	34.00	297	66.50	. . .	. . .
.275	214	37.00	327	70.50	. . .	. . .
.300	227	38.50	345	73.00	. . .	. . .
.325	345	53.00	475	89.50	. . .	. . .
.350	376	57.00	514	94.50	1,131	$193.50
.375	391	59.00	534	97.00	1,162	197.50
.400	424	63.00	574	102.00	1,229	206.50
.425	438	65.00	590	105.50	1,254	212.00
.450	473	69.00	634	111.50	1,325	222.00
.475	498	72.50	665	115.00	1,370	227.50
.500	519	75.00	691	117,00	1,417	230.00
.550	567	79.00	751	125.00	1,506	241.50
.600	620	85.50	816	133.00	1,616	255.50
.650	656	90.00	864	139.00	1,901	294.00
.700	1,118	144.50	1,352	199.00	2,498	369.00
.750	1,194	153.00	1,442	209.50	2,632	384.50
.800	1,194	153.00	1,442	209.50	2,632	384.50

SPECIAL FINISHES—*Continued.*

Diameter of Braided Cable. Inches.	C. L.		C. L. A.		C. L. A. I.	
	Approx. Weight per 1000 feet.	List price per 1000 feet.	Approx. Weight per 1000 feet.	List price per 1000 feet.	Approx. Weight per 1000 feet.	List price per 1000 feet.
.850	1,258	160.50	1,516	218.00	2,742	398.50
.900	1,317	167.00	1,583	226.50	2,847	411.50
.950	1,423	179.50	1,707	241.50	3,022	433.50
1.000	1,482	186.50	1,773	249.00	3,132	447.00
1.05	1,556	190.00	1,859	257.50	3,263	461.00
1.1	1,631	201.00	1,946	267.50	3,397	477.00
1.15	1,705	210.00	2,030	277.50	3,820	533.50
1.2	1,795	220.00	2,131	291.50	3,987	559.00
1.25	1,854	225.50	2,201	298.50	4,098	572.50
1.3	1,959	237.50	2,322	313.00	4,294	595.50
1.35	2,018	240.00	2,393	317.50	4,409	607.00
1.4	2,851	330.00	3,257	415.00	5,419	724.00
1.45	2,989	348.00	3,410	432.50	5,639	750.50
1.5	3,008	350.00	3,432	434.50	5,681	755.00
1.6	3,362	378.00	3,717	470.00	6,097	810.00
1.7	3,400	392.50	3,872	488.00	6,335	827.50
1.8	3,615	416.50	4,113	515.50	6,694	882.00
1.9	3,792	436.00	4,309	538.00	6,987	905.50
2	3,988	457.50	4,529	563.00	7,315	945.00

In leading cables a tape is used over the rubber in place of the regular braid.

For thickness of lead used on above finishes, see page 160. If other thicknesses than these are desired, special prices will be quoted upon application.

PAPER INSULATED AND LEADED WIRES AND CABLES.

There will be found on the following pages data and prices of a full line of paper insulated and lead covered wires and cables. All cables insulated with the fibrous covering depend for their successful operation and maintenance upon the exclusion of moisture by the lead sheath; and this fact should constantly be borne in mind in handling this class of cables, consequently the lead on these cables is extra heavy. The use of jute and asphalt covering over the lead is strongly recommended on all this class of cables, inasmuch as the life of the cable is absolutely dependent upon that of the lead. Paper insulated cables cannot be furnished without the lead covering.

PAPER INSULATED LEADED WIRES AND CABLES.

Table of Resistances and Diameters.

(General Electric Company.)

Thickness of Paper.	$\frac{4}{32}''$				$\frac{5}{32}''$				$\frac{6}{32}''$			
Test Pressure.	8,000 Volts.				10,000 Volts.				12,500 Volts.			
Minimum Puncturing Pressure One Minute.	Minimum 16,000 Volts.				Minimum 20,000 Volts.				Minimum 25,000 Volts.			
Size Conductor	Insulation Resistance Per Mile. Megohms.	Thickness Lead. Inches.	Diameter Over Lead. Inches.	Diameter Over Jute and Asphalt Inches.	Insulation Resistance Per Mile. Megohms.	Thickness Lead. Inches.	Diameter Over Lead Inches.	Diameter Over Jute and Asphalt Inches.	Insulation Resistance Per Mile. Megohms.	Thickness Lead. Inches.	Diameter Over Lead. Inches.	Diameter Over Jute and Asphalt Inches.
10 B.&S. Solid	2,000	$\frac{1}{16}$	.477	.789	2,500	$\frac{1}{16}$	.539	.851	3,000	$\frac{1}{16}$	.602	.914
8 " "	2,000	$\frac{1}{16}$	.503	.815	2,500	$\frac{1}{16}$	.565	.877	2,800	$\frac{1}{16}$	.628	.940
6 " "	2,000	$\frac{3}{32}$	.599	.911	2,250	$\frac{3}{32}$	.661	.973	2,600	$\frac{3}{32}$	.724	1.036
4 " "	2,000	$\frac{3}{32}$	.641	.953	2,250	$\frac{3}{32}$	.703	1.015	2,500	$\frac{3}{32}$	.766	1.078
10 B.&S. Stranded.	2,000	$\frac{1}{16}$	.487	.799	2,500	$\frac{1}{16}$	.549	.861	3,000	$\frac{1}{16}$	.612	.924
8 " "	2,000	$\frac{1}{16}$	.522	.834	2,500	$\frac{1}{16}$	.584	.896	2,800	$\frac{1}{16}$	.647	.959
6 " "	2,000	$\frac{3}{32}$	.617	.929	2,250	$\frac{3}{32}$	.679	.991	2,600	$\frac{3}{32}$	.742	1.054
4 " "	2,000	$\frac{3}{32}$	.671	.983	2,250	$\frac{3}{32}$	.733	1.045	2,500	$\frac{3}{32}$	.796	1.108
3 " "	1,500	$\frac{3}{32}$	.700	1.012	2,000	$\frac{3}{32}$	.762	1.074	2,250	$\frac{3}{32}$	.825	1.137
2 " "	1,500	$\frac{3}{32}$	.732	1.044	2,000	$\frac{3}{32}$	.794	1.106	2,250	$\frac{3}{32}$	.857	1.169
1 " "	1,500	$\frac{3}{32}$	.762	1.074	2,000	$\frac{3}{32}$	.824	1.136	2,250	$\frac{3}{32}$	.887	1.199
0 " "	1,200	$\frac{3}{32}$	.815	1.127	1,500	$\frac{3}{32}$	.877	1.189	2,000	$\frac{3}{32}$	.940	1.252
00 " "	1,200	$\frac{1}{8}$	.925	1.237	1,500	$\frac{1}{8}$	.987	1.299	2,000	$\frac{1}{8}$	1.050	1.362
000 " "	1,200	$\frac{1}{8}$	.975	1.287	1,500	$\frac{1}{8}$	1.037	1.349	2,000	$\frac{1}{8}$	1.100	1.412
0000 " "	1,000	$\frac{1}{8}$	1.024	1.336	1,250	$\frac{1}{8}$	1.086	1.398	1,500	$\frac{1}{8}$	1.149	1.461
250,000 C.M. "	1,000	$\frac{1}{8}$	1.068	1.380	1,250	$\frac{1}{8}$	1.130	1.442	1,500	$\frac{1}{8}$	1.193	1.505
300,000 " "	1,000	$\frac{1}{8}$	1.137	1.449	1,250	$\frac{1}{8}$	1.199	1.511	1,500	$\frac{1}{8}$	1.262	1.574
350,000 " "	1,000	$\frac{1}{8}$	1.180	1.492	1,250	$\frac{1}{8}$	1.242	1.554	1,500	$\frac{1}{8}$	1.305	1.617
400,000 " "	1,000	$\frac{1}{8}$	1.235	1.547	1,250	$\frac{1}{8}$	1.297	1.609	1,500	$\frac{1}{8}$	1.360	1.672
500,000 " "	1,000	$\frac{1}{8}$	1.320	1.632	1,100	$\frac{1}{8}$	1.382	1.694	1,250	$\frac{1}{8}$	1.445	1.757
750,000 " "	750	$\frac{1}{8}$	1.520	1.832	1,100	$\frac{1}{8}$	1.582	1.894	1,250	$\frac{1}{8}$	1.645	1.957
1,000,000 " "	750	$\frac{1}{8}$	1.657	1.969	1,000	$\frac{1}{8}$	1.719	2.031	1,200	$\frac{1}{8}$	1.782	2.094
1,250,000 " "	500	$\frac{1}{8}$	1.796	2.108	750	$\frac{1}{8}$	1.858	2.170	1,000	$\frac{1}{8}$	1.921	2.233
1,500,000 " "	400	$\frac{1}{8}$	1.912	2.224	500	$\frac{1}{8}$	1.974	2.286	750	$\frac{1}{8}$	2.037	2.349
2,000,000 " "	350	$\frac{1}{8}$	2.152	2.464	400	$\frac{1}{8}$	2.214	2.526	500	$\frac{1}{8}$	2.277	2.589

Prices and weights for these conductors are listed on the two pages following.

PAPER INSULATED LEADED WIRES AND CABLES.

Table of Weights and Prices.

(General Electric Company.)

Size Conductor.	$\frac{4}{32}''$ Insulation.				$\frac{5}{32}''$ Insulation.				$\frac{6}{32}''$ Insulation.			
	C. L. Finish.		C. L. A. Finish.		C. L. Finish.		C. L. A. Finish.		C. L. Finish.		C. L. A. Finish.	
	Approximate Weight per 1000 Feet.	List Price Per 1000 Feet	Approximate Weight per 1000 Feet.	List Price Per 1000 Feet	Approximate Weight per 1000 Feet.	List Price Per 1000 Feet	Approximate Weight per 1000 Feet.	List Price Per 1000 Feet	Approximate Weight per 1000 Feet.	List Price Per 1000 Feet	Approximate Weight per 1000 Feet.	List Price Per 1000 Feet
10 B.&S. Solid.	491	$105.00	635	$143.00	575	$120.00	736	$162.00	661	$134.50	837	$179.00
8 " "	542	117.00	692	156.50	628	131.00	795	174.00	716	146.00	896	191.50
6 " "	893	167.00	1,066	211.00	1,011	183.00	1,199	229.00	1,133	204.00	1,341	253.00
4 " "	1,012	191.50	1,196	237.00	1,132	211.00	1,334	259.00	1,256	232.00	1,470	283.00
10 B.&S. Stranded.	506	116.00	654	154.50	591	131.00	752	173.00	678	177.50	855	192.00
8 " "	572	132.00	726	172.00	659	144.00	831	188.00	747	162.50	931	208.50
6 " "	929	179.00	1,107	223.50	1,050	198.00	1,245	245.00	1,171	220.50	1,379	270.00
4 " "	1,076	212.00	1,266	258.50	1,200	231.00	1,408	280.50	1,330	253.50	1,554	306.50
3 " "	1,165	233.00	1,361	280.00	1,290	253.00	1,504	304.50	1,420	276.00	1,649	330.00
2 " "	1,264	257.50	1,472	307.00	1,392	276.00	1,616	329.00	1,527	300.00	1,764	355.50
1 " "	1,347	281.00	1,562	332.50	1,476	300.00	1,698	353.50	1,607	324.00	1,850	380.00
0 " "	1,520	322.00	1,746	375.00	1,653	343.00	1,887	397.50	1,786	367.00	2,044	425.00
00 " "	2,124	417.00	2,376	475.00	2,289	442.00	2,555	501.50	2,455	470.00	2,735	528.50
000 " "	2,340	474.00	2,603	532.00	2,511	498.50	2,795	558.00	2,677	526.50	2,971	587.50
0000 " "	2,556	530.00	2,830	587.50	2,741	557.00	3,032	617.00	2,910	578.50	3,213	643.00
250,000 C. M. "	2,806	598.00	3,091	657.00	2,973	623.00	3,276	685.00	3,164	647.00	3,479	713.00
300,000 " "	3,118	684.00	3,420	745.50	3,289	702.00	3,604	768.00	3,483	738.50	3,815	810.00
350,000 " "	3,349	744.00	3,661	808.50	3,523	768.50	3,848	836.50	3,726	806.50	4,064	878.50
400,000 " "	3,611	808,00	3,935	875.50	3,788	839.00	4,124	910.50	3,970	869.00	4,325	944.00
500,000 " "	4,113	962.50	4,458	1,036.00	4,294	989.00	4,654	1,064.50	4,507	1,023.50	4,880	1,100.00
750,000 " "	5,335	1,335.00	5,727	1,415.50	5,526	1,364.00	5,932	1,446.50	5,752	1,400.00	6,173	1,485.00
1,000,000 " "	6,449	1,161.50	6,873	1,746.50	6,660	1,693.00	7,111	1,782.00	6,881	1,728.00	7,335	1,821.00
1,250,000 " "	7,449	2,010.00	7,905	2,102.00	7,667	2,041.00	8,139	2,136.50	7,878	2,075.00	8,365	2,171.00
1,500,000 " "	8,541	2,335.00	9,025	2,433.50	8,788	2,372.00	9,286	2,468.50	9,005	2,404.50	9,522	2,505.00
2,000,000 " "	10,624	3,040.00	11,165	3,141.00	10,886	3,073,50	11,440	3,181.00	11,118	3,114.50	11,686	3,227.50

TELEPHONE CABLES.

(By John A. Roebling's Son's Co.)

Lead-encased for Underground or Aerial Use.

The insulation of these cables is dry paper. The company manufactures several styles of 19 B. & S. G., 20 B. & S., G., and 22 B. & S. G., according to the use for which they are intended. The most common size is 19 B. & S. G. They also supply terminals and hangers.

Specifications for Telephone Cables.

1. CONDUCTORS.

Each conductor shall be .03589 inches in diameter (19 B. & S. G.), and have a conductivity of 98 per cent. of that of pure soft copper.

2. CORE.

The conductor shall be insulated, twisted in pairs the length of the twist not to exceed three inches, and formed into a core arranged in reverse layers.

3. SHEATH.

The core shall be enclosed in a pipe composed of lead and tin, the amount of the tin shall be not less than $2\frac{9}{10}$ per cent. The pipe shall be formed around the core, and shall be free from holes or other defects, and of uniform thickness and composition.

4. ELECTROSTATIC CAPACITY.

The average electrostatic capacity shall not exceed .080 of a microfarad per mile, each wire being measured against all the rest, and the sheath grounded; the electrostatic capacity of any wires so measured shall not exceed .085 of a microfarad per mile.

5. INSULATION RESISTANCE.

Each wire shall show an insulation of not less than 500 megohms per mile, at 60° F., when laid, spliced, and connected to terminal ready for use; each wire being measured against all the rest and sheath grounded.

6. CONDUCTOR RESISTANCE.

Each conductor shall have a resistance of not more than 47 B. A. ohms, at 60° F., for each mile of cable, after the cable is laid, and connected to the terminals.

TELEPHONE CABLES.

By John A. Roebling's Son's Co.

Number pairs.	Outside diameters. Inches.	Weights 1000 feet. Pounds.
1	$\frac{5}{16}$	214
2	$\frac{3}{8}$	302
3	$\frac{1}{2}$	515
4	$\frac{9}{16}$	629
5	$\frac{5}{8}$	747
6	$\frac{21}{32}$	877
7	$\frac{11}{16}$	912
10	$\frac{13}{16}$	1,214
12	$\frac{15}{16}$	1,375
15	1	1,566

TELEPHONE CABLES—*Continued.*

Number Pairs.	Outside Diameters. Inches.	Weights 1000 feet. Pounds.
18	$1\frac{1}{16}$	1,758
20	$1\frac{1}{8}$	1,940
25	$1\frac{5}{16}$	2,332
30	$1\frac{7}{16}$	2,748
35	$1\frac{1}{2}$	2,985
40	$1\frac{9}{16}$	3,176
45	$1\frac{5}{8}$	3,365
50	$1\frac{3}{4}$	3,678
55	$1\frac{13}{16}$	3,867
60	$1\frac{7}{8}$	4,055
65	$1\frac{15}{16}$	4,241
70	2	4,430
80	$2\frac{1}{8}$	4,804
90	$2\frac{1}{4}$	5,180
100	$2\frac{3}{8}$	5,505

TELEGRAPH CABLES.

By John A. Roebling's Son's Co.

Lead-encased for Underground Use.

These cables are made of either rubber, cotton, or paper insulation. The sizes and weights are approximately correct for rubber and cotton insulation. Both sizes and weights are slightly reduced for paper insulation. In all cases the cables are lead-encased.

Specifications for Telegraph Cables.

1. CONDUCTORS.

Each conductor shall be .064 inches in diameter (14 B. & S. G.), and have a conductivity of 98 per cent of that of pure copper.

2. CORE.

The conductors shall be insulated to $\frac{6}{32}$ with cotton, and formed into a core arranged in reverse layers. This core shall be dried, and saturated with approved insulating compound.

3. SHEATH.

The core shall be enclosed in a pipe composed of lead and tin. The amount of tin shall not be less than 2.9 per cent. The pipe shall be formed around the core, and shall be free from holes or other defects, and of uniform thickness and composition.

4. INSULATION RESISTANCE.

The wire shall show an insulation of not less than 300 megohms per mile, at 60° F., when laid, spliced, and connected to terminals ready for use, each wire being measured against all the rest and the sheath grounded.

5. CONDUCTOR RESISTANCE.

Each conductor shall have a resistance of not more than 28 International ohms, at 60° F., for each mile of cable, after the cable is laid, and connected up to the terminals.

TELEGRAPH CABLES.

By John A. Roebling's Son's Co.

Number conductors.	14 B. & S. G. Insulated to $\frac{6}{32}$.		16 B. & S. G. Insulated to $\frac{5}{32}$.		18 B. & S. G. Insulated to $\frac{4}{32}$.	
	Outside diameters, Inches.	Weights, 1000 feet.	Outside diameters, Inches.	Weights 1000 feet.	Outside diameters, Inches.	Weights, 1000 feet.
1	$\frac{3}{8}$	308	$\frac{3}{8}$	299	$\frac{3}{8}$	291
2	$\frac{7}{16}$	438	$\frac{7}{16}$	421	$\frac{13}{32}$	356
3	$\frac{1}{2}$	573	$\frac{1}{2}$	546	$\frac{7}{16}$	421
4	$\frac{5}{8}$	810	$\frac{9}{16}$	670	$\frac{15}{32}$	486
5	$\frac{3}{4}$	972	$\frac{5}{8}$	793	$\frac{1}{2}$	551
6	$\frac{13}{16}$	1,132	$\frac{11}{16}$	946	$\frac{17}{32}$	616
7	$\frac{7}{8}$	1,295	$\frac{3}{4}$	965	$\frac{9}{16}$	681
10	$\frac{15}{16}$	1,512	$\frac{13}{16}$	1,155	$\frac{5}{8}$	820
12	$1\frac{1}{16}$	1,873	$\frac{7}{8}$	1,327	$\frac{3}{4}$	978
15	$1\frac{3}{16}$	2,263	$\frac{15}{16}$	1,518	$\frac{13}{16}$	1,148
18	$1\frac{1}{4}$	2,523	$1\frac{1}{16}$	1,880	$\frac{7}{8}$	1,318
20	$1\frac{5}{16}$	2,756	$1\frac{1}{8}$	2,076	$\frac{15}{16}$	1,477
25	$1\frac{7}{16}$	3,250	$1\frac{5}{16}$	2,496	1	1,690
30	$1\frac{9}{16}$	3,515	$1\frac{3}{8}$	2,768	$1\frac{1}{16}$	1,903
35	$1\frac{11}{16}$	3,910	$1\frac{7}{16}$	3,040	$1\frac{3}{16}$	2,116
40	$1\frac{3}{4}$	4,175	$1\frac{1}{2}$	3,312	$1\frac{1}{4}$	2,330
45	$1\frac{13}{16}$	4,441	$1\frac{9}{16}$	3,533	$1\frac{9}{32}$	2,471
50	$1\frac{15}{16}$	4,835	$1\frac{5}{8}$	3,755	$1\frac{5}{16}$	2,628
55	2	5,100	$1\frac{11}{16}$	3,978	$1\frac{3}{8}$	2,866
60	$2\frac{1}{16}$	5,365	$1\frac{3}{4}$	4,200	$1\frac{7}{16}$	3,104
65	$2\frac{1}{8}$	5,631	$1\frac{13}{16}$	4,422	$1\frac{15}{32}$	3,245
70	$2\frac{3}{25}$	5,897	$1\frac{7}{8}$	4,644	$1\frac{1}{2}$	3,402
80	$2\frac{5}{16}$	6,408	2	5,087	$1\frac{5}{8}$	3,798
90	$2\frac{7}{16}$	6,916	$2\frac{1}{16}$	5,402	$1\frac{11}{16}$	4,027
100	$2\frac{9}{16}$	7,375	$2\frac{1}{8}$	5,720	$1\frac{3}{4}$	4,275

AERIAL CABLES.

By John A. Roebling's Son's Co.

These cables are made from double-coated rubber wire, taped. After standing, the cable is double-taped, and covered with tarred jute, over which is placed a braid of heavy cotton saturated with weatherproof compound. This outside covering protects the rubber from the action of the air and from mechanical injury. The separate wires are tested in water, and no wire is used which will not fully meet a water test. The result is a cable which will work under water as well as on a pole line, if there is no danger of mechanical injury. The ordinary size for telegraphic work is 14 B. & S., insulated to $\frac{5}{32}$. A trace wire can be placed in each layer, if desired.

Specifications for 14 B. & S. Aerial Cable.

1. CONDUCTORS.

Each conductor shall be .064 inches in diameter (14 B. & S. G.), and have a conductivity of 98 per cent of that of pure copper.

2. CORE.

The conductors shall be insulated to $\frac{6}{32}$ with rubber and tape, and formed into a core arranged in reverse layers.

3. PROTECTIVE COVERING.

The core shall be covered with two wraps of friction tape and one wrap of tarred jute. Over this there shall be a braid saturated with weatherproof compound.

4. INSULATION RESISTANCE.

Each wire shall show an insulation resistance of not less than 300 megohms per mile, at 60° F., after being immersed in water 24 hours. This test shall be made on the core after all the conductors are laid up, but before the outside coverings are put on.

5. CONDUCTOR RESISTANCE.

Each conductor shall have a resistance of not more than 28 international ohms, at 60° F., for each mile of cable.

AERIAL CABLES.

By John A. Roebling's Son's Co.

Rubber Insulation.

Number conductors.	14 B. & S. G. Insulated to $\frac{6}{32}$.		16 B. & S. G. Insulated to $\frac{5}{32}$.		18 B. & S. G. Insulated to $\frac{4}{32}$.	
	Outside diameters, Inches.	Weights, 1000 feet.	Outside diameters, Inches.	Weights, 1000 feet.	Outside diameters, Inches.	Weights, 1000 feet.
2	$\frac{3}{8}$	102	$\frac{3}{8}$	92	$\frac{3}{8}$	82
3	$\frac{1}{2}$	149	$\frac{7}{16}$	126	$\frac{13}{32}$	104
4	$\frac{9}{16}$	183	$\frac{1}{2}$	155	$\frac{7}{16}$	127
5	$\frac{11}{16}$	226	$\frac{5}{8}$	193	$\frac{1}{2}$	151
6	$\frac{3}{4}$	260	$\frac{11}{16}$	222	$\frac{9}{16}$	175
7	$\frac{13}{16}$	297	$\frac{3}{4}$	251	$\frac{5}{8}$	200
10	$\frac{15}{16}$	401	$\frac{7}{8}$	335	$\frac{11}{16}$	256
12	1	465	$\frac{15}{16}$	393	$\frac{3}{4}$	296
15	$1\frac{1}{8}$	563	1	468	$\frac{13}{16}$	355
18	$1\frac{3}{16}$	651	$1\frac{1}{16}$	541	$\frac{7}{8}$	413

AERIAL CABLES—*Continued.*

Number conductors.	14 B. & S. G. Insulated to $\frac{6}{32}$.		16 B. & S. G. Insulated to $\frac{5}{32}$.		18 B. & S. G. Insulated to $\frac{4}{32}$.	
	Outside diameters, Inches.	Weights, 1000 feet.	Outside diameters, Inches.	Weights, 1000 feet.	Outside diameters, Inches.	Weights, 1000 feet.
20	$1\frac{1}{4}$	714	$1\frac{1}{8}$	593	$\frac{29}{32}$	452
25	$1\frac{3}{8}$	863	$1\frac{3}{16}$	708	$\frac{15}{16}$	541
30	$1\frac{7}{16}$	1,008	$1\frac{1}{4}$	824	1	633
35	$1\frac{1}{2}$	1,147	$1\frac{5}{16}$	938	$1\frac{1}{16}$	723
40	$1\frac{9}{16}$	1,268	$1\frac{3}{8}$	1,053	$1\frac{1}{8}$	813
45	$1\frac{5}{8}$	1,431	$1\frac{1}{2}$	1,182	$1\frac{3}{16}$	903
50	$1\frac{3}{4}$	1,577	$1\frac{5}{8}$	1,311	$1\frac{1}{4}$	994

SUBMARINE CABLES.

By John A. Roebling's Son's Co.

Number conductors.	Outside diameters.	Armor wires.		Total weights. Pounds.	
		Number of wires.	Numbers, B. W. G.	1,000 feet.	Mile.
1	$\frac{7}{8}$	12	8	1,250	6,600
2	1	15	8	1,722	9,092
3	$1\frac{1}{8}$	14	6	2,363	12,477
4	$1\frac{5}{16}$	16	6	2,794	14,752
5	$1\frac{5}{16}$	16	6	2,968	15,671
6	$1\frac{1}{2}$	16	4	3,822	20,180
7	$1\frac{1}{2}$	16	4	3,972	20,972
10	$1\frac{7}{8}$	18	3	5,404	28,533

The core consists of 7 × 22 B. & S. tinned copper wires, insulated with rubber to $\frac{8}{32}$ of an inch, laid up with proper jute bedding.

Telegraph cables can be supplied with gutta-percha insulation. This is the best insulation for submarine work, and its reliability and durability more than make up the difference in cost between it and any other insulation.

ALUMINUM.

(From paper by Alfred E. Hunt, S. B., and book published by the Pittsburg Reduction Company.)

Specific gravity	2.68	
Cubic foot weighs, cast	159.6	lbs.
Cubic foot weighs, rolled	167.1	"
Cubic inch weighs, cast	.0924	"
Cubic inch weighs, rolled	.0967	"
Tensile strength in pure soft wire, per square inch	26,000	
Tensile strength in pure hard-drawn rods, per square inch	40,000	

Conductivity as related to 100% cond. copper:

99½% pure	63.09%
99% pure	62.17%
98% pure	56.17%

Approximate weight per mile of aluminum wire = .004817 × cir. mils.

Aluminum for Electrical Conductors.

(From paper by Alfred E. Hunt, S. B.)

1. Any given volume of copper is $\frac{8.98}{2.68}$ or 3.332 times heavier than an equal volume of aluminum.

2. The equivalent price of fourteen cents per pound for copper for any length of any equivalent section of aluminum wire or bar would be 14 cents times the factor 3.332, or 46.65 cents per pound. That is, one thousand feet of wire of, say, one-tenth inch diameter, would cost equally as much if bought of copper at 14 cents per pound or aluminum at 46.65 cents per pound. Aluminum, therefore, at 29 cents per pound is only 62% of the cost of copper at 14 cents per pound, section for section.

3. Reckoning the copper conductor to have its maximum of 100 per cent conductivity, and the aluminum to have a conductivity of 63 per cent (which the Pittsburg Reduction Company are ready to guarantee for their special pure aluminum metal for electrical conductors), then for an equivalent electrical conductivity a given section of copper that can be placed at 100 should be increased in area in round numbers to 160 to give an equal conductivity.

4. Due to their relative specific gravities, the weight of the given equal length of the aluminum conductor with 160 sectional area will be only forty-eight per cent of the weight of the copper conductor with sectional area of 100, having the same electrical conductivity.

$100 \times 8.93 = 893$, weight of the copper.

$160 \times 2.68 = 428.8$, weight of the aluminum.

$\frac{428.8}{893} = 48$ per cent.

5. As to their relative cost for electrical conductors of equal conductivity, aluminum at twenty-nine cents per pound is the most economical conductor, as compared with copper at fourteen cents per pound.

Taking as an illustration, an aluminum conductor to replace a copper wire of No. 10 B. & S. gauge (about one-tenth of an inch diameter), the aluminum wire of equal, in fact somewhat superior, electrical conductivity would be of No. 8 B. & S. gauge (slightly over one-eighth of an inch diameter).

The weight of a mile of No. 10 copper wire is 162.32 pounds; and its cost at 14 cents per pound would be equal to $22.72.

The weight of a mile of No. 8 aluminum wire would be 79.46 pounds, and at twenty-nine cents per pound would cost $23.04.

Forty-eight per cent of the weight of No. 10 copper wire, which will give equal electrical conductivity in aluminum wire, would only weigh 77.91 pounds; so that, more accurately, $22.59 would be the cost of a mile of aluminum wire at 29 cents per pound to replace a mile of No. 10 copper wire at 14 cents per pound, costing $22.72.

6. The Continental requirements in tensile strength for soft copper wire, rods, and bars used as electrical conductors is twenty-two kilograms per square millimeter; the English requirement being similarly fourteen tons per square inch; and our American requirement is about its equivalent of 32,000 pounds per square inch.

FACTORS FOR THE DIFFERENT CONDUCTIVITIES OF ALUMINUM.

(Pittsburgh Reduction Company.)

CONDUCTIVITY OF ALUMINUM.	63	62	61	60	59	58	57	56	55	54
Relative cross-section (Copper equal 100.)	154.	156.5	159.	161.7	164.4	167.3	170.2	173.2	176.3	179.7
Weight of aluminum (weight of copper of equal length and equal resistance equal 100)	46.25	47.	47.77	48.55	49.38	50.24	51.11	52.02	52.97	53.95
Tensile Strength — Factor by which to multiply tensile strength per square inch of aluminum to obtain tensile strength per square inch required in a copper wire of equal resistance in order to secure same breaking strength	154.	156.5	159.	161.7	164.4	167.3	170.2	173.2	176.3	179.7
Price — Factor by which to multiply copper price per pound to obtain equivalent price of aluminum; also factor by which to divide aluminum price per pound to obtain equivalent price of copper	2.16	2.13	2.1	2.06	2.03	1.99	1.96	1.92	1.89	1.85
Price — Factor by which to divide copper price per pound to obtain equivalent price of aluminum; also factor by which to multiply aluminum price to obtain equivalent price of copper	.4025	.47	.4777	.4855	.4938	.5024	.5111	.5202	.5297	.5395

RESISTANCE AND TENSILE STRENGTH OF ALUMINUM TELEPHONE WIRE.

(Pittsburg Reduction Company.)

Grade.	Conductivity.	Comparative section of equal Conductivity, Copper at 100.	Comparative weight of given lengths of equal Conductivity, Copper at 100.
AO.	62%	156.4	47.
A75.	58	167.	50.2
A2.	54	180.	54.

Number in B. & S. Gauge.	Diameter in Mils.	Grade AO.		Grade A75.		Grade A2.	
		Res. per 1,000 ft. at 75° F.	Tensile Strength.	Res. per 1,000 ft. at 75° F.	Tensile Strength.	Res. per 1,000 ft. at 75° F.	Tensile Strength.
4	204.31	.4012	27,000	.4288	33,000	.4605	40,000
5	181.94	.5058	27,500	.5408	34,000	.5818	42,000
6	162.02	.6380	28,000	.6820	35,000	.7325	44,000
7	144.28	.8044	29.000	.8600	36,000	.9235	46,000
8	128.49	1.034	30,000	1.105	37,000	1.187	48,000
9	114.43	1.278	32,000	1.367	39,000	1.468	50 000
10	101.89	1.613	33,000	1.724	40,000	1.852	51,000
11	90.74	2.033	35,000	2.173	41,000	2.335	53,000
12	80.81	2.565	39,000	2.741	42,000	3.084	55,000

TABLE OF RESISTANCES OF PURE ALUMINUM WIRE.*

(Pittsburg Reduction Company.)

Pure aluminum weighs 167.111 pounds to the cubic foot. The conductivity of pure aluminum is 60% of the conductivity of pure copper.

Am. Gauge, B. & S. No.	Resistance at 75% F.			
	R Ohms 1,000 ft.	Ohms per mile.	Feet per ohm.	Ohms per lb.
0000	.08177	.43172	12,229.8	.00042714
000	.10310	.54440	9,699.0	.00067022
00	.13001	.68645	7,692.0	.00108116
0	.16385	.86515	6,245.4	.0016739
1	.20672	1.09150	4,637.35	.0027272
2	.26077	1.37637	3,836.22	.0043441
3	.32872	1.7357	3,036.12	.0069057
4	.41448	2.1885	2.412.60	.0109773
5	.52268	2.7597	1,913.22	.017456
6	.65910	3.4802	1,517.22	.027758
7	.83118	4.3885	1,203.12	.044138
8	1.06802	5.5355	964.18	.070179
9	1.32135	6.9767	756.78	.111561
10	1.66667	8.8000	600.00	.17467
11	2.1012	11.0947	475.908	.28211
12	2.6497	13.9900	377.412	.44856
13	3.3412	17.642	299.298	.71478
14	4.3180	22.800	231.582	1.16225
15	5.1917	27.462	192.612	1.7600
16	6.6985	35.368	149.286	2.8667
17	8.4472	44.602	118.380	4.5588
18	10.6518	56.242	93.882	7.2490
19	13.8148	72.942	72.384	12.1916
20	16.938	89.430	59.0406	18.328
21	21.358	112.767	46.8222	29.142
22	26.920	142.138	37.1466	46.316
23	33.962	179.32	29.4522	73.686
24	42.825	226.12	23.3508	117.170
25	54.000	285.12	18.5184	186.28
26	68.113	359.65	14.6814	296.32
27	85.865	453.37	11.6460	485.56
28	108.277	571.70	9.2358	749.02
29	136.535	720.90	7.3242	1,190.97
30	172.17	908.98	5.8087	1,893.9
31	212.12	1,119.98	4.7144	2,941.5
32	273.97	1,445.45	3.6528	4,788.9
33	345.13	1,822.3	2.8974	7,610.7
34	435.38	2,298.8	2.2969	12,109.4
35	548.92	2,898.2	1.8218	19,251.
36	692.07	3,654.2	1.4449	30,600.
37	872.93	4,609.2	1.1456	48,661.
38	1,100.62	5,811.2	.9086	76.658.
39	1,387.47	7,325.8	.7207	121,881.
40	1,749.50	9,236.8	.5716	193,835.

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* Calculated on the basis of Dr. Matthiessen's standard, viz.: 1 mile of pure copper wire of $\frac{1}{16}$ inch diameter equals 13.59 ohms at 15.5° C. or 59.9° F.

Care in Erecting Aluminum Lines.

The fact that the wire will permanently elongate if seriously strained, makes it necessary to use the utmost care in the erection of lines, and also the known high coefficient of expansion with temperature changes taken in conjunction with this property renders care in line stringing especially important and difficult.

The following table has been gotten out by the Pittsburg Reduction Company, after exhaustive experiments.

Table of Deflections and Tensions for Aluminum Wire.

X = Deflection in inches at center of span.

S = Factor, which multiply by weight of foot of wire to obtain tension.

Maximum Load = 15,000 per square inch.

(Trans. A. I. E. E.)

	$t = -20°$		$-10°$		$0°$		$10°$		$20°$		$30°$	
Span.	S	X	S	X	S	X	S	X	S	X	S	X
80	12940	¾	1660	5¾	1176	8⅛	961	10	833	11½	781	12⅛
100	12940	1⅛	2083	7¼	1470	10¼	1202	12½	1042	14⅜	933	16
120	12940	1⅝	2500	8⅝	1768	12¼	1400	15⅜	1251	17¼	1120	19¼
150	12940	2⅝	3038	11⅛	2540	14½	1788	18⅞	1552	21¾	1390	24
175	12940	3½	3643	12⅝	2576	17⅞	2104	21¾	1822	25¼	1630	28¼
200	12940	4⅝	4206	14¼	2947	20⅜	2403	24⅞	2084	28¾	1930	31⅛

	$t = 40°$		$50°$		$69°$		$70°$		$80°$		$90°$	
Span.	S	X	S	X	S	X	S	X	S	X	S	X
80	680	14⅛	630	15¼	589	16⅜	555	17⅜	527	18¼	502	19⅛
100	869	17¾	768	19	735	20⅜	695	21½	658	22¾	628	23⅞
120	1022	21⅛	946	22⅞	885	24⅜	835	25⅞	792	27¼	755	28⅝
150	1265	26⅝	1177	28⅝	1060	30⅜	1039	32½	987	34¼	941	35⅞
175	1488	30⅛	1377	33⅜	1279	35⅞	1215	37¾	1152	39⅞	1099	41¾
200	1672	35¼	1574	38¼	1473	40¾	1393	43	1316	45½	1256	47¾

STRANDED ALUMINUM WIRE.

Diameter and Properties.

CONDUCTIVITY AT 62 IN THE MATTHIESSEN STANDARD SCALE.

(Pittsburg Reduction Company.)

Number B. & S. Gauge.	Circular Mils.	DIAMETERS.		WEIGHT IN POUNDS.			Resistance in ohms at 75° F. per 1,000 feet.
		Decimal parts of an inch.	Nearest 32d of an inch.	BARE.		Triple Braid Insulated.	
				Per 1,000 feet.	Per mile.	Per 1,000 feet.	
......	1,000,000	1.152	$1\frac{3}{16}$	920.	4,860	1,408	.01675
......	950,000	1.125	$1\frac{1}{8}$	874.	4,617	1,340	.01763
......	900,000	1.092	$1\frac{3}{32}$	828.	4,374	1,270	.01861
......	850,000	1.062	$1\frac{1}{16}$	782.	4,131	1,202	.01969
......	800,000	1.035	$1\frac{1}{32}$	736.	3,888	1,135	.02092
......	750.000	.999	1	690.	3,645	1,067	.02232
......	700,000	.963	$\frac{31}{32}$	644.	3,402	1,001	.02392
......	650,000	.927	$\frac{15}{16}$	598.	3,159	938	.02575
......	600,000	.891	$\frac{29}{32}$	552.	2,916	878	.02789
......	550,000	.855	$\frac{7}{8}$	506.	2,673	806	.03044
......	500,000	.819	$\frac{13}{16}$	460.	2,430	740	.03347
......	450,000	.770	$\frac{25}{32}$	414.	2,187	665	.03720
......	400,000	.728	$\frac{3}{4}$	368.	1,924	567	.04184
......	350,000	.679	$\frac{11}{16}$	322.	1,701	502	.04782
......	300,000	.630	$\frac{5}{8}$	276.	1,458	436	.0558
......	250,000	.590	$\frac{19}{32}$	230.	1,215	375	.06698
0000	211,600	.530	$\frac{17}{32}$	195.	1,028	280	.07912
000	167,805	.470	$\frac{15}{32}$	155.	816	232	.09958
00	133,079	.420	$\frac{7}{16}$	123.	647	192	.12563
0	105,534	.375	$\frac{3}{8}$	97.	513	155	.1584
1	83,694	.330	$\frac{11}{32}$	77.	407	132	.2004
2	66,373	.291	$\frac{5}{16}$	61.	323	108	.2515
3	52,634	.261	$\frac{9}{32}$	48.5	256	88	.3182
4	41,742	.231	$\frac{1}{4}$	38.5	203	72	.4012

Aluminum wire, rods, and bars will be furnished of 63 per cent electrical conductivity, which will have an equal tensile strength per *unit of area* with the copper, and therefore with the electrical conductivity equivalent of 48 per cent of the weight of the copper and sectional area of 160 against the area of the copper section 100, the tensile strength of the aluminum conductors will be as 100 for the copper is to 160 for the aluminum. This would mean, if a square inch of copper conductor was used of, say, 32,000 pounds per square inch tensile strength, the equal conductivity area of 1.6 inches of aluminum would have a tensile strength of 51,200 pounds.

It has already been determined that with aerial lines, the snow and ice load is practically as heavy on lengths of small wire as upon larger sections, so that no objection upon this score can probably be found to the use of the larger sections of aluminum wire.

Both on account of having only 48 per cent of the weight, and on account of having about 60 per cent more strength, the aluminum conductor could be used in much longer spans between supports, and the number of expensive poles and insulators can be materially diminished.

GERMAN SILVER.

German silver is most extensively used for resistances.

A cubic foot weighs about 530 lbs.; specific gravity, 8.5.
Composition : copper, 4 parts ; zinc, 1 part ; nickel, different per centages.
Specific resistance, 20.9, or 13 times copper.
1 mil-foot, resistance 125.91 ohms.
Temperature variation, for 1° C. .044% from 0 to 100° C.

RESISTANCES OF GERMAN SILVER WIRE.

(American Gauge.)

	18%		30%	
Size.	Ohms per 1,000 feet.	Ohms per pound.	Ohms per 1,000 feet.	Ohms per pound.
No. 8	11.772	.23598	17.658	.35397
9	11.832	.37494	17.748	.56241
10	18.72	.59652	28.08	.89478
11	23.598	.94842	35.397	1.42263
12	29.754	1.50786	44.631	2.26179
13	37.512	2.39778	56.268	3.59667
14	47.304	3.8124	70.956	5.7186
15	59.652	6.0624	89.478	9.0936
16	75.222	9.639	112.833	14.458
17	94.842	15.327	142.263	22.990
18	119.61	24.3702	179.41	36.5553
19	155.106	40.9896	232.659	61.4844
20	190.188	61.614	285.282	92.421
21	239.814	97.974	359.721	146.961
22	302.382	155.772	453.573	233.658
23	381.33	247.734	571.99	371.601
24	480.834	393.93	721.251	590.89
25	606.312	626.31	909.468	939.46
26	764.586	995.958	1,146.879	1,493.937
27	964.134	1,583.622	1,446.201	2,375.433
28	1,215.756	2,518.075	1,823.634	3,777.112

RESISTANCES OF GERMAN SILVER WIRE—*Continued.*

Size.	18%		30%	
	Ohms per 1,000 feet.	Ohms per pound.	Ohms per 1,000 feet.	Ohms per pound.
No. 29	1,533.06	4,004.082	2,299.59	6,006.123
30	1,933.038	6,368.356	2,899.557	9,552.534
31	2,437.236	10,119.978	3,655.854	15,179.967
32	3,073.77	16,096.356	4,610.65	24,144.534
33	3,875.616	25,589.628	5,813.424	38,384.442
34	4,888.494	40,712.76	7,332.741	61,069.14
35	6,163.974	64,729.87	9,245.961	97,094.80
36	7,770.816	102,876.482	11,656.224	154,314.723
37	9,797.166	163,524.78	14,695.749	245,287.17
38	12,357.198	257,764.68	18,535,797	386,647.02
39	15,570.828	409,546.8	23,356.242	614,320.2
40	19,653.57	652,024.62	29,480.35	978,036.93

RELATIVE RESISTANCES OF METAL ALLOYS.

Copper	1.
Platinum silver — Platinum, 2 parts Silver, 2 parts	20.5 approximately.
German silver — Copper, 4 parts Nickel, 2 parts Zinc, 1 part	12.8 approximately.
Gold-Silver — Gold, 2 parts Silver, 1 part	11.6 approximately.
Platinoid — German Silver, with 1—2 of Tungsten	19.2 approximately.

RELATIVE CONDUCTIVITIES OF METALS AND ALLOYS.

(Weiller.)

1.	Pure silver	100
2.	Pure copper	100
3.	Refined and crystallized copper	99.9
4.	Telegraphic silicious bronze	98
5.	Alloy of copper and silver (50 per cent)	86.65
6.	Pure gold	78
7.	Silicide of copper, with 4 per cent of silicium	75
8.	Silicide of copper, with 12 per cent of silicium	54.7
9.	Aluminum, 99½	63.09
10.	Tin with 12 per cent of sodium	46.9
11.	Telephonic silicious bronze	35
12.	Copper with 10 per cent of lead	30
13.	Pure zinc	29.9
14.	Telephonic phosphor-bronze	29
15.	Silicious brass with 25 per cent of zinc	26.49
16.	Brass with 35 per cent of zinc	21.5
17.	Phosphor tin	17.7

18.	Alloy of gold and silver (50 per cent)	16.12
19.	Swedish iron	16
20.	Pure Banca tin	15.45
21.	Antimonial copper	12.7
22.	Aluminum bronze (10 per cent)	12.6
23.	Siemens's steel	12
24.	Pure platinum	10.6
25.	Copper with 10 per cent of nickel	10.6
26.	Cadmium amalgam (15 per cent)	10.2
27.	Dronier mercurial bronze	10.14
28.	Arsenical copper (10 per cent)	9.1
29.	Pure lead	8.88
30.	Bronze with 20 per cent of tin	8.4
31.	Pure nickel	7.89
32.	Phosphor-bronze with 10 per cent of tin	6.5
33.	Phosphor-copper with 9 per cent of phosphorus	4.9
34.	Antimony	3.88

TEMPERATURE OF CONDUCTORS WITH COEFFICIENTS.

(From Kempe.)

For metals the resistance increases as the temperature increases. The formula which represents the effect of temperature may be written

$$R_t = R_o (1 + \infty t + \beta t^2)$$

where R_t is the resistance at the final temperature, R_o is the resistance at the standard temperature, t is the increase in temperature, and ∞ and β are coefficients.

For most purposes the following approximate formula may be used:

$$R_t = R_o (1 + \infty t).$$

The value of ∞ for use in the approximate formula is given in the following table, ∞_c being the value per centigrade degree, and ∞_f per Fahrenheit degree.

Metal.	∞_c	∞_f
Silver	0.00377	0.00210
Copper	0.00388	0.00215
Gold	0.00365	0.00203
Aluminum	0.00390	0.00217
Platinum	0.00247	0.00137
Iron	0.00453	0.00252
Tin	0.00365	0.00203
Lead	0.00385	0.00214
Mercury	0.00088	0.00049
Alloy, 2 Pt + 1 Ag	0.00022 to 0.00031	0.00012 to 0.00017
2 Au + 1 Ag	0.00065	0.00036
8 Pt + 1 Ir	0.0013	0.00072
German Silver	0.00028 to 0.00044	0.00016 to 0.00024

Dividing Coefficients for Correcting the observed Resistance of Gutta-Percha at any Temperature to 75° F.

Temp. F.°	Coeff.	Temp. F.	Coeff.	Temp. F.°	Coeff.	Temp. F.°	Coeff.
90	.3197	77.5	.8269	65	2.139	52.5	5.533
89.5	.3320	77	.8589	64.5	2.222	52	5.748
89	.3449	76.5	.8922	64	2.308	51.5	5.970
88.5	.3583	76	.9267	63.5	2.397	51	6.202
88	.3722	75.5	.9627	63	2.490	50.5	6.442
87.5	.3866	75	1.000	62.5	2.587	50	6.692
87	.4016	74.5	1.039	62	2.687	49.5	6.951
86.5	.4171	74	1.079	61.5	2.792	49	7.220
86	.4343	73.5	1.121	61	2.899	48.5	7.500
85.5	.4501	73	1.164	60.5	3.012	48	7.791
85	.4675	72.5	1.209	60	3.128	47.5	8.093
84.5	.4856	72	1.256	59.5	3.250	47	8.406
84	.5044	71.5	1.305	59	3.376	46.5	8.732
83.5	.5240	71	1.355	58.5	3.506	46	9.070
83	.5443	70.5	1.408	58	3.642	45.5	9.422
82.5	.5654	70	1.463	57.5	3.783	45	9.787
82	.5873	69.5	1.519	57	3.930	44.5	10.17
81.5	.6100	69	1.578	56.5	4.082	44	10.56
81	.6337	68.5	1.639	56	4.240	43.5	10.97
80.5	.6582	68	1.703	55.5	4.405	43	11.39
80	.6837	67.5	1.769	55	4.575	42.5	11.84
79.5	.7102	67	1.837	54.5	4.753	42	12.29
79	.7378	66.5	1.908	54	4.937	41.5	12.77
78.5	.7663	66	1.982	53.5	5.128	41	13.27
78	.7960	65.5	2.059	53	5.327	40.5	13.78

Example: The insulation resistance at 62° F. of a wire insulated with Gutta-percha is 500 meghoms; what is the resistance at 75° F.?

Resistance = 500 ÷ 2.687 = 186.1 megohms.

Dividing Coefficients for Correcting the observed Resistance of Hooper's India-Rubber at any Temperature to 75° F.

Temp. F.°	Coeff.	Temp. F.°	Coeff.	Temp. F.°	Coeff.	Temp. F.°	Coeff.
90	.680	80.5	.868	71	1.108	61.5	1.414
89.5	.691	80	.880	70.5	1.122	61	1.433
89	.698	79.5	.891	70	1.137	60.5	1.451
88.5	.708	79	.902	69.5	1.152	60	1.470
88	.716	78.5	.914	69	1.167	59.5	1.489
87.5	.726	78	.926	68.5	1.182	59	1.508
87	.735	77.5	.938	68	1.197	58.5	1.527
86.5	.745	77	.950	67.5	1.212	58	1.547
86	.754	76.5	.963	67	1.228	57.5	1.567
85.5	.764	76	.975	66.5	1.244	57	1.587
85	.774	75.5	.987	66	1.260	56.5	1.608
84.5	.784	75	1.000	65.5	1.276	56	1.629
84	.794	74.5	1.013	65	1.293	55.5	1.650
83.5	.804	74	1.026	64.5	1.309	55	1.671
83	.814	73.5	1.039	64	1.326	54.5	1.693
82.5	.825	73	1.053	63.5	1.343	54	1.715
82	.836	72.5	1.068	63	1.361	53.5	1.737
81.5	.846	72	1.080	62.5	1.378	53	1.759
81	.857	71.5	1.094	62	1.396	52.5	1.782

Dividing Coefficients — *Continued.*

Temp. F.°	Coeff.	Temp. F.°	Coeff.	Temp. F.°	Coeff.	Temp. F.°	Coeff.
52	1.805	49	1.949	46	2.106	43	2.274
51.5	1.828	48.5	1.975	45.5	2.133	42.5	2.303
51	1.852	48	2.000	45	2.160	42	2.333
50.5	1.876	47.5	2.026	44.5	2.188	41.5	2.363
50	1.900	47	2.052	44	2.216	41	2.394
49.5	1.925	46.5	2.079	43.5	2.245	40.5	2.424

Mean Temperature.

A piece of wire or cable whose length is l, and temperature t°, when connected to another wire or cable whose length is l_1, and temperature t_1°, has a mean temperature

$$\frac{lt + l_1t_1}{l + l_1}.$$

Linear Expansion of Metals due to Change of Temperature.

A rod or wire l feet long will, by an increase of temperature of t°, increase its length to

$$l\,(1 + at^\circ) \text{ feet.}$$

where a has the following values :—

Metal.	Value of a for F.°	Value of a for C.°
Zinc	.000016540	.00002976
Lead	.000015830	.00002848
Brass	.000010500	.00001890
Copper	.000009560	.00001720
Iron	.000006830	.00001229
Steel	.000006361	.00001145
Platinum	.000004910	.00000884
Glass	.000004870	.00000876

Specific Heat.

Element.	Specific heat of equal Weights.	Element.	Specific heat of equal Weights.
Water	1.0000	Rhodium	.0580
Lithium	.9408	Silver	.0570
Sodium	.2934	Cadmium	.0567
Magnesium	.2499	Tin	.0562
Aluminum	.2143	Iodine	.0541
Sulphur	.1776	Antimony	.0508
Potassium	.1696	Tellurium	.0474
Manganese	.1140	Thallium	.0336
Iron	.1138	Tungsten	.0334
Nickel	.1091	Iridium	.0325
Cobalt	.1070	Platinum	.0324
Zinc	.0955	Gold	.0324
Copper	.0951	Mercury (*liquid*)	.0333
Bromine (*solid*)	.0843	Lead	.0314
Arsenic	.0814	Bismuth	.0308
Palladium	.0593	Osmium	.0306

If $W =$ weight of one substance whose temperature is T and specific heat S,
$w =$ weight of another substance whose temperature is t and specific heat s.

$$\text{Temperature of mixture} = \frac{WST + wst}{WS + ws} = t_1.$$

$$S = s\,\frac{w\,(t_1 - t)}{W\,(T - t)}.$$

Temperature Coefficients of the Resistivity of Pure Copper.

Temp. C°.	Temp. F°.	Coefficient.	Logarithm of Coefficient.	Matthiessen's Meter-gram Standard in International Ohms.	Temp. C°.	Temp. F°.	Coefficient.	Logarithm of Coefficient.	Matthiessen's Meter-gram Standard in International Ohms.
0	32.0	1.	0.	0.14173	20	68.0	1.07968	.033294	0.15302
1	33.8	1.00388	.001680	0.14228	21	69.8	1.08378	.034939	0.15360
2	35.6	1.00776	.003358	0.14283	22	71.6	1.08788	.036581	0.15418
3	37.4	1.01166	.005036	0.14338	23	73.4	1.09200	.038222	0.15477
4	39.2	1.01558	.006712	0.14394	24	75.2	1.09612	.039859	0.15535
5	42.0	1.01950	.008386	0.14449	25	77.0	1.10026	.041494	0.15594
6	42.8	1.02343	.010059	0.14505	26	78.8	1.10440	.043127	0.15653
7	44.6	1.02738	.011730	0.14561	27	80.6	1.10856	.044758	0.15711
8	46.4	1.03134	.013400	0.14617	28	82.4	1.11272	.046385	0.15770
9	48.2	1.03531	.015068	0.14673	29	84.2	1.11689	.048011	0.15830
10	50.0	1.03929	.016734	0.14730	30	86.0	1.12107	.049633	0.15889
11	51.8	1.04328	.018399	0.14786	40	104	1.16332	.065699	0.16488
12	53.6	1.04728	.020062	0.14843	50	122	1.20625	.081436	0.17095
13	55.4	1.05129	.021723	0.14900	60	140	1.24965	.096787	0.17711
14	57.2	1.05532	.023382	0.14957	70	158	1.29327	.111687	0.18329
15	59.0	1.05935	.025039	0.15014	80	176	1.33681	.126069	0.18946
16	60.8	1.06339	.026694	0.15071	90	194	1.37995	.139863	0.19558
17	62.6	1.06745	.028348	0.15129	100	212	1.42231	.152995	0.20158
18	64.4	1.07152	.029999	0.15186					
19	66.2	1.07559	.031648	0.15244					

Heat Conducting Power of Metals.

Metal.	Relative heat conducting power.	Metal.	Relative heat conducting power.
Silver	100	Iron (*bar*)	43.6
Gold	98.1	Tin	42.2
Copper (*rolled*) . . .	84.5	Steel	39.7
Copper (*cast*) . . .	81.1	Platinum	38.0
Aluminum	66.5	Sodium	36.5
Zinc	64.1	Iron (*cast*)	35.9
Bismuth	61.0	Lead	28.7
Cadmium	57.7	Antimony	21.5

RESISTANCE METALS.

Following are data on modern resistance metals, supplied by Hermann Boker & Co., of 101–103 Duane Street, New York.

The resistance data are from tests by Helmholtz and the German Imperial Physical and Technical Institute of Charlottenburg, Germany.

Dimensions, Resistances, and Weights of Resistance Wires.

B. & S. Gauge No.	Diameter, inch.	Area, Circular Mils.	Ohms per 1000 feet.					Feet per Lb. Approximately.	
			Superior.	Ia Ia.	Nickeline I.	Nickeline II.	German Silver.	All Grades except German Silver.	German Silver.
14	.0641	4107.	125.9	73.5	63.7	49.7	56.6	85.	79.2
16	.0508	2583.	200.3	116.9	101.4	78.9	90.1	135.3	125.9
17	.0453	2048.	252.6	147.4	127.8	99.6	113.9	170.6	158.7
18	.0403	1624.	318.6	185.9	161.2	125.6	143.4	215.5	200.5
19	.0359	1289.	401.4	234.3	203.1	158.2	181.1	271.0	252.
20	.0320	1024.	506.5	295.6	256.3	199.7	227.9	342.3	318.4
21	.0285	812.3	641.5	374.4	324.6	252.9	288.7	433.	402.6
22	.0253	640.1	805.7	470.1	407.7	317.5	362.6	543.5	505.5
23	.0225	506.25	1022.1	596.6	517.2	402.8	459.9	689.6	641.4
24	.0201	404.	1280.7	747.6	648.	504 9	576.3	870.	809.1
25	.0179	320.4	1620.	945.6	819.7	638.9	729.	1098.	1021.2
26	.0159	252.8	2036.5	1192.9	1030.5	802.8	916.4	1370.	1274.1
27	.0142	201.6	2566.2	1497.8	1298.5	1011.5	1154.8	1724.	1604.
28	.0126	158.8	3238.1	1890.1	1638.5	1276.4	1457.1	2174.	2022.
29	.0113	127.7	4125.	2407.8	2087.2	1626.	1856.2	2777.	2583.
30	.0100	100.	5148.7	3005.3	2605.2	2029.5	2316.9	3448.	3207.
31	.0089	79.2	6491.6	3789.2	3284.7	2558.8	2921.2	4347.	4043.
32	.0080	64.	8187.5	4779.1	4142.8	3227.3	3684.3	5555.	5167.
33	.0071	50.4	10322.	6025.1	5222.9	4068.9	4644.9	7142.	6600.
34	.0063	39.69	13020.	7600.4	6588.1	5132.6	5659.	9090.	8354.
35	.0056	31.56	16416.	9582.7	8308.5	6471.1	7387.2	11100.	10323.
36	.005	25.	20698.	12081.	10473.	8158.8	9314.1	14286.	13280.
37	.0044	19.83	26094.	15229.	13203.	10285.	11743.	17543.	16315.
38	.004	16.	32916.	19213.	16655.	12975.	14712.	22220.	20665.
39	.0035	12.25	41495.	24218.	20996.	16357.	18672.	27700.	25761.
40	.0031	9.61	52373.	30570.	26500.	20644.	23567.	35714.	33215.

Maximum Amperes for Safe Constant Load with Free Radiation.

B. & S. Gauge No.	Superior.	Ia Ia.	Nickeline I. and German Silver.	Nickeline II.
18	11.8	15.75	17.2	18.2
19	10.25	13.6	14.4	15.6
20	8.5	11.5	12.1	13.0
21	7.2	9.7	10.0	11.0
22	6.0	8.0	8.4	9.1
23	5.2	6.8	7.1	7.8
24	4.5	5.8	6.0	6.5
25	4.0	4.9	4.8	5.5
26	3.5	4.1	4.1	4.6
27	3.0	3.6	3.6	4.0
28	2.7	3.1	3.1	3.5
29	2.5	2.9	2.9	3.2
30	2.3	2.7	2.7	2.9
32	2.0	2.5	2.5	2.63
34	1.7	2.2	2.2	2.3
36	1.5	2.0	2.0	2.0

Resistance Ribbon. "Superior" Grade.

B. & S. Gauge No.	Thickness, Inch.	Ohms per 1000 feet.							
		⅛ in.	¼ in.	⅜ in.	½ in.	⅝ in.	¾ in.	⅞ in.	1 in.
8	.128	25.36	12.68	8.45	6.34	5.07	4.22	3.62	3.17
9	.114	28.59	14.29	9.53	7.14	5.71	4.76	4.08	3.57
10	.101	32.22	16.11	10.74	8.05	6.44	5.37	4.60	4.02
11	.0907	35.93	17.96	11.98	8.98	7.18	5.99	5.13	5.49
12	.0808	40.19	20.09	13.39	10.04	8.04	6.69	5.74	5.02
13	.0719	45.61	22 80	15.20	11.40	9.12	7.60	6.51	5.70
14	.0641	50.72	25 36	16.90	12.68	10.14	8.45	7.24	6.34
15	.0571	57.18	28.59	19.06	14.29	11.43	9.53	8.16	7.14
16	.0508	64.44	32.22	21.48	16.11	12.89	10.74	9.20	8.05
17	.0452	71.86	35.93	23.95	17.96	14.37	11.97	10.26	8.98
18	.0403	80.38	39.19	26.79	20.09	16.07	13.39	11.48	10.04
19	.0359	91.22	45.61	30.40	22.80	18.24	15.20	13.03	11.40
20	.0320	101.44	50.72	33.81	25.36	20.29	16.90	14.50	12.68
21	.0284	114.36	57.18	38.12	28.59	22.87	19.06	16.33	14.29
22	.0253	128.88	64.44	42.96	32.22	25.77	21.46	18.41	16.11
23	.0225	143.72	71.86	47.90	35.93	28.74	23.95	20.53	17.96
24	.0201	160.76	80.38	53.59	40.19	32.15	26.79	22.96	20.09
25	.0179	182.44	91.22	60.81	45.16	36.49	30.40	26.06	22.80
26	.0159	202.88	101.44	67.62	50.72	40.57	33.81	28.98	25.36
27	.0142	228.72	114.36	76.24	57.18	45.74	38.12	32.67	28.59
28	.0126	257.76	128.88	85.92	64.44	51.55	42.96	36.82	32.22
29	.0112	287.44	143.72	95.81	71.86	57.49	57.90	41.06	35.93
30	.0100	321.52	160.76	107.17	80.38	64.30	53.59	45.93	40.19
31	.0089	364.88	182.44	121.62	91.22	72.97	60.81	52.12	45.16
32	.0079	405.76	202.88	135.25	101.44	81.15	67.62	57.96	50.72
33	.0071	457.44	228.72	152.48	114.36	91.49	76.24	65.33	57.18
34	.0063	515.52	257.76	171.84	128.88	103.10	85.92	73.64	64.44
35	.0056	574.88	287.44	191.62	143.72	114.97	95.81	82.12	71.86
36	.005	643.04	321.52	214.34	160.76	128.60	107.17	91.86	80.38
37	.0044	729.76	364.88	243.25	182.44	145.95	121.62	104.25	91.22
38	.0039	811.52	405.76	270.50	202.88	162.30	135.25	115.93	101.44

The number of feet to the pound of any size of the above ribbon can be found by dividing the constant 0.26 by the cross sectional area in square inches.

Resistance Ribbon. Ia Ia Quality.

B. & S. Gauge No.	Thickness, Inch.	Ohms per 1000 feet.							
		⅛ in.	¼ in.	⅜ in.	½ in.	⅝ in.	¾ in.	⅞ in.	1 in.
8	.128	14.81	7.40	4.93	3.70	2.96	2.46	2.11	1.85
9	.114	16.69	8.34	5.56	4.17	3.34	2.78	2.38	2.08
10	.101	18.80	9.40	6.26	4.70	3.76	3.13	2.70	2.35
11	.0907	20.97	10.48	6.99	5.24	4.19	3.49	2.99	2.62
12	.0808	23.46	11.73	7.82	5.86	4.69	3.91	3.35	2.93
13	.0719	26.63	13.31	8.87	6.65	5.32	4.43	3.80	3.32
14	.0641	29.62	14.81	9.87	7.40	5.92	4.93	4.22	3.70
15	.0571	33.38	16.69	11.12	8.34	6.68	5.56	4.77	4.17
16	.0508	37.60	18.80	12.53	9.40	7.52	6.26	5.37	4.70
17	.0452	41.94	20.97	13.98	10.48	8.38	6.99	5.99	5.24
18	.0403	46.92	23.46	15.64	11.73	9.38	7.82	6.70	5.86
19	.0359	53.26	26.63	17.78	13.31	10.64	8.87	7.60	6.65
20	.0320	59.24	29.62	19.75	14.81	11.84	9.87	8.46	7.40
21	.0284	66.76	33.38	22.25	16.69	13.35	11.12	9.53	8.34
22	.0253	75.20	37.60	25.07	18.80	15.04	12.53	10.74	9.40
23	.0225	83.88	41.94	27.96	20.97	16.77	13.98	11.98	10.48
24	.0201	93.84	46.92	31.28	23.46	18.77	15.64	13.40	11.73
25	.0179	106.52	53.26	35.50	26.63	21.30	17.78	15.21	13.31
26	.0159	118.48	59.24	39.49	29.62	23.69	19.75	16.91	14.81
27	.0142	133.52	66.76	44.50	33.38	26.70	22.25	19.07	16.69
28	.0126	150.40	75.20	50.13	37.60	30.08	25.07	21.50	18.80
29	.0112	167.76	83.88	55.92	41.94	33.55	27.96	23.96	20.97
30	.0100	187.68	93.84	62.56	46.92	37.53	31.28	26.81	23.46
31	.0089	213.04	106.52	71.01	53.26	42.60	35.50	30.43	26.63
32	.0079	236.96	118.48	78.98	59.24	47.40	39.49	33.82	29.62
33	.0071	267.04	133.52	89.01	66.76	53.40	44.50	38.15	33.38
34	.0063	300.80	150.40	100.26	75.20	60.16	50.13	42.97	37.60
35	.0056	335.52	167.76	111.84	83.88	67.10	55.92	47.93	41.94
36	.005	375.36	187.68	125.12	93.84	75.07	62.56	53.62	46.92
37	.0044	426.08	213.04	142.02	106.52	85.21	71.01	60.87	53.26
38	.004	473.92	236.96	157.97	118.48	94.78	78.98	67.64	59.24

Specific Resistance and Temperature Coefficient.

Material.	Specific Resistance at 20° C. microhms.	Coefficient for 1° C.
Superior	85.4 to 86.5	+ .00067 to + .00073
Ia Ia, hard	50.2	— .000011
Ia Ia, soft	47.1	+ .000005
Nickeline No. II., hard	33.9	+ .000168
Nickeline No. II., soft	32.3	+ .000181
Nickeline No. I., hard	43.6	+ .000076
Nickeline No I., soft	40.7	+ .000077
German Silver, average	31.5	+ .00025
Manganin	47.5	± .00001
Constantin	50. — 52	± .00001

"SUPERIOR" WIRE.

Specific gravity, 8.4.
Specific resistance at 20° C., 86 microhms.
Coefficient of temperature, mean value, for 1° C., + 0.00065.

Resistance of one circular mil foot of "Superior" wire at 20° C., 517.5 ohms.

This resistance material does not rust, nor show any sign of oxidation at ordinary temperature, and it shows no sign of deterioration after being submitted to a temperature just below a visible red heat as a permanent load.

Prices of Bare Wire per Pound.

B. & S. Gauge.	Inch.	Superior.	Ia Ia.	Nickeline I.	Nickeline II.
15 and heavier	.057	$1.07	$.078	$0.66	$.61
16	.05082	1.09	.80	.69	.63
17	.04525	1.09	.80	.69	.63
18	.0403	1.09	.80	.69	.63
19	.0358	1.09	.80	.69	.63
20	.0319	1.09	.80	.69	.63
21	.0284	1.12½	.85	.72	.66
22	.0253	1.16	.88	.75	,70
23	.0225	1.16	.88	.75	.70
24	.0201	1.24	.94	.78	.74
25	.0179	1.26	.96	.83	.77
26	.0159	1.28	.96	.85	.79
27	.01419	1.33	1.04	.90	.84
28	.01264	1.37	1.09	.94	.88
29	.01125	1.40	1.12	.97	.91
30	.010	1.45	1.17	1.02	.96
31	.00892	1.52	1.24	1.09	1.03
32	.00795	1.60	1.33	1.16	1.10
33	.00708	1.69	1.45	1.26	1.20
34	.0063	1.81	1.55	1.38	1.33
35	.0056	1.98	1.75	1.55	1.49
36	.005	2.56	2.20	2.13	2.07
37	.00445	4.21	3.85	3.72	3.72
38	.00396	6.36	6.00	5.93	5.87
39	.00353	8.11	7.75	7.68	7.62
40	.00314	10.36	10.00	9.93	9.87
	.00196	15.60	15.25	15.18	15.12

Prices of Silk Covered Wire per Pound.

B. & S. Gauge.	Inch.	Superior.		Ia Ia.		Nickeline I.		Nickeline II.	
		Single.	Double.	Single.	Double.	Single.	Double.	Single.	Double.
20	.031 and heavier	$1.90	$2.60	$1.50	$2.20	$1.52	$2.22	$1.47	$2.17
21	.0284	2.00	2.70	1.60	2.30	1.62	2.32	1.57	2.27
22	.0253	2.05	2.75	1.65	2.35	1.67	2.37	1.62	2.32
23	.0225	2.10	2.80	1.70	2.40	1.72	2.42	1.67	2.37
24	.0201	2.15	2.90	1.75	2.50	1.77	2.52	1.72	2.47
25	.0179	2.30	3.10	1.90	2.70	1.92	2.72	2.87	2.67
26	.0159	2.50	3.30	2.10	2.90	2.12	2.92	2.07	2.87
27	.0141	2.70	3.60	2.30	3.20	2.32	3.22	2.27	3.17
28	.0126	2.85	3.90	2.45	3.50	2.47	3.52	2.42	3.47
29	.01125	3.15	4.20	2.75	3.80	2.77	3.82	2.72	3.77
30	.010	3.40	4.50	3.00	4.10	3.02	4.12	3.00	4.07
31	.0089	3.70	4.90	3.30	4 50	3.32	4.52	3.27	4.47
32	.0079	4.10	5.30	3.70	4.90	3.72	4.92	3.67	4.87
33	.0070	4.40	5.90	4.00	5.50	4.02	5.52	4.00	5.47
34	.0063	4.90	6.40	4.50	6.00	4.52	6.02	4.47	5.97
35	.0056	5.70	7.00	5.30	6.60	5.32	6.62	5.27	6.57
36	.005	6.90	8.65	6.50	8.25	6.52	8.27	6.47	8.22
37	.00445	9.90	12.40	9.50	12.00	9.52	12.02	9.47	11.97
38	.0039	12.40	16.90	12.00	16.50	12.02	16.52	12.00	16.47
39	.00353	15.40	20.40	15.00	19.50	15.02	19.52	15.00	19.47
40	.00314	18.40	22.90	18.00	22.50	18.02	22.52	18.00	22.47

The above prices are for wire, single or double, covered with green or white silk.

Prices of Resistance Sheets per Pound.

B. & S. Gauge.	Inch.	Superior.	Ia Ia.	Nickeline I.	Nickeline II.
28 and heavier	.0126	$1.02	$0.69	$0.63	$0.57
29	.01125	1.05	.71	.65	.60
30	.010	1.05	.71	.65	.60
31	.0089	1.07	.74	.67	.62
32	.0079	1.07	.74	.67	.62
33	.007	1.09	.76	.69	.65
34	.0063	1.09	.76	.69	.65
35	.0056	1.11	.78	.72	.66
36	.005	1.11	.78	.72	.66
37	.0044	1.11	.78	.72	.66
38	.0039	1.11	.78	.72	.66

The above prices are for sheets of maximum width of 12 inches, and maximum length of 7 to 8 feet.

Prices for Resistance Tapes in long lengths per Pound.

B. & S. Gauge.	Inch.	Superior.	Ia Ia.	Nickeline I.	Nickeline II.
18 and heavier	.0403	$1.08	$0.73	$0.66	$0.61
19	.0358	1.10	.74	.67	.62
20	.0319	1.10	.74	.67	.62
21	.0284	1.10	.74	.67	.62
22	.0253	1.10	.74	.67	.62
23	.0225	1.10	.74	.67	.62
24	.0201	1.10	.74	.67	.62
25	.0179	1.10	.74	.67	.62
26	.0159	1.10	.74	.67	.62
27	.0141	1.10	.74	.67	.62
28	.0126	1.10	.74	.67	.62
29	.01125	1.14	.77	.70	.65
30	.010	1.14	.77	.70	.65
31	.0089	1.17	.79	.73	.67
32	.0079	1.17	.79	.73	.67
33	.007	1.21	.83	.76	.70
34	.0063	1.21	.83	.76	.70
35	.0056	1.30	.87	.80	.75
36	.005	1.30	.87	.80	.75
37	.0044	1.30	.87	.80	.75
38	.0039	1.30	.87	.80	.75

The above prices are tapes about $\frac{3}{4}$-inch wide and narrower. Maximum length of tapes is about 300 feet.

KRUPP'S RESISTANCE WIRES.

Following will be found data of the Krupp resistance wires supplied by the American agents, Thomas Prosser & Son, 15 Gold Street, New York.

Krupp's Resistance Metals.

Specific gravity	8.102
Specific resistance at 20° C. mean	85.13 microhms.
Temperature coefficient, mean	.0007007.
Resistance per circular mil-foot	314.067 ohms.
Resistance per 1000′, 1 square inch area	.8513 ohms.

This metal can be permanently loaded with current sufficient to raise its temperature to 600° C. (1112° F.) without undergoing any structural change.

Table of Krupp's Resistance Wires.

Diam. in m.m.	Diam. in inches.	Nearest B. & S. Gauge No.	Feet per lb.	Resistance in ohms per foot.			
				at 68° F.	at 176° F.	at 284° F.	at 428° F.
5	.1968	4	9	.0132	.0138	.0143	.0150
4½	.1772	5	12	.0163	.0170	.0176	.0184
4	.1575	6	15	.0206	.0215	.0224	.0235
3½	.1378	7	19	.0269	.0280	.0291	.0307
3	.1181	9+	26	.0368	.0382	.0396	.0417
2¾	.1083	9—	31	.0437	.0455	.0472	.0497
2½	.0984	10	37	.0528	.0550	.0570	.0601
2¼	.0885	11	46	.0653	.0679	.0705	.0742
2	.0787	12	58	.0825	.0860	.0892	.0940
1¾	.0689	13	76	.1078	.112	.116	.123
1½	.0590	15	104	.1468	.153	.159	.167
1¼	.0492	16	150	.2115	.220	.229	.241
1	.0393	18	234	.3305	.344	.356	.376
¾	.0295	21	415	.5870	.610	.633	.667
½	.0196	24	937	1.324	1.38	1.43	1.51

Price List per Pound.

B. & S. Nos. 4 to 10 inclusive	$1.10
B. & S. Nos. 11 to 12 inclusive	1.15
B. & S. Nos. 13 to 15 inclusive	1.20
B. & S. No. 16	1.25
B. & S. No. 18	1.30
B. & S. No. 21	1.35
B. & S. No. 24	1.40

Table of Specific Resistance.

Substance.	Specific resistance in microhms per cubic cm.	Relative conductance.
Metals at 0° C.		
Copper (annealed)	1.570	100.
Copper (hard)	1.603	98.1
Silver (annealed)	1.492	105
Silver (hard)	1.620	98
Gold	2.077	76
Aluminum (annealed)	2.889	54
Platinum	8.982	17
Iron (pure)	9.638	16
Iron (telegraph wire)	15.	10
Lead	19.63	8.3
Mercury	94.34	1.6
Silenium	6×10^{10}	$\frac{1}{40000000000}$
Carbon (graphite)	2400 to 42000	
Carbon arc light)	about 4000	$\frac{1}{2500}$

Table of Specific Resistance — *Continued.*

Substance.	Specific resistance in microhms per cubic cm.	Relative conductance.
Alloys.		
German silver (Cu 60, Zn 26, Ni 14)	20.76	7·6
Platinum-Silver (Pt 67, Ag 33)	24.4	6.5
Platinoid (Cu 59, Zn 25.5, Ni 14, W 55)	32.5	4.8
Manganin (Cu 84, Ni 12, Mn 3.5)	47.5	3.3
Superior	86.	
Ia Ia, hard	50.2	
Ia Ia, soft	47.1	
Nickeline I., hard	43.6	
Nickeline I., soft	40.7	
Nickeline II., hard	33.9	
Nickeline II., soft	32.3	
Krupp's metal	85.13	
Constantin	50 to 52	
John A. Roebling's Son's Co., Climax	78.5	
Liquids at 18° C.		
Pure water	26.5×10^8	
Dilute H_2SO_4 5%	486×10^4	
H_2SO_4 30 %	137×10^4	
H_2SO_4 80%	918×10^4	
$ZnSO_4$ 24%	214×10^5	
HNO_3 30%	129×10^4	
Insulators.		
Glass at 20° C.	91×10^{18}	
Glass at 200° C.	22.7×10^{12}	
Gutta-percha 24° C.	4.5×10^{20}	

RESISTANCE OF DIELECTRICS.

Insulating materials or non-conductors, such as glass, wood, india-rubber, gutta-percha, etc., are termed dielectrics, and vary in resistance, not only with the material, but with its kind and quality.

The following table gives the

Specific Resistance of Insulators.

Material.	Resistance in megohms per cubic centimeter.
Mica	84×10^6
Gutta-percha	450×10^6
Shellac	9000×10^6
Ebonite	28000×10^6

Specific Resistance of Insulators. — *Continued.*

Material.	Resistance in megohms per cubic centimeter.
Hooper's Compound	15000×10^6
Paraffine	34000×10^6
Paraffine oil	8×10^6
Olive oil	1×10^6
Lard oil	$.35 \times 10^6$
Stearic acid	350×10^6
Benzine	14×10^6
Wood tar	1670×10^6
Ozokerite (crude)	450×10^6

Disruptive Value of Dielectrics.

In a paper on the "Dielectric Strength of Air," June 27, 1898, before the Am. Inst. E. E., Chas. P. Steinmetz gave the results of numerous tests with different shapes of electrodes and under various conditions. Following are his conclusions and some of his tables and curves.

1st. At constant voltage and constant wave shape, that is constant ratio between maximum and effective E.M.F., the striking distance is a constant, especially between sharp points, where the tests have been repeated over and over again, and independent of the atmospheric condition, the frequency, etc., to such an extent that the striking distance between needle points offers the most reliable means to determine very high voltages. For this reason, it is used in this manner as final check in all high potential insulation tests of the General Electric Company.

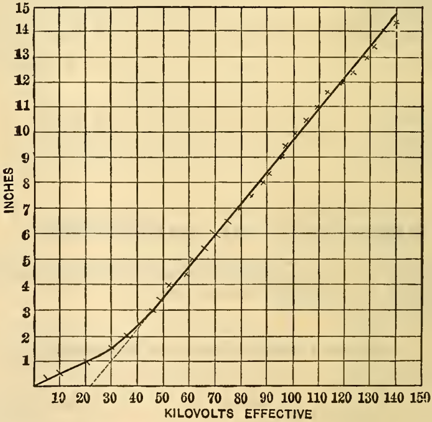


FIG. 0. Points, Smooth Core Alternator, 125 Cycles.

2d. No physical law has been found to represent satisfactorily all the observations. Some point to the existence of a constant dielectric strength of air, analogous to the tensile strength of mechanics. Others point to the existence of a spurious counter E.M.F. of the spark or transition resistance from electrode to air.

3d. Constant dielectric strength. Cylinders of 1.11 in. diameter give an average disruptive strength of air of 60 kilovolts per inch. Cylinders of .315 in. diameter, an average dielectric strength of 77. Spheres at very small distance point toward the latter value. As a disturbing factor in this case, enters the electrostatic brush discharge, which by a partial breakdown of the air surrounding the electrodes changes and increases the size and decreases the distance of the effective terminals.

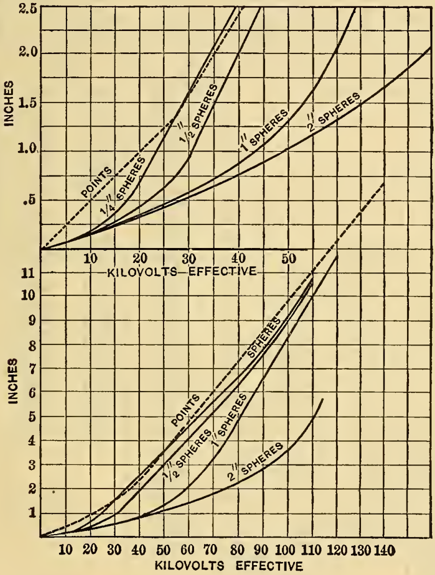


FIG. 0. Comparison of Points and Spheres. Smooth Core Alternator, 125 Cycles.

4th. Counter E.M.F. of the sparks. The tests with sharp points give 22 kilovolts, or 11 kilovolts for a single transition from terminal to air. Spheres give curves pointing to a similar phenomenon. Electric conductors inserted at right angles into or parallel with the discharge, point to the existence of a counter E.M.F. of the same magnitude. The beginning of the electrostatic brush discharge is at a potential of this magnitude also.

TABLE. — Points.

$2\frac{1}{2}''$ needles. 125 cycles.

Smooth Core Alternator: A–10–30–1500.				Ironclad Alternator: A–10–60–1500.					
Distance, inches. *d.*	Kilovolts: effective.			Distance, inches. *d.*	Kilovolts: effective.				
	7–21–'96* in air	7–17–'96† in air	Average.		7–24–'96‡ in air.	Jan. '95 in air.	Average.	Jan. '95 in fog.	Jan. '95 in steam.
.25	4.25			.25	4.13				
.5	10.0			.5	9.0	10.0	9.5	11.0	14.5
1.0	20.4			1.0	16.0	18.5	17.7	22.0	25.3
1.5	29.3			1.5	24.3	26.0	25.1	31.0	35.5
2.0	35.2			2.0	30.5	30.5	30.5	38.0	43.0
2.5	40.4			2.5	33.9	35.0	34.4	43.5	50.3
3.0	45.6			3.0	36.3	38.0	37.1	48.0	54.5
3.5	49.4			3.5	42.2	41.7	42.0	51.0	63.0
4.0	52.5			4.0	41.3	45.0	43.2	55.5	
4.5	59.6			4.5	45.5	48.0	46.7	61.0	
5.0		61.0		5.0	48.4	50.5	49.5		
5.5		65.7		5.5	53.0	55.0	54.0		
6.0	69.8	69.5	69.65	6.0	56.1	58.8	57.4		
6.5	73.4	74.7	74.05	6.5	59.8	62.0	60.9		
7.0	77.5	79.2	78.35	7.0	63.3	64.7	64.0		
7.5	83.8	83.0	83.4	7.5	67.5	69.0	68.3		
8.0	86.8	87.3	87.05	8.0	70.9	73.4	72.1		
8.5	90.5	90.2	90.35	8.5	75.8	76.0	75.9		
9.0	95.0	93.7	94.35	9.0	79.8	79.2	79.5		
9.5	97.7	96.3	97.0	9.5	84.8	82.5	83.6		
10.0	101.5	99.0	100.25	10.0	88.8	86.4	87.6		
10.5	107.0	103.0	105.0	10.5	93.5	89.5	91.5		
11.0	111.5	107.5	109.5	11.0	97.7	93.0	95.4		
11.5	114.0	110.5	112.5	11.5	102.0				
12.0	121.0	116.0	118.5	12.0	107.7				
12.5	125.5	120.0	122.75	12.5	111.0				
13.0	133.0	123.0	128.0	13.0	117.5				
13.5	135.0	127.0	131.0	13.5	122.5				
14.0	140.0	129.0	134.5	14.0	128.0				
14.5	144.0	136.0	140.0	14.5	134.4				
15.0	150.0			15.0	138.3				
15.5	155.0								
16.0	159.5§								

* 85° F. Weather sultry.
† 75°–80° F. Weather clear and bright.
‡ 70° F. Weather cool and cloudy.
§ Internal discharges in intermediary transformers F′ F″.

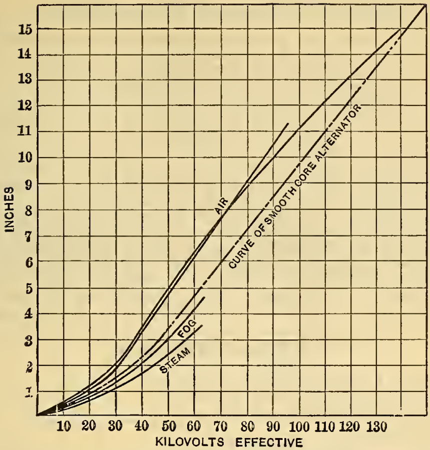


FIG. 0. Points in Air. Fog and Steam at Atmospheric Pressure. Ironclad Armature, 125 Cycles.

Values of Various Dielectrics.

STEINMETZ, February, 1893. A. I. E. E.

Material.	Electrostatic gradient at			Formula for Calculating the Sparking Distance.
	0	5	25	D
	Kilovolts, in Kilovolts per Centimeter.			$E =$ P. D. in Kilovolts.
Air	139	16.7	11.9	
Mica	4170	3200	1660.0	$D = .24\ E + .0145\ E^2$
Vulcanized fiber, red	130	52	15.3	$D = 7.66\ E + 2.3\ E^2$
Dry wood fiber		130		$D = 7.66\ E$
Paraffined paper		339		$D = 3\ E$
Melted paraffine		81		$D = 12.4\ E$
Boiled linseed oil		80		$D = 12.5\ E$
Turpentine oil		64		$D = 15.7\ E$
Copal varnish		30		$D = 30\ E$
Crude lubricating oil (mineral oil)		16		$D = 60\ E$
Vulcabeston		36		$D = 28\ E$
Asbestos paper		43		$D = 23\ E$
Creeping discharge		10.1	.86	$D = 55\ (E - 2)^2$

Tests of Vulcanized India-Rubber.

Lieutenant L. Vladomiroff, a Russian naval officer, has recently carried out a series of tests at the St. Petersburg Technical Institute with a view to establishing rules for estimating the quality of vulcanized India-rubber. The following, in brief, are the conclusions arrived at, recourse being had to physical properties, since chemical analysis did not give any reliable result: 1. India-rubber should not give the least sign of superficial cracking when bent to an angle of 180 degrees after five hours of exposure in a closed air-bath to a temperature of 125° C. The test-pieces should be 2.4 inches thick. 2. Rubber that does not contain more than half its weight of metallic oxides should stretch to five times its length without breaking. 3. Rubber free from all foreign matter, except the sulphur used in vulcanizing it, should stretch to at least seven times its length without rupture. 4. The extension measured immediately after rupture should not exceed 12% of the original length, with given dimensions. 5. Suppleness may be determined by measuring the percentage of ash formed in incineration. This may form the basis for deciding between different grades of rubber for certain purposes. 6. Vulcanized rubber should not harden under cold. These rules have been adopted for the Russian navy. — *Iron Age*, June 15, 1893.

GUTTA-PERCHA.

Specific gravity, 0.9693 to 0.981.
Weight per cubic foot, 60.56 to 61.32 pounds.
Weight per cubic inch, 0.560 to 0.567 oz.
Softens at 115 degrees F.
Becomes plastic at 120 degrees F.
Melts at 212 degrees F.

Oxidizes and becomes brittle, shrinks and cracks when exposed to the air, especially at temperatures between 70 and 90 degrees F.

Oxidation is hastened by exposure to light.

Oxidation may be delayed by covering the gutta-percha insulation with a tape which has been soaked in prepared Stockholm tar.

Where gutta-percha is kept continually under water there is no noticeable deterioration, and the same applies where gutta-percha leads are covered with lead tubing.

Stretched gutta-percha, such as is used for insulating cables, will stand a strain of 1,000 pounds per square inch before any elongation.

The breaking strain is about 3,500 pounds per square inch.

The tenacity of gutta-percha is increased by stretching it.

Where $D =$ diameter of gutta-percha insulation, and $d =$ diameter of conductor of copper (both dimensions in mils) the weight of gutta-percha per knot is $\frac{D^2 - d^2}{491}$.

When $w =$ weight of stranded copper conductor per knot in pounds, and $W =$ weight of gutta-percha per knot in pounds, then outer diameter

$$= \sqrt{70.4\,w + 491\,W} \text{ mils.}$$

If the conductor is solid, then, outer diameter

$$= \sqrt{55\,w + 491\,W} \text{ mils.}$$

After one minute's electrification, the **insulation resistance** per knot of best quality gutta-percha insulated cable will be,

$$= 769\,(\log D - \log d.) \text{ megohms at } 75° \text{ F.}$$

Resistance of Gutta-Percha under Pressure. — The resistance of gutta-percha under pressure increases according to the following formula, when $R =$ the resistance at the pressure of the atmosphere, and r the resistance at p pounds per square inch.

$$r = R\,(1 + 0.00023\,p).$$

Resistance of Gutta-Percha decreases with Rise of Temperature. — The resistance of gutta-percha decreases, as per the following formula as the temperature rises, where

R = resistance at the low temperature,
r = resistance at the high temperature,
t = difference in temperature, degrees F.;

then $\log R = \log r - t \log 0.9399,$
and $\log r = \log R + t \log 0.9399.$

Capacity and Resistance of Gutta-Percha.

The *resistance* of a plate of gutta-percha one foot square and .001 inch thick = 1.066 megohms at 75° F. The *electrostatic capacity* of the same piece at the same temperature is .1356 microfarads.

The product of the resistance in megohms by the electrostatic capacity in microfarads, both taken at 75° F., after one minute's electrification = .144

Ratio of $D \div d$ *for strand and solid conductors.*

For stranded conductor insulated with gutta-percha,

$$\frac{D}{d} = \sqrt{1 + 6.97 \frac{W}{w}}.$$

For solid conductor insulated with gutta-percha,

$$\frac{D}{d} = \sqrt{1 + 8.93 \frac{W}{w}}.$$

In which D = outer diameter of cable,
and d = diameter of conductor,
and W and w = weight of gutta-percha and of conductor respectively in pounds.

The *approximate electrostatic capacity* of a gutta-percha insulated cable per knot is

$$\frac{0.1877}{\log D - \log d} \text{ microfarads.}$$

The *electrostatic capacity* of a gutta-percha insulated cable compared with one of the same size insulated with india rubber is about as 120 is to 100.

Jointing Gutta Percha Covered Wire.

First remove the gutta-percha for about two inches from the ends of the wires which are to be jointed. Fig. 4.

FIG. 4.

Next cross the wires midway from the gutta-percha, and grasp with the pliers. Fig. 5.

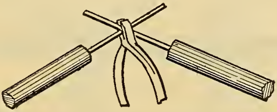


FIG. 5.

Then twist the wires, the overlapping right-hand wire first, and then, reversing the grip of the pliers, twist the left-hand wire over the right. Cut off the superfluous ends of the wires and solder the twist, leaving it as shown in Fig. 6.

FIG. 6.

Next warm up the gutta percha for about two inches on each side of the twist. Then, first draw down the insulation from one side, half way over the twisted wires, Fig. 7, and then from the other side in the same way, Fig. 8.

FIG. 7.

FIG. 8.

Then tool the raised end down evenly over the under half with a heated iron. Then warm up the whole and work the "drawdown" with the thumb and forefinger until it resembles Fig. 9. Now allow the joint to cool and set.

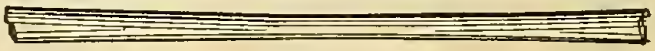


FIG. 9.

Next roughen the drawdown with a knife, and place over it a thin coating of Chatterton's compound for one inch, in the center of the drawdown, which is also allowed to set.

Next cut a thick strip of gutta-percha, about an inch wide and six inches long, and wrap this, after it has been well warmed by the lamp, evenly over the center of the drawdown. Fig. 10.

FIG. 10.

The strip is then worked in each direction by the thumb and forefinger over the drawdown until it extends about 2 inches from center of drawdown. Then tool over carefully where the new insulation joins the old, after which the joint should be again warmed up and worked with the forefinger and thumb as before. Then wet and soap the hand, and smooth and round out the joint as shown in Fig. 11.

FIG. 11.

Between, and at every operation, the utmost care must be exercised to remove every particle of foreign matter, resin, etc.

Joints in Rubber Insulated Cables.

Preparation of Ends.—Remove the outside protecting braid or tape, and bare the conductor of its rubber insulation for two or three inches back from the end. Clean the metal carefully by scraping with a knife or with sandpaper.

Metal Joint.—If solid conductor, scarf the ends with a file so as to give a good long contact surface for soldering. If conductor is stranded, carefully spread apart the strands, cutting out the centres so conductors can be butted together, the loose ends interlacing as in Fig. 9, and bind wires down tight as in Fig. 10. with gas or other pliers. Solder carefully, *using no acid;* resin is the best, although jointers often use a spermaceti candle as being handy to use and easy to procure. Large cables are easiest soldered by dipping the joint into a pot of molten solder, or by pouring the molten metal over the joint.

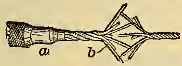


FIG. 9.

FIG. 10.

The insulation of all kinds of joints is done in the same manner, the only difference in the joint being the manner in which the conductors are joined together. Following are some of the styles of joining conductors, which are afterward insulated with rubber, and covered with lead when necessary.

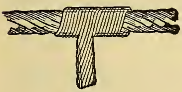


FIG. 11.

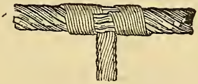
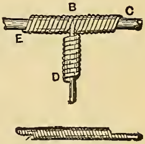
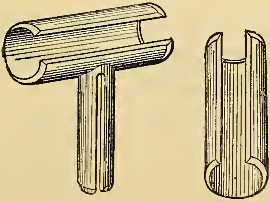


FIG. 12.



FIGS. 13–14.

Seeley's Cable Connectors.—The cuts below show a style of copper connectors very handy in joining cables. They are copper tinned over, and after putting in place can be "sweated" on with solder; when dry can be insulated as previously described.



FIGS. 15–16.

Insulating the Joint.—Jointers must have absolutely dry and clean hands, and all tools must be kept in the best possible condition of cleanliness. Clean the joint carefully of all flux and solder; scarf back the rubber insulation like a lead-pencil for an inch or more with a sharp knife.

Carefully wind the joint with three layers of pure unvulcanized rubber, taking care not to touch the strip with the hands any more than necessary; over this wind red rubber strip ready for vulcanizing. Lap the tape upon the taper ends of the insulation, and make the covering of the same diameter as the rubber insulation on the conductor, winding even and round. Cover the rubber strip with two or three layers of rubber-saturated tape.

Lead covering.—If the insulation is covered and protected by lead, a loose sleeve is slipped over one end before jointing, and slipped back over the joint when the insulation is finished, a plumber's wiped joint being made at the ends.

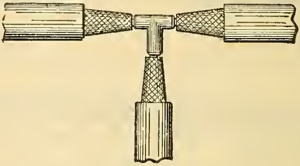


FIG. 17.

Joints in Waring Cables.—This cable is covered with cotton, thoroughly impregnated with a composition of hydro-carbon oils applied at high temperature, the whole being covered with lead to protect the insulation. The insulating properties of this covering are very high if the lead is kept intact.

Metal joints are made as usual, and a textile tape may be used for covering the bare copper. A large lead-sleeve is then drawn over the joint, and wiped onto the lead covering at either end; then the interior space is filled with a compound similar to that with which the insulation is impregnated.

Joints in Paper Insulated Cables.—This cable is covered or insulated with narrow strips of thin manila paper wound on spirally, after which the whole is put into an oven and thoroughly dried, then plunged into a hot bath of resin oil, which thoroughly impregnates the paper. This insulation is not the highest in measurement, but the electrostatic capacity is low and the breakdown properties high. When used for telephone purposes the paper is left dry, and is wound on the conductor very loosely, thus leaving large air spaces and giving very low electrostatic capacity.

Joints are made as in the Waring cable by covering the conductor with paper tape of the same kind as the insulation, then pulling over the lead sleeve, which is finally filled with paraffine wax.

Hundreds of miles of such cables being thus employed at pressures ranging from 500 to 10,000 volts—notably in the Metropolitan district of New York.

Cost of Straight or Sleeve Joints Insulated with Rubber.

On rubber-insulated, lead-covered cable.

Plumber	1 hour	.25
Insulator	½ hour	.15
Helper	1 hour	.15
Red rubber	1 oz. @ $1.00 per lb.	.07
Pure rubber	1 oz. @ $2.00 per lb.	.15
Grimshaw tape	1 oz. @ .50 per lb.	.03

Copper sleeve		.035
Lead sleeve		.06
Solder	1½ lbs. @ .20	.30
Pasters	2	.005
Coal		.10
Candle (for flux)		.01
Total		$1.31

Cost of T Joint on Rubber Insulated Cable.

T on rubber-insulated lead-covered cable.

Plumber	1½ hour		$.375
Insulator	¾ hour		.225
Helper	1½ hour		.225
Red rubber	1½ oz. @	$1.00 per lb.	.11
Pure rubber	1½ oz. @	2.00 per lb.	.23
Grimshaw tape	1½ oz. @	.50 per lb.	.05
Solder	2 lbs. @	.20 per lb.	.40
Lead T			.26
Copper T			.075
Pasters			.0075
Candle			.0125
Coal			.10
Total			$2.07

UNDERGROUND ELECTRICAL CONSTRUCTION.

Mr. Louis A. Ferguson, in paper before the *National Electric Light Association* in May, 1899, gives the results of his observations as to the cost of laying and maintaining underground conductors. Labor, fittings, paving, and laying one length of Edison main tube costs from $5.45 in unimproved streets, with no paving, to $29.81 in asphalt. The annual cost of supervision and maintenance amounts to 1.9% per annum of the original investment.

The total cost per duct foot of laid conduit of various types is given in the following table, where the higher price is for asphalt pavement, and the lower one for no pavement.

National conduit	In groups of 2 or 4	16.74 to 57.24 cents.
Francis conduit	" "	14.66 to 55.16 "
Lithocite conduit	" "	15.18 to 55.68 "
Camp tile	" "	14.14 to 54.64 "
Three-inch iron pipe	" "	22.50 to 66.00 "

Manholes as used in Chicago cost for size 2′ × 2′ × 3′ from $32.18 to $38.63; for size 8′ × 8′ × 8′ $194.65 to $224.72.

LAW OF B. & S. GAUGE.

The absence of a wire table may often be compensated for by remembering the following approximate facts concerning the B. & S. gauge.

Diameter of No. 10 wire = .1 inch.
Resistance of No. 10 per 1000 feet = 1 ohm.
Weight of No. 10 per 1000 feet = 31.37 lbs.

Diameters are halved for every six units increase in gauge No.; i.e., No. 16 has half the diameter of No. 10, and No. 4 has twice the diameter of No. 10. Accordingly cross-sectional areas double at every decrease of three in the gauge number.

The gauge numbers correspond to cross-sections and conductivities which vary as an inverse geometrical progression having a ratio of 1.26.

FUSING EFFECTS OF ELECTRIC CURRENTS.

By W. H. Preece, F. R. S. See "Proc. Roy. Soc.," vol. xliv., March 15, 1888.

The Law — $I = ad^{\frac{3}{2}}$, where I, current; a, constant; and d, diameter — is strictly followed; and the following are the final values of the constant "a," for the different metals as determined by Mr. Preece: —

	Inches.	Centimeters.	Millimeters.
Copper	10,244	2,530	80.0
Aluminum	7,585	1,873	59.2
Platinum	5,172	1,277	40.4
German Silver. . . .	5,230	1,292	40.8
Platinoid	4,750	1,173	37.1
Iron	3,148	777.4	24.6
Tin	1,642	405.5	12.8
Alloy (lead and tin 2 to 1)	1,318	325.5	10.3
Lead	1,379	340.6	10.8

Table Giving the Diameters of Wires of Various Materials Which Will Be Fused by a Current of Given Strength. — W. H. Preece, F. R. S. $d = \left(\frac{I}{a}\right)^{2/3}$

Current in Amperes.	Diameter in Inches.								
	Copper. $a = 10{,}244$.	Aluminum. $a = 7585$.	Platinum. $a = 5172$.	Ger. Silver. $a = 5230$.	Platinoid. $a = 4750$.	Iron. $a = 3148$.	Tin. $a = 1642$.	Tin-lead alloy. $a = 1318$.	Lead. $a = 1379$.
1	0.0021	0.0026	0.0033	0.0033	0.0035	0.0047	0.0072	0.0083	0.0081
2	0.0034	0.0041	0.0053	0.0053	0.0056	0.0074	0.0113	0.0132	0.0128
3	0.0044	0.0054	0.0070	0.0069	0.0074	0.0097	0.0149	0.0173	0.0168
4	0.0053	0.0065	0.0084	0.0084	0.0089	0.0117	0.0181	0.0210	0.0203
5	0.0062	0.0076	0·0098	0.0097	0.0104	0.0136	0.0210	0.0243	0.0236
10	0.0098	0.0120	0.0155	0.0154	0.0164	0.0216	0.0334	0.0386	0.0375
15	0.0129	0.0158	0.0203	0.0202	0.0215	0.0283	0.0437	0.0506	0.0491
20	0.0156	0.0191	0.0246	0.0245	0.0261	0.0343	0.0529	0.0613	0.0595
25	0.0181	0.0222	0.0286	0.0284	0.0303	0.0398	0.0614	0.0711	0.0690
30	0.0205	0.0250	0.0323	0.0320	0.0342	0.0450	0.0694	0.0803	0.0779
35	0.0227	0.0277	0.0358	0.0356	0.0379	0.0498	0.0769	0.0890	0.0864
40	0.0248	0.0303	0.0391	0.0388	0.0414	0.0545	0.0840	0.0973	0.0944
45	0.0268	0.0328	0.0423	0.0420	0.0448	0.0589	0.0909	0.1052	0.1021
50	0.0288	0.0352	0.0454	0.0450	0.0480	0.0632	0.0975	0.1129	0.1095
60	0.0325	0.0397	0.0513	0.0509	0.0542	0.0714	0.1101	0.1275	0.1237
70	0.0360	0.0440	0.0568	0.0564	0.0601	0.0791	0.1220	0.1413	0.1371
80	0.0394	0.0481	0.0621	0.0616	0.0657	0.0864	0.1334	0.1544	0.1499
90	0.0426	0.0520	0.0672	0.0667	0.0711	0.0935	0.1443	0.1671	0.1621
100	0.0457	0.0558	0.0720	0.0715	0.0762	0.1003	0.1548	0.1792	0.1739
120	0.0516	0.0630	0.0814	0.0808	0.0861	0.1133	0.1748	0.2024	0.1964
140	0.0572	0.0698	0.0902	0.0895	0.0954	0.1255	0.1937	0.2243	0.2176
160	0.0625	0.0763	0.0986	0.0978	0.1043	0.1372	0.2118	0.2452	0.2379
180	0.0676	0.0826	0.1066	0.1058	0.1128	0.1484	0.2291	0.2652	0.2573
200	0.0725	0.0886	0.1144	0.1135	0.1210	0.1592	0.2457	0.2845	0.2760
225	0.0784	0.0958	0.1237	0.1228	0.1309	0.1722	0.2658	0.3077	0.2986
250	0.0841	0.1028	0.1327	0.1317	0.1404	0.1848	0.2851	0.3301	0.3203
275	0.0897	0.1095	0.1414	0.1404	0.1497	0.1969	0.3038	0.3518	0.3413
300	0.0950	0.1161	0.1498	0.1487	0.1586	0.2086	0.3220	0.3728	0.3617

TABLES OF LENGTHS AND STRAINS IN SPANS OF WIRE AND SUSPENSION CABLES.

By John A. Roebling's Son's Co.

The formulæ used in calculating these tables of lengths and strains in spans of wire are those of a catenary of small deflection. They are given in Weisbach's "Mechanics of Engineering," page 297 (seventh American edition, translated by Eckley B. Coxe, A. M.).

In these tables the horizontal strain at the centre of the span is given. The strain at any other point equals the strain at the centre plus the weight of a length of the wire equal to the perpendicular distance of that point from the lowest point of the wire in the span. For ordinary spans this is negligible. For any given wire the longest possible span is one where the deflection is about one-third of the span.

The effects of temperature on the strains of wires in spans is at first sight so great as to render the other considerations of little importance. The table, page 209, is calculated on the assumption that the supports of the spans are perfectly rigid under all conditions of strain, and that the wire is inelastic. This is never true in practice. The changes in direction in a pole line afford a chance for the strains, due to a shortening of the wire by a fall in temperature, to be taken up by a bending of the supports.

If the elastic limit of hard-drawn copper wire of 60,000 pounds breaking strain be taken at 20,000 pounds, then S will equal 20,000 divided by 3.85, the weight of a piece of copper one foot long and one square inch in section. This makes S equal 5.195. Looking at the table of values of S, page 218, this value for a span of 130 feet comes between a deflection of .003 and .004. In the same way the allowable deflection for any other span of hard-drawn copper could be found, or for any other material, by substituting the proper terms for the elastic limit and the weight per foot given above. Some of the tables give data for telegraph wire, poles for which are spaced by the number per mile, while other tables are for conductors on poles spaced by the foot, such as electric light and power lines.

Actual deflection of wires of all construction depends much on the judgment of the linemen and the tools at hand.

The following gives the practice of some of the telegraph and telephone companies in their line construction :

SPECIFICATIONS FOR STANDARD CONSTRUCTION OF HARD-DRAWN COPPER.

Temperature in degrees Fahrenheit.	Spans in feet.					
	75	100	115	130	150	200
	Sag in inches.					
—30	1	2	2½	3⅜	4½	8
—10	1¼	2½	3	3¾	5	9
10	1½	2⅝	3½	4⅜	5¾	10¼
30	1¾	3	4	5⅛	6¾	12
60	2½	4¼	5½	7	9	15⅜
80	3⅛	5⅜	7	8⅝	11¼	18¾
100	4⅓	7	9	11	14	22¼

For spans between 400 and 600 feet, the dip shall be 1–40th of the span.

For spans between 600 and 1000 feet, the dip shall be 1–30th of the span.

Another company uses 40 poles to the mile, and in the East allows three-inch dip at centre of spans. In the West, where the variation of temperature is greater, 10 inches dip is allowed in summer, and 8 inches in the winter. This construction applies to both copper and iron wire, and has been found by actual experience to give satisfactory results:

The following formulæ were used in calculating the tables:

(1) $S \times \omega =$ horizontal strain on wire at centre of span.

$$S = \frac{y^2}{2x} + \frac{x}{6}. \tag{2}$$

$$l = y \left[1 + \tfrac{2}{3} \left(\frac{x}{y}\right)^2\right]. \tag{3}$$

$$x = 3S - \sqrt{9\,S^2 - 3y^2}. \tag{4}$$

$$x = \sqrt{\frac{3\,y\,l - 3\,y^2}{2}}. \tag{5}$$

In these formulæ

$y =$ one-half span.
$l =$ one-half length of wire in span.
$x =$ deflection at centre in same units as y.
$w =$ weight per foot of wire.

Suppose we have a span of 200 feet of hard-drawn copper wire weighing one pound to 10 feet, and a deflection of two feet or .01 of the span.

$$S = \left(\frac{100}{2}\right)^2 + \tfrac{2}{6}. \tag{2}$$

$$= 2500.33 +.$$

$$l = 100 \left[1 + \tfrac{2}{3} \left(\frac{2}{100}\right)^2\right]. \tag{3}$$

$$= 100.026\,6 +.$$

$$2l = 200.053 +.$$

$$x = 7501 - \sqrt{56{,}205{,}001 - 30{,}000}. \tag{4}$$

$$= 2.$$

$$x = \sqrt{\frac{30{,}008 - 30.006}{2}}. \tag{5}$$

$$= 2.$$

In calculating the table, page 209, the deflection of the line was determined at — 10° F. by formula 4, the value of S being 30,000 divided by 3.85 or 7,792. For the other temperatures the length of the wire was calculated from the following formula:

$$\text{Length} = l\,(1 + .000009\,3\ t)$$

Here t is the difference in temperature in degrees Fahrenheit.

By formula 5 the deflection corresponding to the new length was found.

The coefficients of linear expansion for each degree Fahrenheit are as follows:

Copper,	.000 009 3.
Iron,	.000 006 8.
Lead,	.000 016.

TEMPERATURE EFFECTS IN SPANS.

Spans in Feet.	Temperature in degrees Fahrenheit.								
	−10°	30°	40°	50°	60°	70°	80°	90°	100°
	Deflections in inches.								
50	.5	6	8	9	9	10	11	11	12
60	.7	8	10	11	11	12	13	13	14
70	1.	10	11	12	13	14	15	15	17
80	1.2	11	13	14	15	16	17	18	19
90	1.6	13	14	16	17	18	19	20	21
100	1.9	14	16	17	19	20	21	23	24
110	2.3	16	18	19	21	22	24	25	26
120	2.8	17	19	21	22	24	26	27	28
130	3.2	19	21	23	25	26	28	29	31
140	3.7	20	23	25	27	28	30	32	33
150	4.3	22	24	26	28	30	32	34	36
160	4.9	23	26	28	30	32	34	36	38
170	5.5	25	28	30	32	35	37	38	40
180	6.2	26	29	32	34	37	39	41	43
190	7.	28	31	34	36	39	41	43	45
200	7.7	31	33	36	38	41	43	45	48

Hard-drawn copper wire, 60,000 pounds strength per square inch.
Strain at — 10° F., 30,000 pounds per square inch.

The following tables give the dip in feet and inches of No. 0 B. & S. copper trolley wire between spans 125′ apart, and the strain in pounds for various temperatures:

Initial Maximum Strain 2000 Lbs.

Temperature F.	Dip.	Strain.
−10°	3.7″	2000 lbs.
0°	9.7″	774 "
32°	1′ 6″	415 "
50°	1′ 10″	340 "
70°	2′ 1″	300 "
90°	2′ 4″	267 "
10°	3.7″	2000 "
32°	1′ 2″	534 "
50°	1′ 6″	415 "
70°	1′ 10″	340 "
90°	2′ 1″	300 "
32°	3.7″	2000 "
50°	1′	623 "
70°	1′ 5″	440 "
90°	1′ 10″	340 "

From the preceding tables the proper height of eyebolts can be determined for various spans and temperatures with a given minimum height of trolley wire above the track.

Sags and Tensions for Suspended Wires.

The tension when the temperature is lowest, i.e., when the strain is greatest, should not exceed one-fourth of the breaking strain.

The sag varies with the material, but not with the gauge; the tension varies directly with the weight per foot of the wire.

$$d = \frac{l^2 w}{8t};\ d = \sqrt{\frac{3l(\mathrm{L} - l)}{8}};\ \mathrm{L} = l + \frac{8d^2}{3l};\ t = \frac{l^2 w}{8d}$$

where

l = span ;
w = weight of unit length ;
d = sag (or dip) ;
L = length of wire in span ;
t = tension;

also,

w for 400-lbs. Iron = .075758 lb. per foot.
" 150 " Copper = .028409 " "
" 100 " " = .018939 " "

and

Coefficient of expansion for iron = .00000683 per deg. F.
Coefficient of expansion for copper = .00000956 " "

TABLE OF TENSILE STRENGTH FOR COPPER WIRE.

Size of Wire, B. & S. Gauge.	Breaking Weight of Hard-Drawn.	Breaking Weight of Annealed.	Size of Wire, B. & S. Gauge.	Breaking Weight of Hard-drawn.	Breaking Weight of Annealed.
	Lbs.	*Lbs.*		*Lbs.*	*Lbs.*
0000	9971	5650	9	617	349
000	7907	4480	10	489	277
00	6271	3553	11	388	219
0	4973	2818	12	307	174
1	3943	2234	13	244	138
2	3127	1772	14	193	109
3	2480	1405	15	153	87
4	1967	1114	16	133	69
5	1559	883	17	97	55
6	1237	700	18	77	43
7	980	555	19	61	34
8	778	440	20	48	27

TABLE OF TOTAL LENGTH OF WIRE CORRESPONDING TO A GIVEN PERCENTAGE DEFLECTION.

Poles to Mile.	Spans in Feet.	Per Cent Deflection.											
		.004	.006	.008	.010	.015	.020	.025	.030	.035	.040	.045	.050
20	264.0	264.011	264.025	264.045	264.070	264.158	264.281	264.440	264.633	264.862	265.126	265.425	265.760
21	251.4	251.410	251.424	251.442	251.466	251.550	251.668	251.819	252.003	252.221	252.472	252.757	253.076
22	240.0	240.010	240.023	240.040	240.063	240.144	240.255	240.400	240.576	240.724	241.024	241.296	241.600
23	229.5	229.509	229.522	229.522	229.561	229.637	229.744	229.882	230.050	230.249	230.479	230.739	231.030
24	220.0	220.009	220.021	220.037	220.058	220.132	220.234	220.366	220.528	220.718	220.938	221.188	221.466
25	211.2	211.209	211.202	211.236	211.256	211.326	211.424	211.552	211.706	211.889	212.101	212.340	212.608
26	203.0	203.008	203.019	203.034	203.053	203.121	203.216	203.338	203.487	203.663	203.866	204.096	204.353
27	195.5	195.508	195.518	195.533	195.552	195.617	195.708	195.825	195.969	196.138	196.334	196.555	196.803
28	188.5	188.508	188.518	188.532	188.550	188.613	188.700	188.814	188.952	189.115	189.304	189.517	189.756
29	182.0	182.007	182.017	182.031	182.048	182.109	182.193	182.303	182.436	182.594	182.776	182.982	183.213
30	176.0	176.007	176.016	176.030	176.046	176.105	176.187	176.193	176.422	176.574	176.750	176.950	177.173
31	170.3	170.307	170.316	170.329	170.345	170.402	170.481	170.583	170.708	170.856	171.026	171.219	171.435
32	165.0	165.007	165.015	165.028	165.043	165.099	165.176	165.275	165.396	165.539	165.704	165.891	166.100
33	160.0	160.006	160.015	160.027	160.042	160.096	160.170	160.266	160.384	160.522	160.682	160.864	161.066
34	155.3	155.306	155.314	155.326	155.341	155.393	155.465	155.558	155.672	155.807	155.962	156.138	156.335
35	150.8	150.806	150.814	150.825	150.840	150.890	150.960	151.051	151.161	151.292	151.443	151.614	151.805
36	146.6	146.606	146.614	146.625	146.638	146.687	146.756	146.844	146.951	147.078	147.225	147.391	147.577
37	142.7	142.706	142.713	142.724	142.737	142.785	142.852	142.937	143.042	143.166	143.308	143.470	143.651
38	138.9	138.905	138.913	138.923	138.937	138.983	139.048	139.131	139.233	139.353	139.492	139.650	139.826
39	135.4	135.405	135.412	135.423	135.436	135.481	135 544	135.625	135.724	135.842	135.977	136.131	136.302
40	132.0	132.005	132.012	132.022	132.035	132.079	132.140	132.220	132.316	132.431	132.563	132.712	132.880
41	128.8	128.805	128.812	128.821	128.834	128.877	128.937	129.014	129.109	129.220	129.349	129.495	129.658
42	125.7	125.705	125.712	125.721	125.733	125.775	125.834	125.909	126.001	126.110	126.236	126.378	126.538
43	122.8	122.805	122.811	122.820	122.832	122.873	122.930	123.004	123.094	123.201	123.323	123.463	123.618
44	120.0	120.005	120.011	120.020	120.031	120.072	120.128	120.200	120.288	120.392	120.512	120.648	120.800
45	117.3	117.305	117.311	117.320	117.331	117.370	117.425	117.495	117.581	117.683	117.800	117.933	118.082
46	114.7	114.704	114.711	114.719	114.730	114.768	114.822	114.891	114.975	115.074	115.189	115.319	115.464
47	112.3	112.304	112.310	112.319	112.329	112.367	112.419	112.487	112.569	112.666	112.779	112.906	113.048
48	110.0	110.004	110.010	110.018	110.029	110.066	110.116	110.183	110.264	110.359	110.469	110.594	110.733
49	107.7	107.704	107.710	107.718	107.728	107.764	107.814	107.879	107.958	108.051	108.159	108.281	108.418
50	105.6	105.604	105.610	105.618	105.628	105.663	105.712	105.776	105.853	105.944	106.050	106.170	106.304

TABLE OF TOTAL LENGTH OF WIRE CORRESPONDING TO A GIVEN PERCENTAGE DEFLECTION.

Spans in Feet.	Per Cent Deflection.														
	.010	.015	.020	.025	.030	.035	.040	.045	.050	.055	.060	.065	.070	.075	.080
10	10.002	10.006	10.010	10.016	10.024	10.032	10.042	10.054	10.066	10.080	10.096	10.112	10.130	10.150	10.170
20	20.005	20.012	20.021	20.033	20.048	20.065	20.085	20.108	20.133	20.161	20.192	20.225	20.261	20.300	20.341
30	30.008	30.018	30.032	30.050	30.072	30.098	30.128	30.162	30.200	30.242	30.288	30.338	30.392	30.450	30.512
40	40.010	40.024	40.042	40.066	40.096	40.130	40.170	40.216	40.266	40.322	40.384	40.450	40.522	40.600	40.682
50	50.013	50.030	50.053	50.083	50.120	50.163	50.213	50.270	50.333	50.403	50.480	50.563	50.653	50.750	50.853
60	60.016	60.036	60.064	60.100	60.144	60.196	60.256	60.324	60.400	60.484	60.576	60.676	60.784	60.900	61.024
70	70.018	70.042	70.074	70.116	70.168	70.228	70.298	70.378	70.466	70.564	70.672	70.788	70.914	71.050	71.194
80	80.021	80.048	80.085	80.133	80.192	80.261	80.341	80.432	80.533	80.645	80.768	80.901	81.045	81.200	81.365
90	90.024	90.054	90.096	90.150	90.216	90.294	90.384	90.486	90.600	90.726	90.864	90.014	91.176	91.350	91.536
100	100.026	100.060	100.106	100.166	100.240	100.326	100.426	100.540	100.666	100.806	100.960	101.126	101.306	101.500	101.706
110	110.029	110.066	110.117	110.183	110.264	110.359	110.469	110.594	110.733	110.887	111.056	111.239	111.437	111.650	111.877
120	120.032	120.072	120.128	120.200	120.288	120.392	120.512	120.648	120.800	120.968	121.152	121.352	121.568	121.800	122.048
130	130.034	130.078	130.138	130.216	130.312	130.424	130.554	130.702	130.866	131.048	131.248	131.464	131.698	131.950	132.218
140	140.037	140.084	140.149	140.233	140.336	140.457	140.597	140.756	140.933	141.129	141.344	141.577	141.829	142.100	142.389
150	150.040	150.090	150.160	150.250	150.360	150.490	150.640	150.810	151.000	151.210	151.440	151.690	151.960	152.250	152.560
160	160.042	160.096	160.170	160.266	160.384	160.522	160.682	160.864	161.066	161.290	161.536	161.802	162.090	162.400	162.730
170	170.045	170.102	170.181	170.283	170.408	170.555	170.725	170.918	171.133	171.371	171.632	171.915	172.221	172.550	172.901
180	180.048	180.108	180.192	180.300	180.432	180.588	180.768	180.972	181.200	181.452	181.728	182.028	182.352	182.700	183.072
190	190.050	190.114	190.202	190.316	190.456	190.620	190.810	191.026	191 266	191.532	191.824	192.140	192.482	192.850	193.242
200	200.053	200.120	200.213	200.333	200.480	200.653	200.853	201.080	201.333	201.613	201.920	202.253	202.613	203.000	203.413

TABLE OF TOTAL LENGTHS OF WIRE CORRESPONDING TO A GIVEN PERCENTAGE DEFLECTION.

Spans in Feet.	Per Cent Deflection.													
	.085	.090	.095	.100	.110	.120	.130	.140	.150	.160	.170	.180	.190	.200
10	10.192	10.216	10.240	10.266	10.322	10.384	10.450	10.522	10.600	10.682	10.770	10.864	10.962	11.066
20	20.385	20.432	20.481	20.533	20.645	20.768	20.901	21.045	21.200	21.365	21.541	21.728	21.925	22.133
30	30.578	30.648	30.722	30.800	30.968	31.152	31.352	31.568	31.800	32.048	32.312	32.592	32.888	33.200
40	40.770	40.864	40.962	41.066	41.290	41.536	41.802	42.090	42.400	42.730	43.082	43.456	43.850	44.266
50	50.963	51.080	51.203	51.333	51.613	51.920	52.253	52.613	53.000	53.413	53.853	54.320	54.813	55.333
60	61.156	61.296	61.444	61.600	61.936	62.304	62.704	63.136	63.600	64.096	64.624	65.184	65.776	66.400
70	71.348	71.512	71.684	71.866	72.258	72.688	73.154	73.658	74.200	74.778	75.394	76.048	76.738	77.466
80	81.541	81.728	81.925	82.133	82.581	83.072	83.605	84.181	84.800	85.461	86.165	86.912	87.701	88.533
90	91.734	91.944	92.166	92.400	92.904	93.456	94.056	94.704	95.400	96.144	96.936	97.776	98.664	99.600
100	101.926	102.160	102.406	102.666	103.226	103.840	104.506	105.226	106.000	106.826	107.706	108.640	109.626	110.666
110	112.119	112.376	112.647	112.933	113.549	114.224	114.957	115.749	116.600	117.509	118 477	119.504	120.589	121.733
120	122.312	122.592	122.888	123.200	123.872	124.608	125.408	126.272	127.200	128.192	129.248	130.368	131.552	132.800
130	132.504	132.808	133.128	133.466	134.194	134.992	135.858	136.794	137.800	138.874	140.018	141.232	142.514	143.866
140	142.697	743.024	143.369	143.733	144.517	145.376	146.309	147.317	148.400	149.557	150.789	152.096	153.477	154.933
150	152.890	153.240	153.610	154.000	154.840	155.760	156.760	157.840	159.000	160.240	161.560	162.960	164.440	166.000
160	163.082	163.456	163.850	164.266	165.162	166.144	167.210	168.362	169.600	170.922	172.330	173.824	175.402	177.066
170	173.275	173.672	174.091	174.533	175.485	176.528	177.661	178.885	180.200	181.605	183.101	184.688	186.365	188.133
180	183.468	183.888	184.332	184.800	185.808	186.912	188.112	189.408	190.800	192.288	193.872	195.552	197.328	199.200
190	193.660	194.104	194.572	195.066	196.130	197.296	198.562	199.930	201.400	202.970	204.642	206.416	208.290	210.166
200	203.853	204.320	204.813	205.333	206.453	207.680	209.013	210.453	212.000	213.653	215.413	217.280	219.253	221.333

TABLE OF ACTUAL DEFLECTIONS OF WIRE IN FEET CORRESPONDING TO A GIVEN PERCENTAGE DEFLECTION.

Poles to Mile.	Length of Span in Feet.	Per Cent Deflections.											
		.004	.006	.008	.010	.015	.020	.025	.030	.035	.040	.045	.050
		Deflections in Feet.											
20	264.0	1.05	1.58	2.11	2.64	3.96	5.28	6.60	7.92	9.24	10.56	11.88	13.20
21	251.4	1.01	1.51	2.01	2.51	3.77	5.03	6.29	7.54	8.80	10.05	11.31	12.57
22	240.0	0.96	1.44	1.92	2.40	3.60	4.80	6.00	7.20	8.40	9.60	10.80	12.00
23	229.5	0.92	1.38	1.84	2.29	3.44	4.59	5.74	6.88	8.03	9.18	10.33	11.47
24	220.0	0.88	1.32	1.76	2.20	3.30	4.40	5.50	6.60	7.70	8.80	9.90	11.00
25	211.2	0.85	1.27	1.69	2.11	3.17	4.22	5.28	6.33	7.39	8.44	9.50	10.56
26	203.0	0.81	1.22	1.62	2.03	3.04	4.06	5.08	6.09	7.10	8.12	9.14	10.16
27	195.5	0.78	1.17	1.56	1.95	2.93	3.91	4.89	5.86	6.84	7.82	8.80	9.77
28	188.5	0.75	1.13	1.50	1.88	2.83	3.77	4.71	5.65	6.60	7.54	8.48	9.42
29	182.0	0.73	1.09	1.45	1.82	2.73	3.64	4.55	5.46	6.37	7.28	8.19	9.10
30	176.0	0.70	1.05	1.41	1.76	2.64	3.52	4.40	5.28	6.16	7.04	7.92	8.81
31	170.3	0.68	1.02	1.36	1.70	2.55	3.41	4.26	5.11	5.96	6.81	7.66	8.51
32	165.0	0.66	0.99	1.32	1.65	2.47	3.30	4.12	4.95	5.77	6.60	7.42	8.25
33	160.0	0.64	0.96	1.28	1.60	2.40	3.20	4.00	4.80	5.60	6.40	7.20	8.00
34	155.3	0.62	0.93	1.24	1.55	2.33	3.11	3.88	4.66	5.44	6.21	6.99	7.76
35	150.8	0.60	0.90	1.21	1.51	2.26	3.02	3.72	4.52	5.28	6.03	6.79	7.54
36	146.6	0.59	0.88	1.17	1.47	2.20	2.92	3.66	4.39	5.13	5.86	6.60	7.33
37	142.7	0.57	0.86	1.14	1.43	2.14	2.85	3.57	4.28	4.99	5.70	6.42	7.13
38	138.9	0.55	0.83	1.11	1.39	2.08	2.77	3.47	4.16	4.86	5.55	6.25	6.94
39	135.4	0.54	0.81	1.08	1.35	2.03	2.71	3.38	4.06	4.74	5.41	6.09	6.77
40	132 0	0.53	0.79	1.05	1.32	1.98	2.64	3.30	3.96	4.62	5.28	5.94	6.60
41	128.8	0.52	0.77	1.03	1.29	1.93	2.57	3.22	3.86	4.51	5.15	5.80	6.44
42	125.7	0.50	0.75	1.01	1.26	1.88	2.51	3.14	3.77	4.40.	5.02	5.66	6.28
43	122.8	0.49	0.74	0.98	1.23	1.84	2.45	3.07	3.68	4.30	4.91	5.53	6.14
44	120.0	0.48	0.72	0.96	1.20	1.80	2.40	3.00	3.60	4.20	4.80	5.40	6.00
45	117.3	0.47	0.70	0.94	1.17	1.76	2.34	2.93	3.52	4.11	4.69	5.28	5.86
46	114.7	0.46	0.69	0.92	1.15	1.72	2.29	2.87	3.44	4.01	4.58	5.16	5.73
47	112.3	0.45	0.67	0.90	1,13	1.68	2.25	2.81	3.38	3.94	4.49	5.05	5.61
48	110.0	0.44	0.66	0.88	1.10	1.65	2.20	2.75	3.30	3.85	4.40	4.95	5.50
49	107.7	0.43	0.65	0.86	1.08	1.62	2.15	2.69	3.23	3.77	4.30	4.85	5.38
50	105.6	0.42	0.63	0.84	1.06	1.58	2.11	2.64	3.16	3.70	4.22	4.75	5.28

TABLE OF ACTUAL DEFLECTIONS OF WIRE IN FEET CORRESPONDING TO A GIVEN PERCENTAGE DEFLECTION.

Feet.	Per Cent Deflections.														
	.010	.015	.020	.025	.030	.035	.040	.045	.050	.055	.060	.065	.070	.075	.080
	Deflections in Feet.														
10	.1	.150	.200	.250	.300	.350	.400	.450	.500	.550	.600	.650	.700	.750	.800
20	.2	.300	.400	.500	.600	.700	.800	.900	1.000	1.100	1.200	1.300	1.400	1.500	1.600
30	.3	.450	.600	.750	.900	1.050	1.200	1.350	1.500	1.650	1.800	1.950	2.100	2.250	2.400
40	.4	.600	.800	1.000	1.200	1.400	1.600	1.800	2.000	2.200	2.400	2.600	2.800	3.000	3.200
50	.5	.750	1.000	1.250	1.500	1.750	2.000	2.250	2.500	2.750	3.000	3.250	3.500	3.750	4.000
60	.6	.900	1.200	1.500	1.800	2.100	2.400	2.700	3.000	3.300	3.600	3.900	4.200	4.500	4.800
70	.7	1.050	1.400	1.750	2.100	2.460	2.800	3.150	3.500	3.850	4.200	4.550	4.900	5.250	5.600
80	.8	1.200	1.600	2.000	2.400	2.800	3.200	3.600	4.000	4.400	4.800	5.200	5.600	6.000	6.400
90	.9	1.350	1.800	2.250	2.700	3.150	3.600	4.050	4.500	4.950	5.400	5.850	6.300	6.750	7.200
100	1.	1.500	2.000	2.500	3.000	3.500	4.000	4.500	5.000	5.500	6.000	6.500	7.000	7.500	8.000
110	1.1	1.650	2.300	2.750	3.300	3.850	4.400	4.950	5.500	6.050	6.600	7.150	7.700	8.250	8.800
120	1.2	1.800	2.400	3.000	3.600	4.200	4.800	5.400	6.000	6.600	7.200	7.800	8.400	9.000	9.600
130	1.3	1.950	2.600	3.250	3.900	4.550	5.200	5.850	6.500	7.150	7.800	8.450	9.100	9.750	10.400
140	1.4	2.100	2.800	3.500	4.200	4.900	5.600	6.300	7.000	7.700	8.400	9.100	9.800	10.500	11.200
150	1.5	2.250	3.000	3.750	4.500	5.250	6.000	6.750	7.500	8.250	9.000	9.750	10.500	11.250	12.000
160	1.6	2.400	3.200	4.000	4.800	5.600	6.400	7.200	8.000	8.800	9.600	10.400	11.200	12.000	12.800
170	1.7	2.550	3.400	4.250	5.100	5.950	6.800	7.650	8.500	9.350	10.200	11.050	11.900	12.750	13.600
180	1.8	2.700	3.600	4.500	5.400	6.300	7.200	8.100	9.000	9.900	10.800	11.700	12.600	13.500	14.400
190	1.9	2.850	3.800	4.750	5.700	6.650	7.600	8.550	9.500	10.450	11.400	12.350	13.300	14.250	15.200
200	2.	3.000	4.000	5.000	6.000	7.000	8.000	9.000	10.000	11.000	12.000	13.000	14.000	15.000	16.000

TABLE OF ACTUAL DEFLECTIONS OF WIRE IN FEET CORRESPONDING TO A GIVEN PERCENTAGE DEFLECTION — *Continued.*

Feet.	Per Cent Deflections.													
	.085	.090	.095	.100	.110	.120	.130	.140	.150	.160	.170	.180	.190	.200
	Deflections in Feet.													
10	.850	.900	.950	1.000	1.100	1.200	1.300	1.400	1.500	1.600	1.700	1.800	1.900	2.000
20	1.700	1.800	1.900	2.000	2.200	2.400	2.600	2.800	3.000	3.200	3.400	3.600	3.800	4.000
30	2.550	2.700	2.850	3.000	3.300	3.600	3.900	4.200	4.500	4.800	5.100	5.400	5.700	6.000
40	3.400	3.600	3.800	4.000	4.400	4.800	5.200	5.600	6.000	6.400	6.800	7.200	7.600	8.000
50	4.250	4.500	4.750	5.000	5.500	6.000	6.500	7.000	7.500	8.000	8.500	9.000	9.500	10.000
60	5.100	5.400	5.700	6.000	6.600	7.200	7.800	8.400	9.000	9.600	10.200	10.800	11.400	12.000
70	5.950	6.300	6.650	7.000	7.700	8.400	9.100	9.800	10.500	11.200	11.900	12.600	13.300	14.000
80	6.800	7.200	7.600	8.000	8.800	9.600	10.400	11.200	12.000	12.800	13.600	14.400	15.200	16.000
90	7.650	8.100	8.550	9.000	9.900	10.800	11.700	12.600	13.500	14.400	15.300	16.200	17.100	18.000
100	8.500	9.000	9.500	10.000	11.000	12.000	13.000	14.000	15.000	16.000	17.000	18.000	19.000	20.000
110	9.350	9.900	10.450	11.000	11.100	13.200	14.300	15.400	16.500	17.600	18.700	19.800	20.900	22.000
120	10.200	10.800	11.400	12.000	12.200	14.400	15.600	16.800	18.000	19.200	20.400	21.600	22.800	24.000
130	11.050	11.700	12.350	13.000	13.300	15.600	16.900	18.200	19.500	20.800	22.100	23.400	24.700	26.000
140	11.900	12.600	13.300	14.000	14.400	16.800	18.200	19.600	21.000	22.400	23.800	25.200	26.600	28.000
150	12.750	13.500	14.250	15.000	15.500	18.000	19.500	21.000	22.500	24.000	25.500	27.000	28.500	30.000
160	13.600	14.400	15.200	16.000	16.600	19.200	20.800	22.400	24.000	25.600	27.200	28.800	30.400	32.000
170	14.450	15.300	16.150	17.000	17.700	20.400	22.100	23.800	25.500	27.200	28.900	30.600	32.300	34.000
180	15.300	16.200	17.100	18.000	18.800	21.600	23.400	25.200	27.000	28.800	30.600	32.400	34.200	36.000
190	16.150	17.100	18.050	19.000	19.900	22.800	24.700	26.600	28.500	30.400	32.300	34.200	36.100	38.000
200	17.000	18.000	19.000	20.000	21.000	24.000	26.000	28.000	30.000	32.000	34.000	36.000	38.000	40.000

TABLE OF STRAINS AT CENTRE OF SPANS RESULTING FROM A GIVEN PERCENTAGE DEFLECTION.

Poles to Mile.	Spans in Feet.	Per Cent Deflections.											
		.004	.006	.008	.010	.015	.020	.025	.030	.035	.040	.045	.050
		Multipliers.											
20	264.0	8250.176	5500.264	4125.352	3300.440	2200.660	1650.880	1321.100	1101.320	944.397	826.760	735.313	662.200
21	251.4	7856.417	5237.751	3928.460	3142.919	2095.628	1572.088	1258.047	1048.757	899.323	787.301	700.218	630.595
22	240.0	7500.160	5000.240	3750.320	3000.400	2000.600	1500.800	1201.000	1001.200	858.542	751.600	668.466	602.000
23	229.5	7172.028	4781.479	3586.243	2869.132	1913.073	1435.140	1148.456	957.364	820.981	718.717	639.221	575.662
24	220.0	6875.146	4583.553	3437.793	2750.366	1833.883	1375.733	1100.916	917.766	786.997	688.966	612.761	551.833
25	211.2	6600.140	4400.211	3300.281	2640.352	1760.528	1320.704	1056.880	881.056	755.517	661.408	588.250	529.760
26	203.0	6343.885	4229.369	3172.145	2537.838	1692.174	1269.426	1015.845	846.848	726.184	635.728	565.410	509.191
27	195.5	6109.505	4073.112	3054.948	2444.075	1629.655	1222.526	978.314	815.560	699.354	612.240	544.521	490.379
28	188.5	5890.750	3927.271	2945.563	2356.564	1571.304	1178.753	943.285	786.359	674.314	590.319	525.024	472.820
29	182.0	5687.621	3791.848	2843.992	2275.303	1517.121	1138.106	910.758	759.243	658.204	569.963	506.920	456.516
30	176.0	5500.117	3666.842	2750.234	2200.293	1467.106	1100.586	880.733	734.213	629.598	551.173	490.208	441.466
31	170.3	5321.988	3548.086	2661.164	2129.033	1419.592	1064.942	852.209	710.434	609.207	533.322	474.332	427.169
32	165.0	5136.360	3437.665	2578.345	2062.775	1375.412	1031.800	825.687	688.325	590.248	516.725	459.570	413.875
33	160.0	5000.106	3333.493	2500.213	2000.266	1333.733	1000.533	800.666	667.466	572.361	501.066	445.644	401.333
34	155.3	4853.228	3235.571	2426.769	1941.508	1294.554	971.142	777.147	647.859	555.548	486.347	432.552	389.544
35	150.8	4712.600	3141.817	2356.451	1885.251	1257.043	943.002	754.628	629.087	539.451	472.255	420.019	378.256
36	146.6	4581.347	3054.313	2290.820	1832.744	1222.033	916.738	733.610	611.566	524.426	459.102	408.321	367.721
37	142.7	4459.470	2973.059	2229.877	1783.987	1189.523	892.350	714.096	595.296	510.475	446.888	397.459	357.939
38	138.9	4340.717	2893.888	2170.497	1736.481	1157.847	868.588	695.078	579.444	496.881	434.988	386.875	348.407
39	135.4	4231.340	2820.968	2115.805	1692.725	1128.671	846.701	677.564	564.843	484.361	424.027	377.126	339.628
40	132.0	4125.088	2750.132	2062.676	1620.220	1100.330	825.440	660.550	550.660	472.198	413.380	367.656	331.100
41	128.8	4025.085	2683.462	2012.671	1610.214	1073.655	805.429	644.536	537.310	460.751	403.358	358.743	323.073
42	125.7	3928.208	2618.875	1964.230	1571.459	1047.814	786.044	629.023	524.378	449.661	393.650	350.109	315.297
43	122.8	3837.581	2558.456	1918.913	1535.204	1023.640	767.909	614.511	512.280	439.287	384.568	342.032	308.023
44	120.0	3750.080	2500.120	1875.160	1500.200	1000.300	750.400	600.500	500.600	429.271	375.800	334.233	301.000
45	117.3	3665.703	2443.867	1832.968	1466.445	977.793	733.516	586.988	489.336	419.612	367.344	326.713	294.227
46	114.7	3584.451	2389.698	1792.339	1433.941	956.120	717.257	573.977	478.490	410.311	359.202	319.471	287.705
47	112.3	3509.449	2339.695	1754.836	1403.937	936.114	702.249	561.967	468.478	401.726	351.686	312.786	281.685
48	110.0	3437.573	2291.776	1718.896	1375.183	916.941	687.866	550.458	458.883	393.498	344.483	306.380	275.916
49	107.7	3365.696	2243.857	1682.955	1346.429	897.769	673.484	538.948	449.288	385.271	337.280	299.974	270.147
50	105.6	3300.070	2200.105	1650.140	1320.176	880.264	660.352	528.440	440.528	377.758	330.704	294.125	264.880

RULE.—To find strain in pounds on wire of given span and deflection, multiply numbers in column answering to wire span and deflection by the weight per foot of wire.

TABLES OF STRAINS AT CENTRE OF SPANS RESULTING FROM A GIVEN PERCENTAGE DEFLECTION.

Spans in Feet.	Per Cent Deflections.										
	.001	.002	.003	.004	.005	.006	.007	.008	.009	.010	.015
	Multipliers.										
10	1250.001	625.003	416.671	312.506	250.008	208.343	178.583	156.263	138.903	125.016	83.358
20	2500.003	1250.006	833.343	625.013	500.016	416.686	357.166	312.526	277.807	250.033	166.716
30	3750.005	1875.010	1250.015	937.520	750.025	625.030	535.749	468.790	416.711	375.050	250.075
40	5000.006	2500.013	1666.686	1250.026	1000.033	833.373	714.332	625.053	555.615	500.066	333.433
50	6250.008	3125.016	2083.358	1562.533	1250.041	1041.716	892.915	781.316	694.519	625.083	416.791
60	7500.010	3750.020	2500.030	1875.040	1500.050	1250.060	1071.498	937.580	833.423	750.100	500.150
70	8750.011	4375.023	2916.701	2187.546	1750.058	1458.403	1250.081	1093.843	972.327	875.116	583.508
80	10000.013	5000.026	3333.373	2500.053	2000.066	1666.746	1428.664	1250.106	1111.231	1000.133	666.866
90	11250.015	5625.030	3750.045	2812.560	2250.075	1875.090	1607.247	1406.370	1250.135	1125.150	750.225
100	12500.016	6250.033	4166.716	3125.066	2500.083	2083.433	1785.830	1562.633	1389.038	1250.166	833.583
110	13750.018	6875.036	4583.388	3437.573	2750.091	2291.766	1964.414	1718.896	1527.942	1375.183	916.941
120	15000.020	7500.040	5000.060	3750.080	3000.100	2500.120	2142.997	1875.160	1666.846	1500.200	1000.300
130	16250.021	8125.043	5416.731	4062.586	3250.108	2708.463	2321.580	2031.423	1805.750	1625.216	1083.658
140	17500.023	8750.046	5833.403	4375.093	3500.116	2916.806	2500.163	2187.686	1944.654	1750.233	1167.016
150	18750.025	9375.050	6250.075	4687.600	3750.125	3125.150	2678.746	2343.950	2083.558	1875.250	1250.375
160	20000.026	10000.053	6666.746	5000.106	4000.133	3333.493	2857.329	2500.213	2222.462	2000.266	1333.733
170	21250.028	10625.056	7083.418	5312.613	4250.141	3541.836	3035.912	2656.476	2361.366	2125.283	1417.091
180	22500.030	11250.060	7500.090	5625.120	4500.150	3750.180	3214.495	2812.740	2500.269	2250.300	1500.450
190	23750.031	11875.063	7916.761	5937.626	4750.158	3958.523	3393.078	2969.003	2639.173	2375.316	1583.808
200	25000.033	12500.066	8333.433	6250.133	5000.166	4166.866	3571.661	3125.266	2778.077	2500.333	1667.166

TABLES OF STRAINS AT CENTRE OF SPANS RESULTING FROM A GIVEN PERCENTAGE DEFLECTION — *Continued.*

Spans in Feet.	Per Cent Deflections.											
	.020	.025	.030	.035	.040	.045	.050	.055	.060	.065	.070	.075
	Multipliers.											
10	62.533	50.041	41.716	35.772	31.316	27.852	25.083	22.818	20.933	19.339	17.973	16.791
20	125.066	100.083	83.433	71.545	62.633	55.705	50.166	45.637	41.866	38.678	35.947	33.583
30	187.600	150.125	125.150	107.317	93.950	83.558	75.250	68.456	62.800	58.017	53.921	50.375
40	250.133	200.166	166.866	143.090	125.266	111.411	100.333	91.275	83.733	77.356	71.895	67.166
50	312.666	250.208	208.583	178.863	156.583	139.263	125.416	114.094	104.666	96.695	89.869	83.958
60	375.200	300.250	250.300	214.635	187.900	167.116	150.500	136.913	125.600	116.034	107.842	100.750
70	437.733	350.291	292.016	250.408	219.216	194.969	175.583	159.732	146.533	135.373	125.816	117.541
80	500.266	400.333	333.733	286.180	250.533	222.822	200.666	182.551	167.466	154.712	143.790	134.533
90	562.800	450.375	375.450	321.953	281.850	250.674	225.750	205.370	188.400	174.051	161.764	151.125
100	625.333	500.416	417.166	357.726	313.166	278.527	250.833	228.189	209.333	193.391	179.738	167.916
110	687.866	550.458	458.883	393.498	344.483	306.380	275.916	251.008	230.266	212.730	197.711	184.708
120	750.400	600.500	500.600	429.271	375.800	334.233	301.000	273.827	251.200	232.069	215.685	201.500
130	812.933	650.541	542.316	465.044	407.116	362.086	326.083	296.646	272.133	251.408	233.659	218.291
140	875.466	700.583	584.033	500.816	438.433	389.938	351.166	319.465	293.066	270.747	251.633	235.083
150	938.000	750.625	625.750	536.589	469.750	417.791	376.250	342.284	314.000	290.086	269.607	251.875
160	1000.533	800.666	667.466	572.361	501.066	445.644	401.333	365.103	334.933	309.425	287.580	268.666
170	1063.066	850.708	709.183	608.134	532.383	473.497	426.416	387.921	355.866	328.764	305.554	285.458
180	1125.600	900.750	750.900	643.907	563.700	501.349	451.500	410.740	376.800	348.103	323.528	302.250
190	1188.133	950.791	792.616	679.679	595.016	529.202	476.583	433.559	397.733	367.442	341.502	319.041
200	1250.666	1000.833	834.333	715.452	626.333	557.055	501.666	456.378	418.666	386.782	359.476	335.833

TABLE OF STRAINS AT CENTRE OF SPANS RESULTING FROM A GIVEN PERCENTAGE DEFLECTION.

Spans in Feet.	Per Cent Deflections.														
	.080	.085	.090	.095	.100	.110	.120	.130	.140	.150	.160	.170	.180	.190	.200
	Multipliers.														
10	15.758	14.847	14.038	13.316	12.666	11.546	10.616	9.832	9.161	8.583	8.079	7.636	7.244	6.895	6.583
20	31.516	29.695	28.077	26.632	25.333	23.093	21.233	19.664	18.323	17.166	16.158	15.272	14.488	13.791	13.166
30	47.275	44.542	42.116	39.948	38.000	34.640	31.850	29.496	27.485	25.750	24.237	22.908	21.733	20.686	19.750
40	63.033	59.390	56.155	53.264	50.666	46.187	42.466	39.328	36.647	34.333	32.316	30.545	28.977	27.582	26.333
50	78.791	74.237	70.194	66.581	63.333	57.734	53.083	49.160	45.809	42.916	40.395	38.181	36.222	34.478	32.916
60	94.550	89.085	84.233	79.897	76.000	69.281	63.700	58.992	54.971	51.500	48.475	45.817	43.466	41.373	39.500
70	110.308	103.392	98.272	93.213	88.666	80.828	74.316	68.824	64.133	60.083	56.554	53.453	50.711	48.269	46.083
80	126.066	118.780	112.311	106.529	101.333	92.375	84.933	78.656	73.295	68.666	64.633	61.090	57.955	55.164	52.666
90	141.825	133.627	126.350	119.846	114.000	103.922	95.550	88.488	82.457	77.250	72.712	68.726	65.199	62.060	59.250
100	157.583	148.475	140.388	133.162	126.666	115.469	106.166	98.320	91.619	85.833	80.791	76.362	72.444	68.956	65.833
110	173.341	163.323	154.427	146.478	139.333	127.016	116.783	108.152	100.780	94.416	88.870	83.999	79.688	75.851	72.416
120	189.100	178.170	168.466	159.794	152.000	138.563	127.400	117.984	109.942	103.000	96.950	91.635	86.933	82.747	79.000
130	204.858	193.018	182.505	173.110	164.666	150.110	138.016	127.816	119.104	111.583	105.029	99.271	94.177	89.642	85.583
140	220.616	207.865	196.544	186.427	177.333	161.657	148.633	137.648	128.266	120.166	113.108	106.907	101.422	96.538	92.166
150	236.375	222.713	210.583	199.743	190.000	173.204	159.250	147.480	137.428	128.750	121.187	114.544	108.666	103.434	98.750
160	252.133	237.560	224.622	213.059	202.666	184.751	169.866	157.312	146.590	137.333	129.266	122.180	115.911	110.329	105.333
170	267.891	252.408	238.661	226.375	215.333	196.298	180.483	167.144	155.752	145.916	137.345	129.816	123.155	117.225	111.916
180	283.650	267.255	252.700	239.692	228.000	207.845	191.100	176.976	164.914	154.500	145.425	137.452	130.399	124.121	118.500
190	299.408	282.103	266.738	253.008	240.666	219.392	201.716	186.808	174.076	163.083	153.504	145.089	137.644	131.016	125.083
200	315.166	296.950	280.777	266.324	253.333	230.939	212.333	196.641	183.238	171.666	161.583	152.725	144.888	137.912	131.666

RULE.—To find strain in pounds on wire of given span and deflection, multiply numbers in column answering to wire span and deflection by the weight per foot of wire.

Notes.

Comparative Resistance of Woods (Addenbrooke). The measurements were made along the grain by inserting terminals two inches apart in sound, dry, well-seasoned pieces of the woods, each piece being 3″ × ⅞″ × ⅜″. Other tests across the grain gave results from 50 to 100 per cent higher.

Wood.	Megohms.	Wood.	Megohms.
Mahogany	48	Lignum Vitae	397
Pine	214	Walnut	478
Rosewood	291	Teak	734

BREAKING WEIGHTS COPPER AND SILICON BRONZE WIRES.

Breaking weight hard-drawn copper wire per 1000 C. M. = 47.12 lbs.

Breaking weight soft-drawn or annealed copper wire per 1000 C. M. = 26.69 lbs.

Breaking weight No. 0 B. & S. hard-drawn copper wire = 4973 lbs.

Breaking weight No. 0 B. & S. soft-drawn or annealed copper wire = 2817 lbs.

Breaking weight silicon bronze wire per square inch, 80920 lbs.

Breaking weight No. 4 B. W. G. silicon bronze wire, 3600 lbs.

Horse-power lost in copper conductor at a density of 1000 amperes per square inch cross section, is equal to the number of thousands of cubic inches of copper + 10%.

— By Prof. G. Forbes.

DIMENSIONS OF CROSS ARMS.

Regular size, 3¼ inches × 4½ inches, 1½-inch holes.
Special size, 4 inches × 5 inches, 1½-inch holes.
2-pin, 3 feet long; 4-pin, 4 or 5 feet long; 6-pin, 6 feet long.

CABLE TESTING.

CABLES.

Cables — Underground and Submarine.

The majority of the methods of tests and measurements given herein are applicable to aërial, underground, and submarine cables.

Insulation Resistance.

Direct Deflection Method, with Mirror Galvanometer.— This method, Fig. 1, is generally used in this country in underground and submarine work.

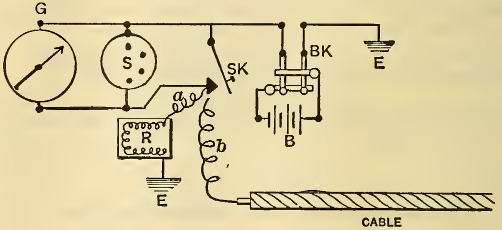


FIG. 1.

a and b = leads.
G = galvanometer, Thomson or D'Arsonval, mirror type.
S = shunts for G, usually $\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{1000}$.
B = battery, 20, 50, or 100 chloride silver cells.
R = resistance box of 100,000 ohms.
BK = battery reversing key.
SK = short-circuit key for G.

First connect a to lower contact point of SK, and take constant of G, using $\frac{1}{1000}$ shunt, and small number of cells, say 5 (depending upon the sensitiveness of G), with standard resistance R only in circuit, b being disconnected as shown. If 5 cells are used in taking constant, and 100 cells are to be used for test,

$$\text{Constant} = \frac{\text{G deflec.} \times \text{shunt} \times R \times 20}{1{,}000{,}000} = \text{megohms.}$$

After obtaining the constant, measure insulation resistance of lead b, by joining it to SK instead of a, disconnecting the far end of b from the cells. The result should be infinity; but if not, deduct this deflection from the deflection to be obtained in testing the cable proper. Now connect the far end of b to the conductor of the cable, the far terminal of latter being free. Then open SK carefully, and observe if there are any earth currents from the cable. If any, note deflection due to the same, and deduct from battery reading if in the same direction, or add to it if in opposite direction. Short-circuit G with SK, and close one knob of BK, using, say, the $\frac{1}{100}$ shunt. After a few seconds open SK; if spot goes off the scale, use a higher shunt. If deflection is low, use a lower shunt. After one minute's electrification, note the deflection. The result may be worked out from this reading, but the current should be kept on for three or five minutes longer, and readings taken at end of each minute. The deflection should decrease gradually. At the end of the last minute of test, open BK, and allow the cable to discharge fully. Then close *SK* and press the other knob of *BK*, reversing the battery. After a few moments, open *SK*, and take readings of deflections as before.

$$\text{The insulation resistance in megohms} = \frac{\text{constant}}{d \times S},$$

where d is the deflection at a given time, and S is the shunt used. If no shunt is used, $x = \frac{\text{constant}}{d}$.

Note that in the above constant, the ordinary constant is multiplied by 20 for the reason that the battery is increased 20-fold, or 5 :: 100, In case the same battery is used for testing as for obtaining the constant, then

$$\text{constant} = \frac{G \text{ deflec.} \times S \times R}{1{,}000{,}000}.$$

If there be no earth currents, the readings with opposite poles of battery to the cable should not vary appreciably at any given minute. Pronounced variation between the readings at given times and unsteady deflection indicate defective cable.

Insulation Resistance by Method of Loss of Charge.

The insulation resistance of a cable or other conductor having considerable capacity may be measured by its loss of charge. Let one end of the conductor be insulated, and the other end attached to an electrometer, in the manner shown in FIG. 2.

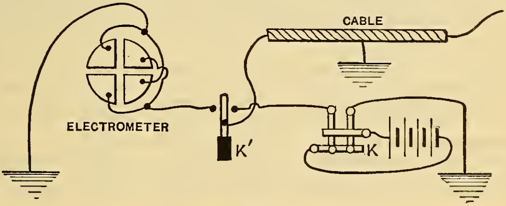


FIG. 2.

Let R = Insulation resistance in megohms per mile.
C = Capacity in microfarads per mile.
E = potential of cable as charged.
e = potential of cable after a certain time.

Depress one knob of key K, and throw key K' to the right, and charge the cable for one minute; then throw key K′ to the left, thus connecting the cable to the electrometer. Note the deflection E. Noting the movement of the spot for one minute, take reading e at end of minute, then

$$R = \frac{26.06}{C \log \frac{E}{e}}$$

If an electrometer is not conveniently at hand, use a reflecting galvanometer, and after charging cable as before, take an instantaneous discharge, noting deflection E due thereto. Recharge cable as before, then open K' and at end of one minute, the galvanometer having been disconnected from cable in the meantime, take another discharge-reading of cable e, and apply the same formula as before. If a condenser of low capacity be inserted between K' and the galvanometer, the latter need not be disconnected. The advantage of the use of the electrometer is that the actual loss of potential of the cable may be observed as it progresses.

Testing Joints of Cables by Clark's Method.

In the figure (FIG. 3) the letters refer to the parts as follows :

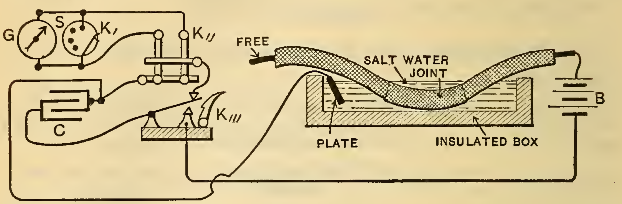


FIG. 3.

G is a high-resistance mirror galvanometer.
S is the shunt.
$K_{,}$ is the short-circuit key. It may be on the shunt box or separate.
$K_{,,}$ is a reversing key.
$K_{,,,}$ is a discharge key. ·
B the battery, usually 100 cells chloride of silver.
C is a $\frac{1}{3}$ microfarad standard condenser.

The joint to be tested is placed in a well-insulated trough, nearly filled with salt water. A copper plate attached to the lead wire is placed in the water to ensure a good connection with the liquid. The connections are made as shown in the figure, one end of the cable being free. To make test close $K_{,,,}$ for a half minute; then release it (first depressing one knob of key $K_{,,}$), thereby discharging the condenser *C*, through the galvanometer, and note the deflection, if any. A perfect piece of cable of the same length as the joint is then placed in the vessel, and if the results with the joint are practically equal to those obtained with the perfect cable, the joint is passed. When the deflection is very low, it is evident that the joint is sound, and it may then be considered unnecessary to compare it with the piece of cable. It is very important that the trough and apparatus be thoroughly insulated.

Electrometer Method. — This method possesses the advantage that it dispenses with a condenser, and thereby avoids possible misleading results due to electric absorption by that instrument. The connections for the electrometer test are shown in the accompanying figure (Fig. 4).

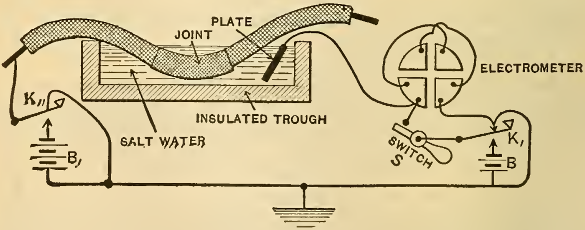


FIG. 4.

B is a battery of about 10 cells.
$B_{,}$ is a battery of 100 or more cells.

As in the preceding test, it is here highly essential that the insulation of the trough should be practically perfect, or at least known, so that if not perfect, proper deductions may be made for deflections due to it alone.

To test the insulation of the trough, depress $K_{,,}$ and close switch *S*. This charges the quadrants of the electrometer, and produces a steady deflection of its needle, and shows the potential due to the small battery *B*. Now open switch *S*, still keeping $K_{/}$ closed, and watch the deflection of needle for about two minutes. If the insulation of the trough is not perfect, there will be a circuit, so to speak, from the earth at the trough to the earth shown in the figure, and a fall in the deflection will be the result. If, however, the drop of potential is not more than is indicated by a fall of two or three divisions, the insulation of the trough will suffice. The electrometer is discharged by closing switch *S*, which short-circuits the quadrants, $K_{/}$ being open at this time. The joint is now connected as in the figure. Switch *S* is opened, and key $K_{//}$ depressed, thus charging the joint with the large battery $B_{/}$. This produces a quick throw of the needle, due to the charging of the joint. Next, keeping $K_{//}$ closed, discharge the electrometer by closing switch *S* for a moment. The switch is then opened, and if the joint is imperfect as to its insulation, the deflection will rise as the electricity accumulates in the trough. The deflections are recorded after one and two minutes, and are compared, as in the previous test, with a piece of perfect cable. The results obtained with the joint should not greatly exceed those of the cable proper.

Direct Deflection Method.—The insulation resistance of joints may also be tested by the direct deflection method already described, and when great accuracy is not required, is preferable, owing to its simplicity.

Capacity.

Capacity tests are usually made by the aid of standard condensers. Condensers, or sections of the plates of condensers, may be arranged in parallel or in series (cascade).

Arrangement of Condensers—Parallel.—Join like terminals of the condensers together, as in the figure; then the joint capacity of the condensers is equal to the sum of the respective capacities.

Capacity, $C = C + C_{/} + C_{//} + C_{///}$.

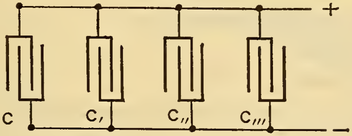


FIG. 5.

Condensers in Series or Cascade.—Join the terminals, as in Fig. 6. The total capacity of the condensers as thus arranged is equal to the reciprocal of the sum of the reciprocals of the several capacities, or

$$\text{Capacity in series} = \frac{1}{\frac{1}{c} + \frac{1}{c_{/}} + \frac{1}{c_{//}} + \frac{1}{c_{///}}}$$

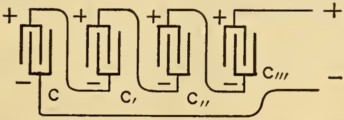


FIG. 6.

Condensers are now constructed so that these two methods of arranging the plates of a condenser may conveniently be combined in one condenser, thereby obtaining a much wider range of capacities.

Testing Capacity by Direct Discharge.—It is frequently desirable to know the capacity of a condenser, a wire, or a cable. This may be ascertained by the aid of a standard condenser, a trigger key, and an astatic or ballistic galvanometer. First, obtain a *constant.* This is done by noting the deflection d, due to the discharge of the standard condenser after a charge of, say, 10 seconds from a given E.M.F. Then discharge the other condenser, wire, or cable through the galvanometer after 10 seconds charge, and note the deflection d'. The capacity c' of the latter is then

$$c_{,} = c\frac{d_{,}}{d},$$

c being the capacity of the standard condenser.

Capacity by Thomson's Method.—This method is used with accurate results in testing the capacity of long cables. In the figure (Fig. 7)

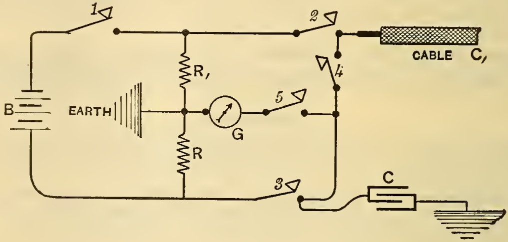


FIG. 7.

B = battery, say 10 chloride silver cells.
R = adjustable resistance.
$R_{,}$ = fixed resistance.
G = galvanometer.
C = standard condenser.
1, 2, 3, 4, 5, keys.

To test, close key 1, thus connecting the battery B, through the resistances R, $R_{,}$, to earth. Then

$$V : V_{,} :: R : R_{,}$$

where V and $V_{,}$ = the potentials at the junctions of the battery with R $R_{,}$.

Next close keys 2 and 3 simultaneously for, say 5 minutes, thereby charging the condenser to potential V, and the cable to potential $V_{,}$

Let C be the capacity in microfarads of the condenser, and $C_{,}$ capacity of cable, and let Q and $Q_{,}$ be their respective charges when the keys were closed. Then $$Q : Q_{,} :: VC : V_{,}C_{,}.$$

Open keys 2 and 3, keeping key 1 closed for say 10 seconds, to allow the charges of cable and condenser to mix or neutralize, in which case, if the charges are equal, there will be no deflection of the galvanometer when key 5 is closed. If there is a deflection, it is due to a preponderance of charge in C or $C_{,}$. Change the ratio of R to $R_{,}$, until no deflection occurs.

Then, $$VC = V_{,} C_{,}$$
or $$V_{,} : V :: C : C_{,}.$$
But we found $$V_{,} : V :: R_{,} : R$$
or $$R_{,} : R :: C : C_{,}.$$
and $$C_{,} = \frac{R}{R_{,}} C \text{ microfarads.}$$

Testing Capacities by Lord Kelvin's Dead-Beat, Multicellular Voltmeter.—Suitable for short lengths of cable.

MV = multicellular voltmeter.
AC = air condenser.

$B =$ battery.
$S =$ switch.
$Q =$ total charge in condenser and MV, due to battery.
$Ca =$ capacity of AC.
$Cb =$ capacity of cable.

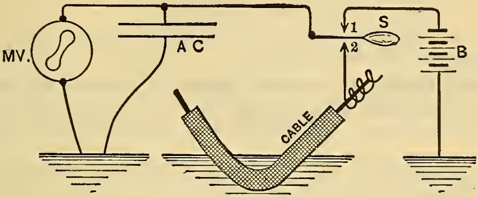


FIG. 8.

First close switch S on upper point 1, and charge MV and AC to a desired potential, V. Next move switch S from point 1 to lower point 2, and note the potential $V_{,}$ at MV.

Then $Q = V(C + Ca) = V_{,}(C + Ca + Cb)$, where C is the capacity of voltmeter. Ordinarily C can be neglected, as compared with the capacities of AC and the cable, in which case, by transposition,

$$Cb = (V - V_{,})\,Ca \div V_{,}.$$

Conductors of telephone cables are measured for capacity with the lead sheathing or armor and all conductors but the one under test grounded.

Locating Crosses in Cables or Aerial Wires.— Prof. Ayrton Method.— To locate the cross at d (Fig. 9) arrange the connections as shown. This is virtually a Wheatstone bridge, in which one of the wires, n, is one of the arms of same. Adjust r until $a(x + y) = br$, when r will be equal to $x + y$, if $a = b$.

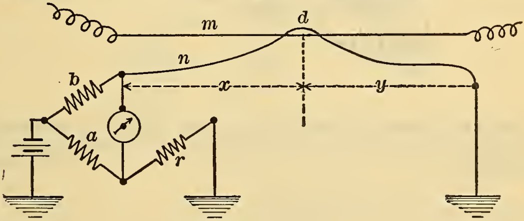


FIG. 9.

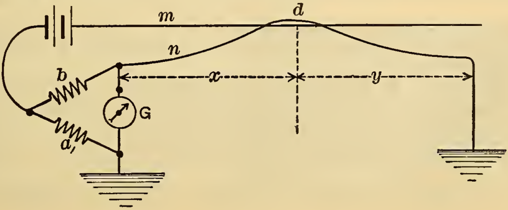


FIG. 10.

Next connect the battery to line m instead of to earth, as in Fig. 10, and adjust a until $ax = by$.

Then
$$\frac{x}{x+y} = \frac{b}{b+a}$$
and as $x + y = r$ in the first arrangement,

hence,
$$x = \frac{b \times r}{b+a}.$$

This test may be varied by transposing G and the battery, in Fig. 9, which is the old method of making this test.

Locating Faults in Aerial Wires or Cables by the Loop Test. — Two conductors are necessary for this test, or both ends of a cable must be available at the testing-point. Also it is assumed there is but one defect in the conductor. The resistance of the fault itself is negligible in this test.

Measure the resistance L of the loop by the ordinary Wheatstone bridge, — **Murray's Method.** Connect as in Fig. 11, in which a and b are the arms of a Wheatstone bridge, and y x are resistances to fault, the conductors being joined at J (in the case of aerial wire, for instance). Close key and note the deflection of needle due to earth current, if any. This is called the false zero.

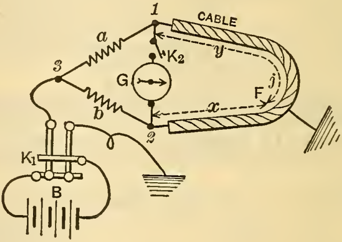


FIG. 11.

Now apply the positive or negative pole of the battery, by depressing one of the knobs of reversing key K, and balance to the false zero previously obtained by varying the resistance in arms a or b. Then, by Wheatstone bridge formula,
$$ax = by,$$
and
$$l = x + y$$
$$y = l - x$$
$$x = \frac{b}{a+b} l$$
$$y = \frac{a}{a+b} l.$$

To ascertain distance in knots or miles from 2 to F, divide x by resistance per knot or mile; to ascertain distance from 1 to F, divide y by resistance per knot or mile.

The foregoing test is varied in the case of comparatively short lengths of cable, in the manner shown in Fig. 12, in which the positions of the battery and galvanometer are transposed. Otherwise the test and formula are the same. It is advisable to reverse the connections of cable or conductors at 2 and 1, and take the average of results obtained in the different positions. In this latter method, battery B should be of low resistance, and well insulated.

Best conditions for making test, according to Kempe. — Resistance of b should be as high as necessary to give required range of adjustment in a.

Resistance of galvanometer should not be more than about five times the resistance of the loop.

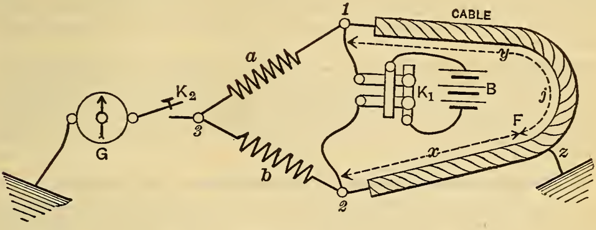


FIG. 12.

Varley Loop Test. — Measure resistance of looped cable or conductors as before. Then connect, as shown in Fig. 13, in which r is an adjustable resistance. Obtain false zero as before. Then close key K, and adjust r for balance. In testing, when earth current is present, the best results are obtained when the fault is cleared by the negative pole, and just before it begins to polarize.

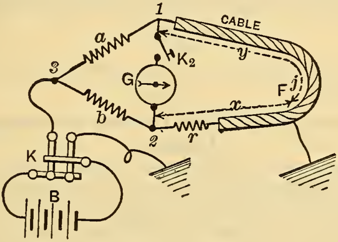


FIG. 13.

Then $$x = \frac{L - r}{2},$$

where x is the distance of fault, in ohms, from point 2 of cable proper.

Then $x \div$ by the resistance of the cable or conductor per knot or mile gives the distance of fault in knots or miles.

Locating Faults in Insulated Wires. — The following, so to speak, "rule of thumb," or point to point electro-mechanical methods of locating faults in unarmored cables, in which the defect is not a pronounced one, have been found successful.

Warren's Method. — The cable should be coiled on two insulated drums, one-half on each drum. The surface of the cable between the drums is carefully dried. One end of the conductor is connected to a battery which is grounded. The other terminal is connected to the insulated quadrants of an electrometer, the other pairs of quadrants of which are connected to the earth. Both drums being well insulated, no loss of potential is observed after three or four minutes. An earth wire is now connected first to one and then another of the drums, and the fault will be found on the drum which shows the greater fall on the electrometer. The coil is now uncoiled from the defective drum to the other drum, and tests are made at intervals until the defect is found.

F. Jacob coils the core from a tank to a drum. The battery is connected between the tank and the conductor, one end of which is free. A galvanometer is joined between the tank and drum, which need only be partially insulated. The needle shows when the fault has passed to the drum, and it can be localized by running the galvanometer lead along the insulated wire.

Insulating Cable Ends for Tests.—Much care must be exercised in order to insure accurate results in testing for insulation resistance. The ends should be well cleaned and thoroughly dry. The ends are for this purpose sometimes immersed in boiling paraffin wax for a few seconds; at other times they may be dried by the careful application of heat from a spirit lamp.

Copper Resistance, or Conductivity of Cables.

The copper resistance of the submarine and underground cables used in telephony and telegraphy is always tested at the factory, usually by the Wheatstone bridge method. In such a case both ends of the cable are accessible. When the cable is laid, if the far end is well grounded, the copper resistance may be measured, either by the Wheatstone bridge method, or by a substitution method, as follows. First, note the deflection due to copper resistance of conductor. Then substitute an adjustable resistance box and vary the resistance in the box until the deflection equals that due to cable. This latter resistance is the resistance of the cable. If there are earth currents on the cable, take readings of cable resistance with each pole of battery. Should there be any difference between the results obtained with the respective poles of the battery, the actual resistance will, according to F. Jacob, be equal to the harmonic mean of the two results, i.e.,

$$R = \frac{2\,rr'}{r + r'}$$

where R is the actual resistance, r is the resistance with + pole, r' is the resistance with — pole.

Testing Submarine Cable During Manufacture and Laying.

The Core of the cable, that is, the insulated copper conductor, is made, as a rule, in lengths of 2 knots, which are coiled upon wooden drums, and are then immersed in water at a temperature of 75° F. for about 24 hours. The coils are then tested for copper resistance, insulation resistance, and capacity; the results of which tests, together with data as to length of coils, weight, etc., are entered on suitably prepared blanks.

After the tests of some of the coils have been made, the jointing up of the cable begins, which is followed by the sheathing or armoring. The joints are tested after 24 hours immersion in water. During the sheathing process, continuous galvanometer or electrometer tests are made of the core, to see that no injury befalls the cable during this process. In fact, practically continuous tests of the cable for insulation resistance, copper resistance, and capacity should be made until the laying of the cable begins.

During laying, the cable should be tested continuously, and communication should be practically constant between the ship and the shore. An arrangement to permit such tests and communication is shown in Fig. 14.

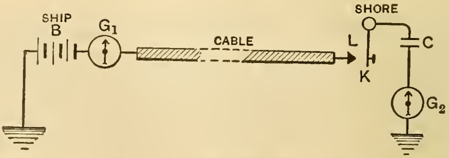


FIG. 14.

In this figure, G_1 is a marine galvanometer, B is a battery of about 100 cells on ship-board. In the shore station, L is a lever of key K, C is a condenser, G_2 is a galvanometer. Normally key K is open and the cable is charged by battery B. If, while the cable is being paid out a defect occurs in the insulation, or if the conductor breaks, a noticeable throw of the galvanometer follows, and the ship should be stopped and the cause ascertained. By pre-arrangement the lever of shore key K is closed, say every 5 minutes. thereby charging the condenser C, which causes a throw of the galvanometers' needles. If the ship or shore fails to get these periodic signals, or if they vary as to their strength, it indicates the occurrence of a defect. At the end of every hour the ship reverses the battery, which reverses the direction of the deflection of the galvanometers. If the ship desires to communicate with the shore, the battery is not reversed at the hour, or it is reversed before the hour. If the shore wishes to speak with the ship, the key K is opened and closed several times in succession. In either event, both connect in their regular telegraphing apparatus for conversation.

Compound Cables, that is, cables of more than one conductor, have their conductors connected in series for these tests. If there is an even number of conductors, two of them must be connected in parallel.

DYNAMOS.

CONTINUOUS CURRENT MACHINES.

Electro Motive Force.

The E.M.F. of a dynamo depends upon,

a, The speed of revolution of the armature,
b, The number of conductors on the armature,
c, The method of connecting same,
d, The total flux or lines of force forced through the armature core by the field magnets.

If the above four items be expressed in C.G.S. measure, the absolute E.M.F. will be expressed in the same units, which can be changed to volts by dividing by 100,000,000 or 10^8. Then for a two-pole dynamo,

Let $rev =$ revolutions of armature per second,
$n =$ number of external conductors all around the armature,
$\Phi =$ the total flux passing through the armature core from pole to pole,
$E =$ total E.M.F. generated by the machine,
$V =$ E.M.F. at machine terminals $= E - rI$ where $rI =$ volts drop or loss in the machine itself.

Then
$$E = \frac{rev. \times n \times \Phi}{10^8}$$

and
$$\Phi = \frac{E \times 10^8}{rev. \times n}.$$

For multipolar dynamos, in addition to the above symbols,

let $p =$ number of pairs of poles,
$\Phi_{/} =$ flux from one pole,

then in a *Series wound multipolar dynamo;*

$$E = \frac{rev. \times p \times n \times \Phi_{/}}{10^8}$$

and
$$\Phi_{/} = \frac{E \times 10^8}{rev. \times p \times n}.$$

In a *Multiple wound multipolar dynamo,*

$$E = \frac{rev. \times n \times \Phi_{/}}{10^8}$$

and
$$\Phi_{/} = \frac{E \times 10^8}{rev. \times n}.$$

ALTERNATING CURRENT MACHINES.

For alternating or periodically varying currents there are three values of the E.M.F. used, or of which the value is required :

a, The maximum value, or the top of the wave,
b, The instantaneous value of a point in the wave,
c, the virtual E.M.F., or $\sqrt{\text{mean}^2}$ value of the full wave.

In addition to the symbols used for continuous currents, let

$k =$ a constant varying from 1.1 to 2.5 depending on the relative widths of the armature coils and pole-pieces, usually taken as 2.22.

$\theta =$ angle through which the armature coil is turned at the instant taken.

Then, for *single-phase alternators*,

$$\text{maximum } E = \frac{2\pi \times n \times \Phi_{,} \times rev. \times p}{10^8}$$

In this case $n =$ number *turns* in series, and $\Phi =$ maximum flux enclosed per turn,

and $$\Phi_{,} = \frac{E\ max. \times 10^8}{2\pi \times n \times rev. \times p}$$

$$\text{Instantaneous } E = \frac{2\pi \times n \times \Phi_{,} \times rev. \times p \times sin\ \theta}{10^8}$$

In this case $n =$ number *turns* in series, and $\Phi =$ maximum flux enclosed per turn,

and $$\Phi_{,} = \frac{E\ inst. \times 10^8}{2\pi \times n \times rev. \times p \times sin\ \theta}$$

$$\text{Virtual } E = \frac{rev. \times p \times k \times \Phi_{,} \times n}{10^8}$$

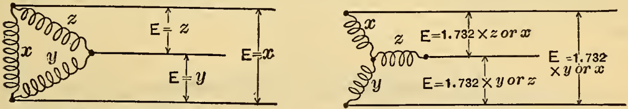
In this case $n =$ number of *conductors* joined in series with one another around the armature,

and $$\Phi_{,} = \frac{E\ vir. \times 10^8}{rev. \times p \times k \times n}$$

For *multiphase alternators*

$n =$ the number of conductors in series in a phase, and in *two-phase* machines the E.M.F.'s of each phase would be the same as in a single-phase dynamo.

In *three-phase* alternators the E.M.F. between terminals will depend upon the method of connecting the armature conductors. The two most common methods are called the delta connection and the Y or star connection, both shown in the following diagrams.



DELTA CONNECTION

Y OR STAR CONNECTION

FIGS. 1 and 2. Values of E.M.F. in three-phase connections when $x = y = z$.

In the delta-connected armature the E.M.F.'s between terminals are those generated in each coil, as shown in the diagram.

In the Y-connected armature the E.M.F. between any two terminals is the E.M.F. generated by one of the coils in that phase multiplied by the $\sqrt{3}$ or 1.732.

Two-phase circuits are sometimes connected as a three-phase circuit; that is, both phases have a common return wire. In this case the pressure between the two outgoing wires is $\sqrt{2} \times E$, and the current in the common return will be $I\sqrt{2}$, both conditions are on the assumption that E and I in each phase is the same.

Let $V =$ the E.M.F. at machine terminals where
$E =$ total E.M.F. generated. Then, in alternators the E.M.F.'s are shown in the following diagram, the load of the alternator being non-inductive, and the armature reaction being neglected, $2\pi\, n\, LI \times Ir = V$ at machine terminals.
$V = \sqrt{(2\pi n LI)^2 + (Ir)^2}$ when $L =$ coefficient of self-induction, $r =$ resistance of armature + external circuit.

FIG. 3.

CURRENT.

Continuous Current Machines.

The current in a dynamo depends upon

a. Its E.M.F.
b. The resistance of its internal circuit + the resistance of the external circuit on which it is working.
c. Any counter or opposing E.M.F. in circuit, such as storage batteries being charged or motors being run.

Then let

$E =$ total E.M.F. of the dynamo,
$e =$ counter E.M.F. of the circuit,
$R =$ internal resistance of the dynamo,
$r =$ resistance of external circuit,
$I =$ current in amperes flowing.

Then if the external circuit have no counter E.M.F., as when supplying current for incandescent lamps,

$$I = \frac{E}{R + r} = \text{amperes}$$

or, if a storage battery is being charged and its opposing E.M.F. $= e$

then
$$I = \frac{E - e}{R + r}$$

If $E_{\prime} =$ external E.M.F. of dynamo as measured by voltmeter at brushes at the load in question

then
$$I = \frac{E_{\prime}}{r}$$

Alternating Current Dynamos.

In alternating-current machines another factor in addition to the resistance of the circuits, internal and external, tends to retard or reduce the current, viz., the reactance of the circuits (see index for reactance and impedance).

Let $L =$ coefficient of self-induction of armature,
$L' =$ coefficient of self-induction of external circuit,
$n =$ number of cycles, $\sim$
$\omega = 2\pi\, n$,
$E_0 =$ open-circuit voltage of alternator,
other symbols same as for d.c. machine,
then, reactance $= \omega\, L$ ohms,
and impedance $= \sqrt{R^2 + (\omega\, L)^2}$ ohms,

In A.C. dynamos $E = \sqrt{\text{mean}^2}$

$$\text{or } E_{\prime} = I\left(r^2 + \overline{\omega L'^2}\right)^{\frac{1}{2}} = \frac{E_0}{\sqrt{\overline{R+r^2} + \overline{\omega L' + \omega L^2}}} \left(r^2 + \overline{\omega L'^2}\right)^{\frac{1}{2}}$$

The *inductance* L of a circuit in henrys is the ratio $\frac{\Phi \times n\,turns \times 10^{-9}}{I\,(c.g.s.)\,max.} = L$

or if I is expressed in virtual amperes then $L = \frac{\Phi \times n \times 10^{-8}}{\sqrt{2}\,I}$

$n\,\Phi = L\,I\,\sqrt{2}\,10^8$ and the E.M.F. of self-inductance is
$E = \sqrt{2}\,\pi\,n\,\Phi\,v\,10^{-8}$ where $v =$ cycles per second.
or $E = 2\pi\,v\,L\,I$ volts.
If $\omega = 2\pi v$, $\omega L =$ reactance of the circuit in ohms, and the E.M.F. of self-inductance of the circuit is $=$
$M = I\omega L =$ reactance voltage.

Energy in Balanced Three-phase Circuit.

In the following diagram of a Y connected multiphase generator and circuits, let

$e_{\prime} =$ E.M.F. of any phase in the armature,
$i_{\prime} =$ current of any phase in the armature,
$E =$ E.M.F. between mains,
$I =$ current in any main,

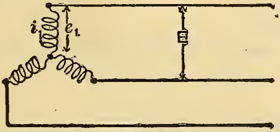


FIG. 4.

$w_{\prime} =$ energy of one phase of the armature,
$W =$ total energy,
$w_{\prime} = e_{\prime}\,i_{\prime}$
but $E = e_{\prime}\,\sqrt{3}$
$I = i_{\prime}$

$$W = 3\,w_{\prime} = \frac{3\,E\,I}{\sqrt{3}} = 1.732\,E\,I.$$

$$I = \frac{W}{1.732\,E}$$

In the following diagram of a delta connected multiphase generator and circuits, let

$e_2 = E$
$I = i_2\,\sqrt{3}$
$w_2 = e_2\,i_2$

$$W = 3\,w_2 = \frac{3\,E\,I}{\sqrt{3}} = 1.732\,E\,I$$

$$I = \frac{W}{1.732\,E}.$$

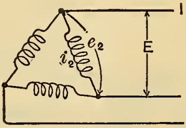


FIG. 5.

Therefore for any balanced three-phase system, the energy is equal to the product of the E.M.F. between any pair of mains and the current in one main, divided by $\sqrt{3}$; the result being multiplied by the cosine of the angle of lag; i.e., the power factor.

If $R =$ resistance per leg of Y-connected armature,
$r =$ resistance per phase of Δ connected armature,

then,

I^2R loss in Y-connected armature $= 3\,I_2R$

I^2R loss in Δ connected armature $= 3\left(\frac{I}{\sqrt{3}}\right)^2 r = I^2r.$

Energy in Three-phase Circuits.

$I_{,} =$ current in any one of the three wires of external circuit,
$i =$ current in one phase of the armature for delta connection,
$W =$ watts output of a balanced three-phase generator,
$1.732 = \sqrt{3}$
$.577 = 1 \div \sqrt{3}$
$E =$ volts between terminals (or lines) on either delta or Y system,
$v =$ volts of one phase of the armature if connected in " Y,"
$R =$ resistance per leg, of Y connected armature,
$r =$ resistance per phase of Δ connected armature,

$W = 3\,I_{,}\,v = \frac{3\,I_{,}\,E}{\sqrt{3}} = I'\,E\;1.732$ (either with Y or Δ armature.

For Δ

$$W = 3\,v_{,}\,i = 3\,v_{,}\,\frac{I_{,}}{\sqrt{3}}$$

for Δ

$$v_{,} = E$$

$\because W = \frac{3\,E\,I_{,}}{\sqrt{3}} = 1.732\,E\,I_{,}$ which shows statement in brackets to be true.

$$I_{,} = \frac{W}{E \times 1.732}$$

$I_{,} = 1.732\,i$ in delta system.

I^2R loss in Y connected armature $= 3\,I_{,}^2R.$

I^2R loss in Δ connected armature $= 3\left(\frac{I_{,}}{\sqrt{3}}\right)^2 r = I_{,}^2r.$

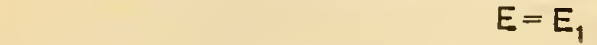


FIG. 6.

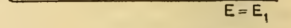
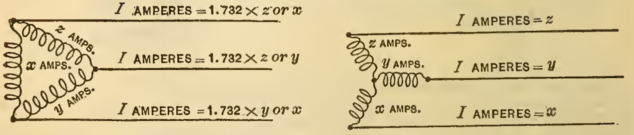


FIG. 7.

$$E = \sqrt{3}\,E_{,} = 1.732\,E_{,}.$$



Delta Connection. Star or Y Connection.

FIGS. 8 and 9. Values of current in three-phase connections, where $x = y = z$.

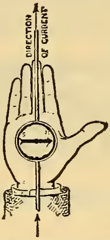
Direction of Current in a Conductor.

To determine in which direction the current in a conductor is flowing, place a compass *underneath* it. If the north pole of the needle points to the left, the current is flowing forward or away from the observer. With the compass *above* the conductor, if the north pole of the needle points to the right the current is still flowing away from the observer.

These results are often shown as in the accompanying cuts.

RIGHT HAND ABOVE THE CONDUCTOR
NEEDLE BELOW THE CONDUCTOR

FIG. 10.



RIGHT HAND BELOW THE CONDUCTOR
NEEDLE ABOVE THE CONDUCTOR

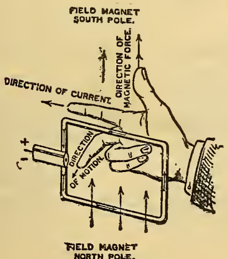
FIG. 11.

Direction of Current about an Electromagnet, and Location of its Poles.

If the direction of the current flowing in the wire of the coil is not known, then with a magnet find the north pole of the magnet, by approaching the compass to one of the poles; the north-pointing pole will be repelled by the north pole of the magnet, but attracted by the south pole.

Then by placing the right hand on the coil, with the thumb extended at right angles and pointing in the same direction as the north pole of the core, current will be flowing in the direction pointed by the fingers.

Of course, if we know the direction of the current, and wish to find the north pole of the magnet, placing the hand on top of the coil, as above, with the fingers extended in the direction in which the current is flowing, the north pole of the core is in the direction in which the thumb is extended. Another way is to look at pole of magnet. If current is going round right-handed you have a south pole; if left-handed, a north. See "Corkscrew" Rule.



DYNAMO - RIGHT HAND.

FIG. 12.

Direction of Current in a Dynamo Armature.

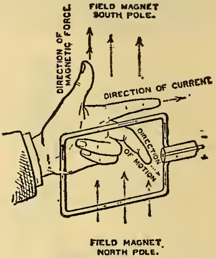
A simple rule is: facing the commutator of the dynamo, speaking now especially of the bipolar type, and assuming the left pole to be north or +, and the armature to be revolving counter clock-wise, then the current is flowing to the right *across* the face of the armature, or the left brush is positive, or the terminal from which current will flow, returning by the negative or right-hand brush.

Reversing the direction of rotation will reverse the polarity of the terminals.

The accompanying figure illustrates a graphic method, called Fleming's Right-hand Rule.

Direction of Rotation in a Motor.

Knowing the direction of current in the circuit, or which is the positive and which the negative terminals of the circuit, the direction of rotation of the armature can easiest be determined by use of the accompanying diagram (Fig. 13), which is called Fleming's " left-hand rule."



MOTOR LEFT HAND.

FIG. 13.

Field Magnets.

In the paragraph on the E.M.F. of dynamos, preceding, the symbol Φ is used to indicate the total flux or quantity of magnetic lines forced through the core of the armature by the field magnets.

This value of course depends upon the degree of excitation, i.e., the amount of current and number of turns of wire on the field magnets.

To determine this value in an existing machine. run it at a proper speed, and measure the E.M.F. with a voltmeter.

Then

$$\Phi = \frac{E \times 10^8}{rev. \times n} \text{ for continuous current machines,}$$

and

$$\Phi = \frac{E \times 10^8}{rev. \times n \times p \times k} \text{ for alternating current dynamos.}$$

and if $\mathcal{B} =$ magnetic induction, or Gauss = lines of force per square centimeter,

and $A =$ area of cross-section of armature core in square centimeters.

Then density of lines in armature $= \mathcal{B} = \dfrac{\Phi}{A}$.

Magnetic Circuit of a Dynamo.

The path over which lines of force flow, be it iron or air, is called the magnetic circuit, and is subject to laws analogous to those for electric conductors. It has its magnetic resistance, which is directly proportional to the length of the circuit, and inversely proportional to its cross-section and permeability, the latter being somewhat analogous to conductivity in an electric conductor.

In a dynamo the path through field-magnet cores, pole-pieces, field-yoke, air-gaps, and armature core, forms the magnetic circuit of that machine. The calculation of its value follows well-known laws, and is as easily carried out as the calculation of the resistance or conductance value of an electric conductor or path.

In any piece of iron

Let $l =$ length of the piece.

$s =$ cross-section of the same,

$\mu =$ permeability $= \mathcal{B} \div \mathcal{H}$,

then the

$$\text{magnetic resistance} = \frac{l}{s\,\mu} \text{ called } \textit{reluctance.}$$

In the magnetic circuit of a dynamo
let

$A_a =$ area of cross-section of armature core,

$A_g =$ area of cross-section of air-gap under the full pole-piece + a percentage for fringe,

$A_m =$ area of cross-section of magnet core,

$A_p =$ area of cross section of pole-piece,

$A_y =$ area of cross-section of yoke,

$l =$ length of any part,

$\Phi =$ total flux,

then

$$\text{Total reluctance} = \left(\frac{l_a}{A_a\mu_a}\right) + \left(\frac{2l_g}{\mu_g}\right) + \left(\frac{l_m}{A_m\mu_m}\right) + \left(\frac{l_p}{A_p\mu_p}\right) + \left(\frac{l_y}{A_y\mu_y}\right)$$

call this total reluctance R_m,

Then

$$\Phi = \frac{1.257 \times n \times I}{R_m} = \text{total flux through magnetic circuit,}$$

where $1.257 = \frac{4\pi}{10}$, and n = number of turns of wire, and I = current in amperes.

Application of Magnetic Circuit to Dynamo Design.

Let $\mathfrak{B}$ = flux per square centimeter, then in any part of the magnetic circuit of a dynamo,

$\mathfrak{B} = \frac{\Phi}{A}$, and after it is decided at what induction it is best to work the iron of the circuit the cross-section

$$A = \frac{\Phi}{\mathfrak{B}}.$$

The armature core is invariably of laminated soft annealed wrought iron or steel, while the magnet cores and yokes are often of cast iron, although most generally to-day some part, if not all, of the core is of mild cast steel. If cast iron is used, it is only necessary to increase the cross-section to satisfy the equation

$$A = \frac{\Phi}{\mathfrak{B}}$$

Experience has shown that there is a very considerable leakage of lines of force in an electro magnet; some cutting across without going through the armature path, others leaking across corners, etc. This leakage, amounting to 30 to 50 per cent of the the total flux, has to be made up by increasing the ampere turns of the magnets beyond that necessary to furnish the requisite flux for the armature part of the circuit, by a percentage or amount represented by the leakage.

This leakage has been determined for different types of field magnets by Edison and others, and a table of such values follows. In dynamo calculation the leakage value may be represented by v.

Stray Field in Dynamos.

Name of Dynamo.	Field.	Armature.	Remarks.	Value of v.
Edison-Hopkinson	Bipolar	Drum	Poles next to bed-plate	1.32
Edison (American)	Bipolar	Drum	Poles next to bed-plate	1.40
General Electric Co.	Multipolar	Drum	Direct driven	1.25
Kapp	Bipolar	Drum	Yoke next to bed-plate	1.30
Siemens	Bipolar	Drum	Yoke next to bed-plate	1.30
Manchester . . .	Double magnet 2 pole	Long ring	Bed and one pole cast together	1.49
Ferranti	Double magnet Multipolar	coreless disk	Ordinary pattern alternating.	2.00

The following formulæ are useful in calculating approximately the magnetic leakage in a dynamo:

1. The permeance, or reciprocal of magnetic reluctance, between two parallel opposed surfaces is

$$\frac{A_1 + A_2}{2d}$$

where d is the distance between the surfaces in centimeters, and where A_1 and A_2 are the areas of the surfaces in square centimeters (see Fig. 14).

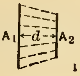


FIG. 14.

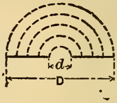


FIG. 15.

2. The permeance between two equal rectangular areas situated in the same plane, having corresponding sides parallel and a common axis of symmetry, is

$$\frac{L}{\pi} lg_e \left(\frac{D}{d}\right) \text{ if } \frac{D}{d} \text{ is large (see Fig. 15),}$$

$$\text{or } \frac{L}{\pi} lg_e \left\{1 + \frac{\pi (D - d)}{d}\right\} \text{ if } \frac{D}{d} \text{ is not large (see Fig. 16),}$$

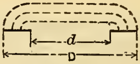


FIG. 16.

where $L =$ length of each rectangle, measured perpendicularly to common axis of symmetry (i.e., to the plane of the paper in the figure) in centimeters.

$d =$ distance between adjacent parallel sides in centimeters.

$D =$ distance between remote parallel sides in centimeters.

3. The permeance between two equal rectangular areas at right angles to one another, having one pair of sides in the one parallel to the corresponding pair in the other, is

$$\frac{2L_2}{\pi} lg_e \left\{1 - \frac{\pi L_1}{2D + d(\pi - 2)}\right\}.$$

where d, D, L_1, and L_2 are the lengths in centimeters of the dimensions shown in Fig. 17.

If $d = D$, the permeance in this case becomes

$$\frac{2L_2}{\pi} lg_e \left(1 - \frac{L_1}{D}\right)$$

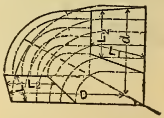


FIG. 17.

As the resistance of the two air-gaps in any dynamo is usually more than 80% of the total resistance of the magnetic circuit, the length of the iron part of the circuit is of little consequence excepting in cost of material, and is determined largely by the amount and style of winding necessary for the field magnet coils.

Other considerations govern the length of air-gap, such as sparking at the brushes, heating of pole-tips, heating of teeth in Paccinotti ring, regulation of voltage, current, etc., thus compelling the use of more magnetizing force to overcome that part of the circuit than all other parts combined.

If

$R_m =$ total reluctance of the magnetic circuit of a dynamo,

then

$$\text{ampere turns} = \frac{\Phi R_m}{1.257}$$

and, as it is necessary to know the ampere-turns required for each part of the circuit, the items may be tabulated as follows : —

Formulæ for Different parts of the Magnetic Circuit of a Dynamo.

Square centimetre units.

Armature core ; ampere-turns $= \Phi \times \frac{l_a}{A_a \times \mu_a} \div 1.257$

The two air-gaps ; ampere-turns $= \Phi \times \frac{2l_g}{A_g} \div 1.257$

Magnet cores ; ampere-turns $= \Phi \times \frac{l_m}{A_m \times \mu_m} \div 1.257$

Pole-pieces ; ampere-turns $= \Phi \times \frac{l_p}{A_p \times \mu_p} \div 1.257$

Yoke ; ampere-turns $= \Phi \times \frac{l_y}{A_y \times \mu_y} \div 1.257$

For square inch units the divisor will be $1.257 \times 2.54 = 3.193$, or better, multiply by $\frac{1}{3.193} = .3132$. The formulæ are then, *for square inch units*,

Armature core ; ampere-turns $= \Phi \times \frac{l_a}{A_a \times \mu_a} \times .3132$

The two air-gaps ; ampere-turns $= \Phi \times \frac{2l_g}{A_g} \times .3132$

Magnet cores ; ampere-turns $= \Phi \times \frac{l_m}{A_m \times \mu_m} \times .3132$

Pole-pieces ; ampere-turns $= \Phi \times \frac{l_p}{A_p \times \mu_p} \times .3132$

Yoke ; ampere-turns $= \Phi \times \frac{l_y}{A_y \times \mu_y} \times .3132$

Types of Dynamos as Determined by their Connections.

There are five types of dynamo connections in common use in the United States, viz.: —

1. Magneto machines.
2. Separately excited machines.
3. Series machines.
4. Shunt machines.
5. Compound wound machines ; this last having two classes, i.e., long shunt and short shunt.

The above types apply especially to continuous current dynamos, but *alternating* current machines are usually made separately excited as per No. 2, and are sometimes made *self-excited*, from separate coils on the armature, connected to a commutator on the shaft adjacent to the collecting-rings.

Other alternating current dynamos, in fact nearly all those used in the United States to-day for lighting, or for lighting and power purposes, that have been constructed since 1891, are of the type known as *composite wound*, in which the fields are separately excited from an outside source, and in addition to this a heavy wire series winding is also wound on the field coils, and a portion of the current from the main circuit is shunted through them, being passed through a commutator on the armature shaft first to be rectified.

This current is of course in proportion to that flowing in the main circuit, and adds excitation in proportion to the load, thus keeping the terminal pressure practically constant under all conditions. Alternators for transmission of power are not " composite " wound.

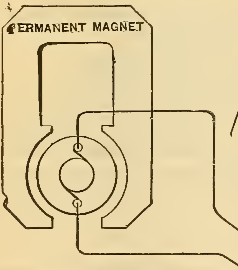
Compensated Revolving Field Alternators.

The General Electric Company in October, 1899, placed on the market a new type of multiphase alternator, which is claimed to overcome many of the faults common to the old style of machine, especially when used on combined lighting and motor loads. While it has been found a comparatively easy matter to compound and over-compound for non-inductive loads, it has been heretofore quite difficult to add excitation enough to compound for inductive loads which require considerably more field current than do loads of a non-inductive nature.

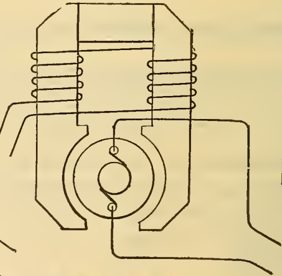
The following description is taken from the bulletin issued by the makers describing the machine, which is of the revolving field type :—

"The means by which this result is accomplished are as follows: The shaft of the alternator which carries the revolving field carries also the armature of the exciter, which has the same number of poles as the alternator, so that the two operate in synchronous relation. In addition to the commutator, which delivers current to the fields of both the exciter and the alternator, the exciter has three collector rings through which it receives current from one or several series transformers inserted in the lines leading from the alternator. This alternating current, passing through the exciter armature, reacts magnetically upon the exciter field in proportion to the strength and phase relation of the alternating current. Consequently the magnetic field and hence the voltage of the exciter, are due to the combined effect of the shunt field current and the magnetic reaction of the alternating current. This alternating current passes through the exciter armature in such a manner as to give the necessary rise of exciter voltage as the non-inductive load increases, and without other adjustment, to give a greater rise of exciter voltage with additions of inductive load."

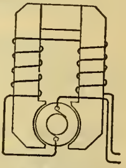
Following are cuts of the types mentioned above.



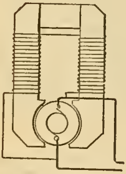
MAGNETO DYNAMO
FIG. 18.



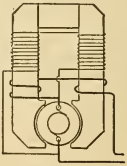
SEPARATELY EXCITED DYNAMO
FIG. 19.



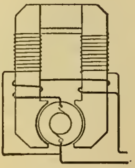
SERIES WOUND DYNAMO
FIG. 20.



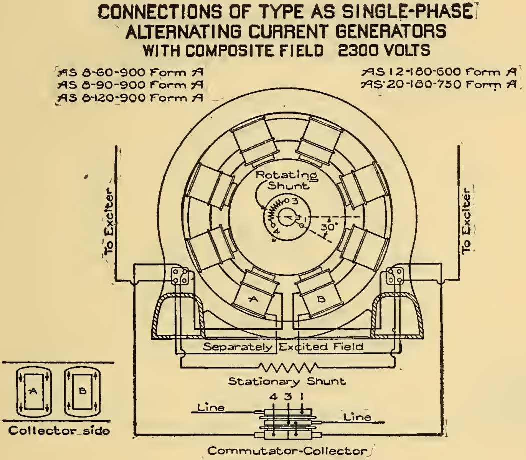
SHUNT WOUND DYNAMO
FIG. 21.



COMPOUND WOUND DYNAMO SHORT SHUNT
FIG. 22.



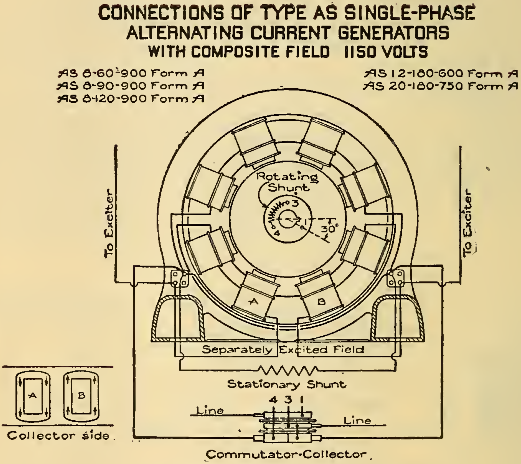
COMPOUND WOUND DYNAMO LONG SHUNT
FIG. 23.



MANNER OF PLACING SPOOLS.

The observer is supposed to be looking at faces of pole pieces marked A and B. The series field winding should be nearest the armature — that is, toward the observer. The arrows correspond to those on spool flanges, the spools being so placed that the arrows point in opposite directions on each succeeding spool.

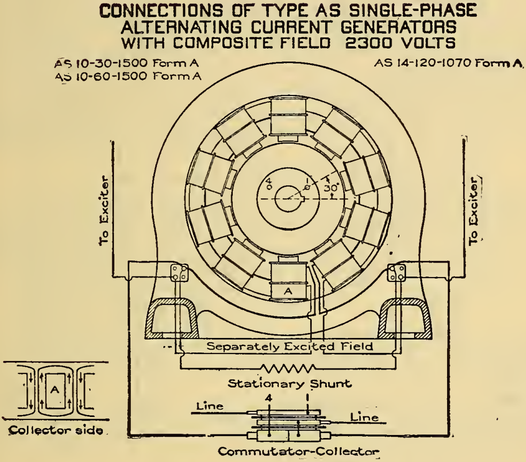
FIG. 24. — General Electric Composite wound alternator.



Manner of Placing Spools.

The observer is supposed to be looking at faces of pole pieces marked A and B. The series field winding should be nearest the armature—that is, toward the observer. The arrows correspond to those on spool flanges, the spools being so placed that the arrows point in opposite directions on each succeeding spool.

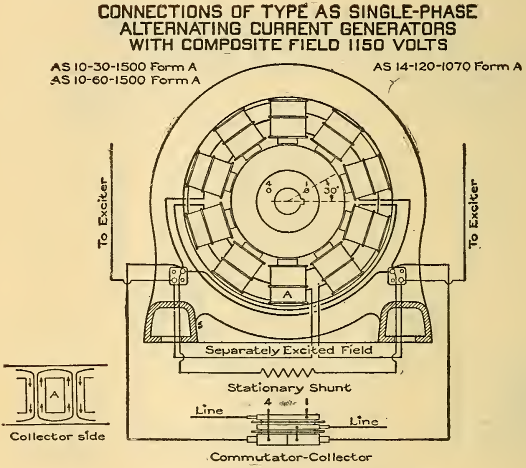
Fig. 25.—General Electric Composite wound alternator.



MANNER OF PLACING SPOOLS.

The observer is supposed to be looking at face of pole piece marked A. The series field winding should be nearest armature, that is, toward observer. The arrows correspond to those on spool flanges, the spools being so placed that the arrows point in opposite directions on each succeeding spool.

FIG. 26.—General Electric Composite wound alternator.



MANNER OF PLACING SPOOLS.

The observer is supposed to be looking at face of pole piece marked A. The series field winding should be nearest armature, that is, toward observer. The arrows correspond to those on spool flanges, the spools being so placed that the arrows point in opposite directions on each succeeding spool.

FIG. 27. — General Electric Composite wound alternator.

Magneto dynamos are now used in the United States only for ringing telephone bells, and for other signalling purposes.

Separately excited dynamos are seldom used, except for alternating current production; with the exception that one occasionally finds a street railway power-house where the shunt fields of all the dynamos are separately excited from one generator.

Series dynamos are used for arc lighting on constant current circuits, where many lamps are distributed over wide area The constant potential arc lamp, both for continuous and alternating currents, has reached such a degree of perfection and low cost as to encourage its use to a very great extent to displace the old style constant current lamp. Series dynamos are also often used as boosters to vary the voltage on a line automatically in proportion with load.

Shunt dynamos are used for charging storage batteries, and for large central stations supplying constant potential current, and this applies especially to the "Edison" stations throughout the country. It is easier to adjust the load between large machines when shunt wound, and in these large stations attendance is always at hand.

Compound wound dynamos are used in street railway power-houses, in order to keep the pressure somewhere near constant under the great variation in output; and are used to a very considerable extent, it may be said almost wholly, in isolated plant work, in order to save attendance and adjustment of the field rheostat.

DYNAMO CHARACTERISTICS.

Dr. John Hopkisson is said to have devised the "characteristic" or curve of properties of the dynamo, to show the results to be expected in a certain design of machine, and to indicate actual results after completion, although it is also said that Deprez first used the name.

The characteristics most commonly developed are as follows: —

1. Magnetization or saturation curve.
2. External characteristic.
3. Curve of magnetic distribution.

1. **Magnetization Curve.** — This curve is always determined for each new type of dynamo by reputable builders, and can easily be determined by any one having available a separate exciting current, a voltmeter, and an ammeter.

The turns of wire on the field remaining the same, it is sufficient to read the amperes in the field, voltage at the brushes, and revolutions of the armature. Curve, Fig. 28, following shows the result of such a test. In a case where, like the above, the dynamo is already in existence, the field is excited from some outside source, and the curve determined by gradual increase of the current in the field, and the volts at the brushes are read after each such change.

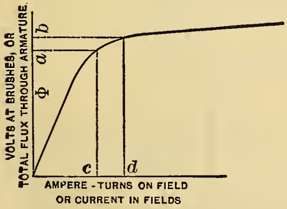


FIG. 28. Magnetization Curve.

The accompanying curve is the resultant of the magnetizing force necessary to force the flux through the following parts, in the case of a bipolar dynamo, all of which may be of different character: —

a. Armature core.
b. Two air-gaps.
c. Two polec-pieces.
d. Yoke.
e. And to overcome leakage of magnetic lines.

Individual curves for each of these parts can be predetermined by use of formulas for calculating the magnetic circuit of dynamos, and from a combination of those curves the curve shown above can be constructed, showing the aggregate excitation necessary to produce certain voltages.

For sample of such a composite curve the reader is referred to page 149 of the fifth edition of S. P. Thompson's book, *Dynamo Electric Machinery*.

This curve is valuable not only to show the character of one machine, but is useful to compare different machines by, and for that reason some standard ratio of the scales on which the curves are based should be settled upon.

2. **External Characteristic.**—This curve is a curve of results, in which the dynamo is excited from its own current, and with the speed constant, the terminal voltage is read for different values of load.

The curves for series, shunt, and compound wound machines all differ.

The observations are best plotted in a curve in which the ordinates represent volt values, and abscissæ amperes of load.

Series dynamo. In a series machine all the current flowing magnetizes the field, the volts increase with the current, and if fully developed the curve is somewhat like the magnetization curve, being always below it, however, due to the loss of pressure in overcoming internal resistance and armature reactions.

The following diagram (armature reaction being neglected) is a sample of the external characteristic of a series dynamo.

To construct this curve from an existing machine, the curve of terminal voltage can be taken from the machine itself by driving its armature at a constant speed, and varying the load in amperes.

The curve "drop due to internal resistance," sometimes called the "loss line," can be constructed by learning the internal resistance of the machine, and computing one or more values by ohms law, and drawing the straight line through these points, as shown.

The curve of total voltage is then constructed by adding together the ordinates of the "terminal voltage" and "drop due to internal resistance."

A very good sample of curve from a modern series machine is to be found in the following description of the Brush arc dynamo.

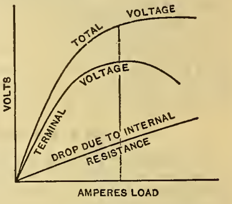


FIG. 29. External Characteristic of Series Dynamo.

Following is a characteristic curve of the new Brush 125-lt. Arc Dynamo

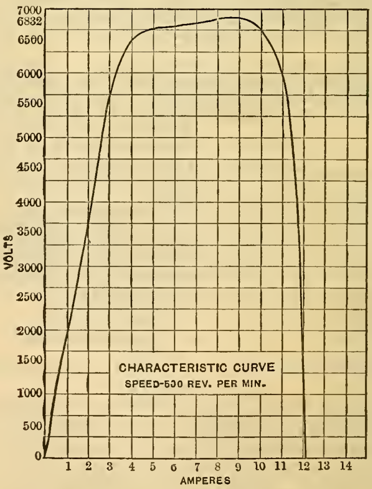


FIG. 30. Characteristic curve of Brush 125-Light Arc Dynamo without Regulator.

machine without any regulator. The readings were all taken at the sparkless position of commutation. This curve is remarkable from the fact that after we get over the bend, the curve is almost perpendicular, and is probably the nearest approach to a constant current machine ever attained. By winding more wire on the armature the machine could have been made to deliver a constant current of 9.6 amperes at all loads, without shunting any of the current from the field; but this would have increased the internal resistance, and also have made the machine much less efficient at light loads. By the present method of regulation the I^2R loss at one-quarter load is reduced from 4,018 to 3,367 watts, the gain being almost one electrical horse-power.

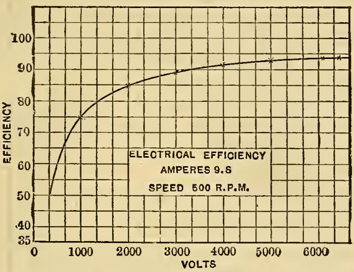


FIG. 31. Electrical Efficiency Curve of Brush 125-Light Arc Dynamo.

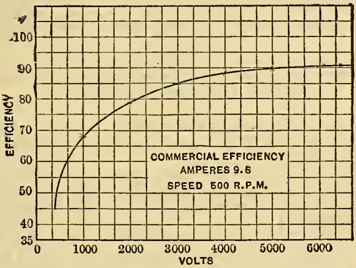


FIG. 32. Commercial Efficiency Curve of Brush 125-Light Arc Dynamo.

Fig. 31 is a curve of the electrical efficiency. It will be noticed that this at full load reaches 94 per cent, which is accounted for by the liberal allowance of iron in the armature, thus reducing the reluctance of the magnetic circuit, and by the large size of the wire used on both field and armature.

Fig. 32 is a curve of the commercial efficiency. At full load this is over 90 per cent, and approaches very closely the efficiency of incandescent dynamos of equal capacity, but the most noteworthy point is the high efficiency shown at one-quarter load.

Fig. 33 is a curve of the machine separately excited, with no current in the armature. The ordinates are the volts at the armature terminals, and the abscissæ the amperes in the field. This is in reality a permeability curve of the magnetic circuit. By a comparison of the voltage shown here when there are nine amperes in the field, with that of the machine when delivering current, can be seen the enormous armature reaction. The curve also

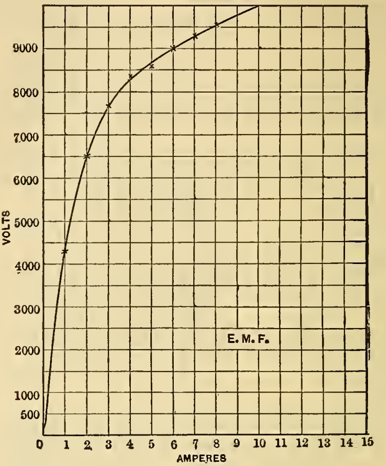


FIG. 33. Permeability Curve of Magnetic Circuit of Brush 125-Light Arc Dynamo.

indicates a new departure in arc dynamo design, namely, that the magnetic circuit is not worked at nearly as high a point of saturation as in the old types.

Shunt dynamo. The shunt dynamo has, besides an *external characteristic*, shown below, an *internal characteristic.* The first is developed from the volts read while the load in amperes is being added, the armature revolutions being kept constant.

Adding load to a shunt dynamo means simply reducing the resistance of the external circuit. With all shunt machines there is a point of external resistance, as at *n*, beyond which, if the resistance is further reduced, the volts will drop away abruptly, and finally reach zero at a short circuit.

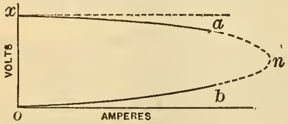


FIG. 34. External Characteristic of Shunt-wound Dynamo.

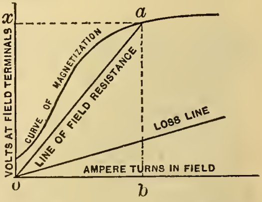


FIG. 35. Internal Characteristic of Shunt Dynamo.

The *internal characteristic*, or, more correctly, curve of magnetization, of a shunt dynamo, is plotted on the same scale as those previously described, from the volts at the field terminals and the amperes flowing in the field.

The resistance line $o\ a$ only applies to the point a on the curve, and the resistance value $a\ b$ for that point is determined by ohms law, or as follows: As the curve of magnetization is determined from the reading of volts plotted vertically and amperes horizontally, and as $r = \frac{v}{I}$ or $r = \frac{a\ b}{o\ b}$ and $\frac{a\ b}{o\ b} = \text{tang}\ a\ o\ b$, therefore the resistance at any point on the curve will be the tangent of the angle made by joining that point to the origin o.

Compound dynamo. As the compound dynamo is a combination of the series and shunt machines, the characteristics of both may be obtained from it.

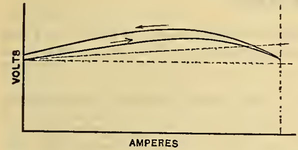


FIG. 36. Characteristic of Over-compounded Compound-wound Dynamo.

The external characteristic is of considerable importance where more than one dynamo is to be connected to the same circuit, or when close regulation is necessary.

Fig. 36 is a sample curve from a compound-wound dynamo, where the increase of magnetization of the fields due to the series coils and load causes the terminal voltage to rise as the load is increased. This is commonly done to make up for drop in feeders to the centre of distribution. It is impossible in ordinary commercial dynamos to make this curve closely approach a straight line, and the author has found it difficult for good makes to approach a straight line of regulation nearer than $1\frac{1}{2}$ per cent either side of it for the extreme variation.

Curve of Magnetic Distribution.—This curve is constructed from existing dynamos to show the distribution of the field about the pole-pieces; it can be plotted on the regular rectangular co-ordinate plan, or on the polar co-ordinate.

The following cuts illustrate the commonest methods of getting the data for the curve. With the dynamo running at the speed and load desired, the pilot brush, a, in the first cut, or the two brushes, a and b, in the second cut, is started at the brush x, and moving a distance of one segment at a time, the difference in volts between the brush x and the location of the pilot brush, a, is read on the voltmeter.

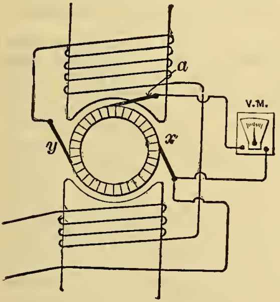


FIG. 37.

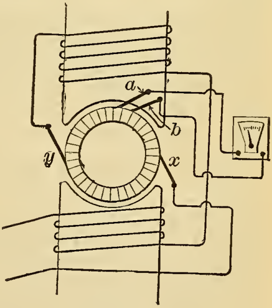


FIG. 38.

Where the one pilot brush is used, the total difference between that and the origin is read; while with two brushes, as a and b, which are commonly fastened to a handle in such a manner as to be the width of a segment apart, just the difference between the two adjacent segments is read, and the total difference is determined by adding the individual differences together.

In taking the distribution curve on a commutator, with the two-brush method of S. P. Thompson, the curve of potential may be plotted in two ways, viz.: the heights of the ordinates may be made equal to the sum of all the readings to the given point, or they may be made equal to the reading at each bar, in which case the curve will indicate the value of the induction at each point of the field where a reading is made.

Potential curves of this kind are often plotted on a circle, the circle itself representing the commutator, with the segments plotted as radial ordinates, which are made equal in value to the readings of the voltmeter brushes.

ARMATURES.

Armatures for continuous current dynamos differ much in practice from those used for alternating-current machines, although the former produce alternating currents that are *rectified* or turned in the same direction by a *commutator.*

Direct-current armatures are divided into two general forms,— *drum* armatures, in which the conductors are placed wholly on the surface or ends of a cylindrical core of iron; and *ring* armatures, in which the conductors are wound on an iron core of ring form, the conductors being wound on the outside of the ring and threaded through its interior.

Another form used somewhat abroad is the *disk* armature, in which the conductors are arranged in disk form, the plane of which is perpendicular to the shaft, and without iron core, as the disk revolves in a narrow slot between the pole-pieces.

Armature Cores.

In some early dynamos cores were made of solid iron; but the heat from Foucault or eddy currents was found so excessive as to endanger the insulation of the conductors, and the loss in the core reduced the efficiency greatly. Iron wire wound on a frame constructed for the purpose was then introduced in place of solid cores. This answers the purpose for *ring* armatures fairly well, but there is considerable waste space, as round wire is always used.

To-day armature cores are invariably made of thin sheet iron or annealed soft steel from .015 to .025 inch thick.

In order to prevent Foucault currents in such laminated cores, it is necessary to insulate the disks from each other in some manner. Very thin tissue paper between disks, rust on the surfaces, varnish, oil, or paint, are all used for the purpose. Most of the better builders of to-day use a light japan on the disks, with a layer of good insulating paper about every half inch. Open spaces are left in the core about every two inches for ventilation.

Armature cores are divided again as to outer surface into *smooth body* and *toothed;* the latter called formerly the Pacinnotti armature, after its inventor.

The *smooth body* armature core is enough smaller in diameter than the inner circle of the pole faces, to allow laying on the winding; the full diameter of the *toothed* armature core is only enough smaller than the field pole space to allow proper air-gap, and slots are provided in its periphery in which are laid the conductors. The *toothed ring* armature is used to-day in the United States to perhaps a greater extent than any other form, although the winding is of the drum form used with multipolar dynamos.

The toothed armature is said by Professor Crocker to possess the following advantages and disadvantages over the smooth body.

Advantages:

1. The reluctance of air-gap is minimum.
2. The conductors are protected from injury.
3. The conductors cannot slip along the core by action of the electrodynamic force.
4. Eddy currents in the conductors are avoided.
5. If the teeth are practically saturated by the field magnetism, they oppose the shifting of the lines by armature reaction.

Disadvantages.

1. More expensive.
2. The teeth tend to generate eddy currents in the pole-pieces.
3. Self-induction of the armature is increased.

If the slots are made less in width than $2\frac{1}{2}$ or 3 times the air-gap, so that the lines spread and become nearly uniform over the pole faces, but little effect will be felt from eddy currents induced in the pole faces. When it is not possible to make such narrow slots, pole-pieces must be laminated in the same plane as the disks of the armature core, or the gap must be considerably increased.

Hysteresis in the armature core can be avoided to a great extent by using the best soft sheet iron or mild steel, which must be annealed to the softest point by heating to a red heat and cooling very slowly. Disks are always punched, and are somewhat hardened in the process; annealing will not only remove the hardness, but will remove any burrs that may have been raised.

Disks should be punched of such careful dimensions as to need no filing or truing up after being assembled. Turning down the surface of a smooth-body armature core burrs the disks together, and is apt to cause dangerous heating in the core when finished. Light filing is all that is permissible for truing up such a surface. Slotted cores should be filed as little as possible, and can sometimes be driven true with a suitable mandril.

End plates of iron are seldom satisfactory, and the use of gun metal or other bronze is to be commended. Bolts through the core must be insulated, or currents will be induced in them as in any conductor.

Cores were formerly designed of small diameter, especially so in those of the drum type; but now the dimensions of the core take no particular shape, excepting in some cases it is said to be better to make the cross-section of each side of ring-armature cores approximately square, although cores of a rectangular cross-section answer better the purpose for avoiding excessive heating, and for least cost.

The *size* of core is determined first by the number and size of conductors it has to carry to produce the required E.M.F.; and secondly, by the surface necessary to avoid excessive rise of temperature.

Armature conductors are usually made 600 to 800 circular mils per ampere, and the number of paths through the armature between which the current is divided is determined by the design of the winding and the number of poles. In a bipolar closed-coil winding there are two paths, each carrying one-half the total current, while a four-pole closed-coil winding may have either two or four circuits. The method of determining the number of conductors necessary to produce the required E.M.F. is explained in the early part of this chapter. For losses in cores of armatures, see chapter on *Magnetic Qualities of Iron.*

Armature shafts must be very strong and stiff, to avoid trouble from the magnetic pull should the core be out of centre. They are made of machinery steel, and have shoulders to prevent too much side play.

Core Insulation. — A great variety of material is used for insulating the core, including asbestos, which is usually put next to the core to prevent damage from heating of that part; oiled or varnished paper, linen, and silk; press board; mica and micanite. For the slots of slotted cores the insulation is frequently made into tubes that will slide into the slots, and the conductors are then threaded through. Special care must be taken at corners and at turns, for the insulation is often cut at such points. The armature conductors of the Niagara dynamos are insulated by a layer of mica wound on to the bar $\frac{1}{8}$ inch thick, and then pressed into place under high and hot steam pressure.

Armature Windings.

For all small dynamos, and in many of considerable size, the winding is of double cotton-covered wire. Where the carrying capacity is more than the safe carrying capacity of a No. 8 B. & S. gauge, the conductor should be stranded. In large dynamos, rectangular copper bars, cables of twisted copper, and in some cases large cable compressed into rectangular shape, are more commonly used. If the copper bars are too wide, or wide enough so that one edge of the bar enters the field perceptibly before the remaining parts of the bar, eddy currents are induced in it; such bars are therefore made quite narrow, and it is common to slope the pole face a trifle, so that the bars may enter the field gradually.

Methods or arrangement of windings are of a most complex nature, and only the most general in use will be described here, and these only in theory. Parshall & Hobart have described about all the possible combinations; S. P. Thompson, Hawkins & Wallis, and others have also written quite fully on the subject.

Unipolar windings are not windings at all, as the armature is simply a cylinder or disk of metal; and as none have as yet been put to practical use, no further comment will be made on them.

Ring or Gramme Windings.

The form of core does not to-day determine the form of winding, for, while the drum core is always of necessity wound with the drum winding, the ring core can be wound with either the ring or drum winding, as will be explained.

The simplest form of ring winding is the *two-circuit single winding*, where a continuous conductor is wound about the ring, and taps taken off to the commutator at regular intervals.

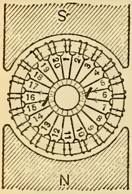


FIG. 39.

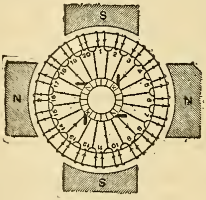


FIG. 40.

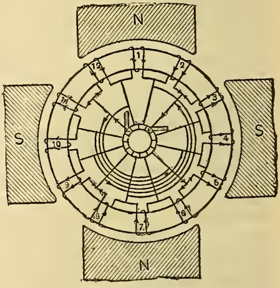


FIG. 41.

The first variation on this will be the *multi-circuit single winding*, used where there are more than one pair of poles. Fig. 40 shows the *four-circuit single winding*.

Where it is advisable to reduce the number of brushes in use, the multi-circuit winding can be cross-connected; that is, those parts of the winding occupying similar positions in the various fields are connected in parallel to the same commutator bar. Fig. 41 shows one of the simplest forms of cross-connected armatures.

Where, from the shape of the frame, the magnetic circuits are somewhat unequal, the winding shown in Fig. 42 will average up the unequal induction values, and prevent sparking to some extent. It also halves the number of commutator segments; that is, there are two coils connected to each segment instead of one, as in the previously mentioned windings. If $n =$ number of coils, and $p =$ number of poles, any coil is connected across to one $\left(\frac{n}{p} \pm 1\right)$ in advance of it.

Multiple Windings for Ring Armatures. — An important class of windings much in use at present, and for many purposes invaluable, is the *double*, *triple*, *quadruple*, etc., wound ring In these classes two or more entirely separate and distinct windings are employed, each connected to its own set of segments, the segments of the different windings following each other in consecutive order.

Fig. 43 shows the simplest form of *two-circuit double winding*, used in a bipolar machine. As no two segments of the same circuit are adjacent, the liability of short-circuit of the commutator is diminished.

Two-circuit Windings for Multipolar Fields.—This is an important class of windings, and, as it has but two circuits irrespective of the number of poles, has the advantage over the multiple-circuit windings that it needs but $\frac{2}{n}$ as many conductors as are necessary in that class, and therefore needs but $\frac{2}{n}$ as much space for insulation.

But two sets of brushes are necessary for the two-circuit windings, unless the current is heavy enough to require a long commutator, in which case other sets of brushes can be added, up to the number of poles.

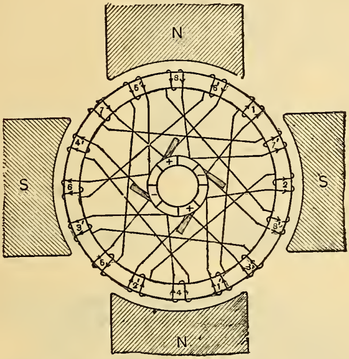


FIG. 42.

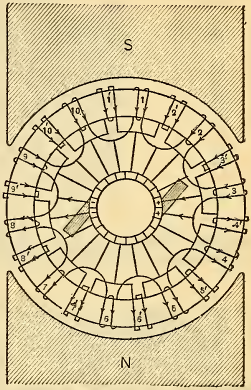


FIG. 43.

In the *short-connection* type of this class, conductors under adjacent field poles are connected together so that the circuits from brush to brush are influenced by all the poles, and are therefore equal.

In the *long-connection* type the conductors under every other pole are connected, so that the conductors from brush to brush are influenced by but one-half the number of poles.

The number of coils in a *two-circuit long-connection multipolar winding* is determined by the formula

$$S = \frac{n}{2} y \pm 1$$

where $S =$ the number of coils, $n =$ the number of poles, and $y =$ the pitch. The number of commutator segments is equal to the number of coils, and must be *odd* for machines with an *even number of pairs* of poles, but may be either *odd* or *even* for machines having an *odd number of pairs* of poles.

The pitch, y, is the number of coils advanced over for end connections, as, for instance, in an armature with a pitch of 7 the end of coil number 1 is connected to the beginning of coil $1 + 7 = 8$, and from 8 to $8 + 7 = 15$, and so on. In multipolar *ring* long-connection windings y may be any integer, but not so in drum windings.

Mr. Kapp gives, in the following table, the best practice as to angular distance between brushes for this class of windings.

Number of poles.	Angular distance between brushes.				
	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.
2	180				
4	90				
6	60	180			
8	45	135			
10	36	108	180		
12	30	90	150		
14	25.7	77	128	180	
16	22.5	67.5	112	158	
18	. . .	60	100	140	180
20	. . .	54	90	126	162

Fig. 44 shows a simple form of *two-circuit multipolar single winding*, and Fig. 45 another sample as used with a greater number of poles.

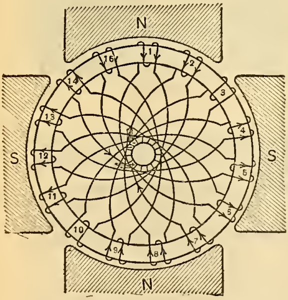


FIG. 44.

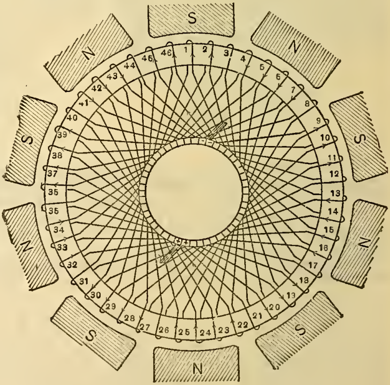


FIG. 45.

Both of the above samples are of the *long-connection* type. In the *short-connection* type the formula for determining the number of coils is

$$S = ny \pm 2,$$

and Fig. 46 is a sample diagram of one of the type.

Two-circuit Multiple-wound Multipolar Rings.—The formula for determining the number of coils and other factors for this class of windings is

$$S = \frac{n}{2} \times y \pm m$$

where
$S =$ number of coils,
$n =$ number of poles,
$y =$ pitch,
$m =$ number of windings, as double, triple, etc.

" m " will equal a number of independently *re-entrant* windings equal to the *greatest common factor* of y and m.

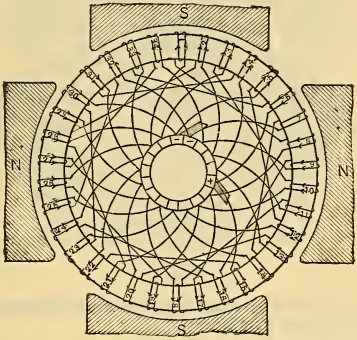


FIG. 46.

The following figure is a diagram of a *two-circuit doubly re-entrant, double wound* ring armature :

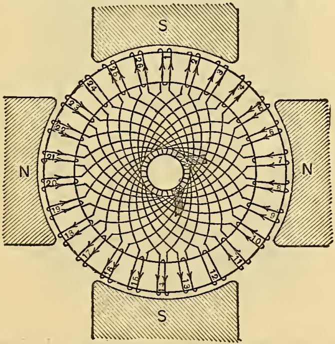


FIG. 47.

Fig. 48 is a diagram of a *two-circuit, singly re-entrant, double-wound* ring.

Drum Windings.

In order that the E.M.F.'s generated in the coils of a drum armature may be in the same direction, it is necessary that the two sides of each coil be in fields of opposite polarity, and therefore the sides of the coils are connected across the ends of the core; directly across, for bipolar machines, and part way so for those of the multipolar type.

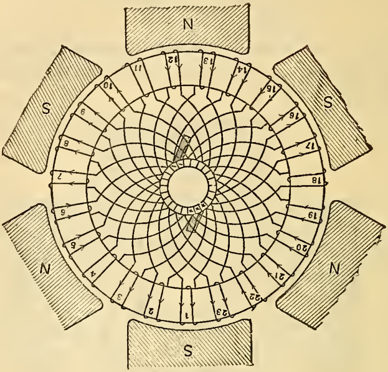


FIG. 48.

Figure 49 shows the Von Hefner-Alteneck drum winding, used principally in small and smooth core armatures.

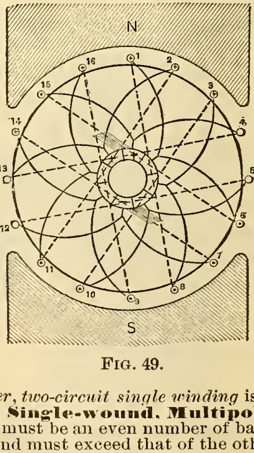


FIG. 49.

A sample of *two-layer*, *two-circuit single winding* is shown in Fig. 50.

Multiple-circuit Single-wound, Multipolar Drums.—In this class of winding there must be an even number of bars; and for single windings the pitch at one end must exceed that of the other by 2, and must both be *odd*. If n is the number of poles, and c the number of face conductors, the average pitch y should be about $\frac{c}{n}$. For *chord* windings y should be as much smaller than $\frac{c}{n}$ as convenient.

In iron-clad windings the number of conductors must be a multiple of the number of conductors per slot.

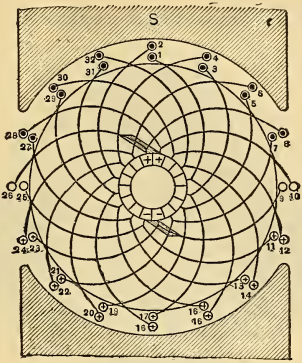


FIG. 50.

Following is a diagram of a *six-circuit, single winding.*

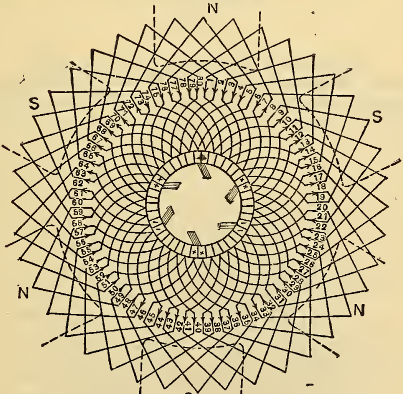


FIG. 51

Two-circuit, Single-wound, Drum Armatures.—In this type of winding, the pitch y is always *forward*, and must be an odd number, the connections leading the winding from a certain bar under one pole to a bar similarly situated under the next pole in advance. Two-circuit drum windings have for a given voltage $\frac{2}{n}$ as many conductors as multiple-circuit windings.

When as many sets of brushes are used as there are poles, careful adjustment of the brushes is necessary in order to avoid excessive flow of current and bad sparking at any one set of brushes, with symbols the same as in the previous paragraph, $c = n\,y \pm 2$.

The following diagram shows the connections of a two-circuit single winding.

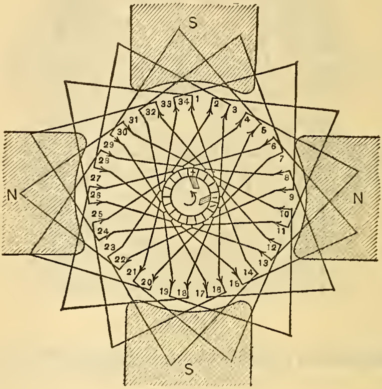


FIG. 52.

Two-circuit, Multiple-wound, Drum Armatures. — With the same symbols as before, and m = *number of windings*, the general formula is $c = n\,y \pm 2\,m$.

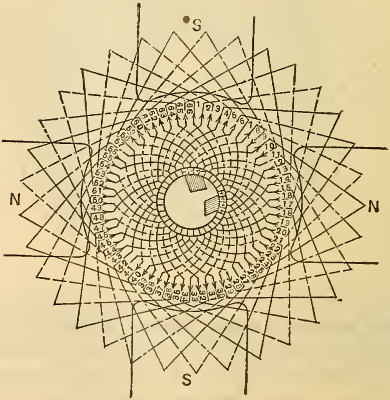


FIG. 53.

This is a large class, and many combinations have been worked, Figs. 53 and 54 showing two of the simpler ones ; the first a *two-circuit triple winding*, and the second a *two-circuit double winding.*

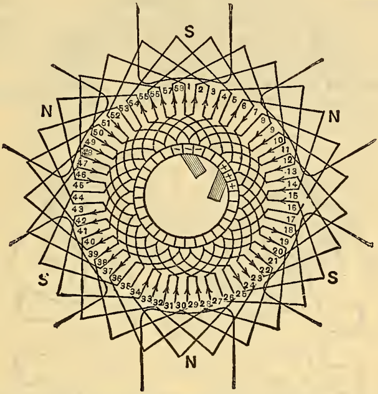


FIG. 54.

Alternating current Armatures.

Almost any continuous current armature winding may in a general way be used for alternating currents, but they are not well suited for such work, and special windings better adapted for the purpose are designed.

Alternating current armature windings are *open-circuit* windings, excepting in the rotary converter, where the rings are tapped directly on to the direct current armature windings.

Early forms of armature windings of this type, as first used in the United States, had *pan-cake* or flat coils bound on the periphery of the core. In the next type the coils were made in a bunched form, and secured in large slots across the face of the core. Both these types were used for single-phase machines. After the introduction of the multiphase dynamo, armature windings began to be distributed in subdivided coils laid in slots of the core ; and this is the preferred method of to-day, especially so in the case of revolving field machines.

The single coil per pole type of winding gives the larger E.M.F., as the coils are thus best distributed for influence by the magnetic field. This type also produces the highest self-induction with its attendant disadvantages.

The *pan-cake* and *distributed-coil* windings are much freer from self-induction, but do not generate as high E.M.F. as does the single-coil windings.

In well-considered multiphase windings the E.M.F. is but little less for distributed coils than for single coils, and has other advantages, especially where the use of step-up transformers permits the use of low voltages, and consequently light insulation for the coils. The distributed-coil winding offers better chance for getting rid of heat from the armature core, and the conductor can in such case be made of less cross-section than would be required for the single-coil windings.

The greater number of coils into which a winding is divided, the less will be the terminal voltage at *no load.* Parshall & Hobart give the following ratio for terminal voltage under *no-load* conditions :

Single-coil winding = 1. for the same total number of conductors, the spacing of conductors being uniform over the whole circumference.
Two-coil winding = .707.
Three-coil winding = .667.
Four-coil winding = .654.

When the armature is loaded, the current in it reacts to change the terminal E.M.F., and this may be maintained constant by manipulation of the exciting current. With a given number of armature conductors this reaction is greatest with the single coil per pole winding, and the ratios just given are not correct for full-load conditions.

Single-phase Windings. — The following diagram shows one of the simplest forms of single-phase winding, and is a *single coil per pole* winding.

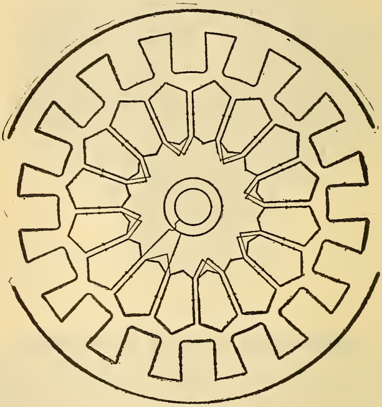


FIG. 55.

Another similar winding, but with bars in place of coils, is shown in the following figure. It can be used for machines of large output.

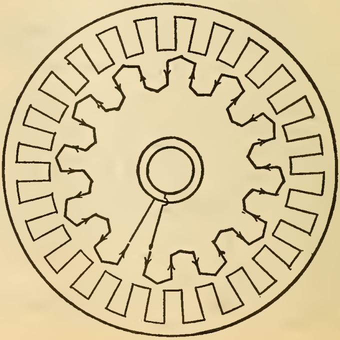


FIG. 56.

The following figure shows a good type of three bars per pole winding, which is simple in construction.

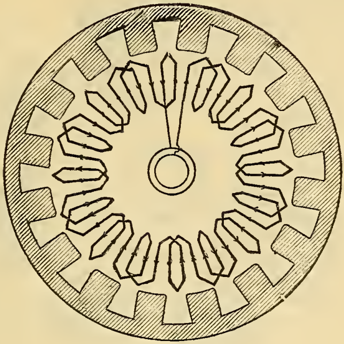


FIG. 57.

Two-phase Windings. — The following diagram shows a good type of winding for *quarter-phase* machines. It utilizes the winding space to good advantage, and is applicable to any number of coils per pole per phase.

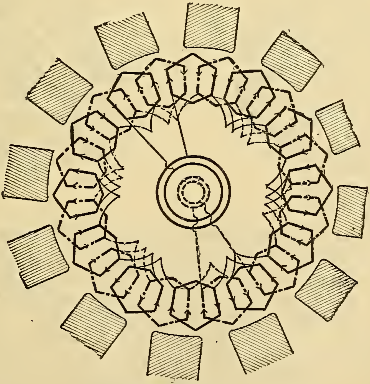


FIG. 58.

Fig. 59 is a diagram of a bar winding for a quarter-phase machine, with four conductors per pole per phase.

Three-phase Windings. — Fig. 60 is a diagram of a three-phase winding connected in Y, in which one end of each of the three windings is connected to a common terminal, the other ends being connected to three collector rings.

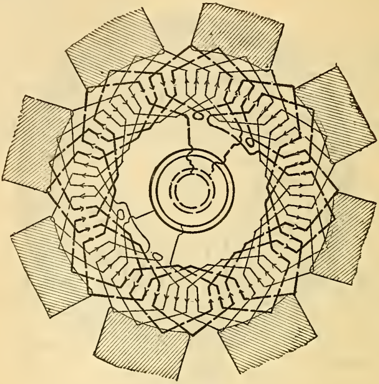


Fig. 59.

Fig. 61 is a sample of a three-phase delta winding, in which all the conductors on the armature are connected in series, a lead being taken off to a collector ring at every third of the total length.

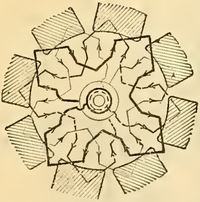


Fig. 60.

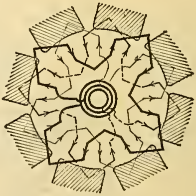


Fig. 61.

In the Y windings the proper ends to connect to the common terminal and to the rings may be selected as follows: Assume that the conductor in the middle of the pole-piece is carrying the maximum current, and mark its direction by an arrow; then the current in the conductors on either side of and adjacent to it will be in the same direction. As the maximum current must be *coming from* the common terminal, the end toward which the arrow points must be connected to one of the rings, while the other end is connected to the common terminal. It is quite as evident that the currents in the two adjacent conductors must be *flowing into* the common terminal, and therefore the ends toward which the arrows point must be connected to the common terminal, while their other ends are connected to the remaining two rings.

In a delta winding, starting with the conductors of one phase in the middle of pole-piece, assume the maximum current to be induced at the moment in this conductor; then but one-half the same value of current will be included at the same moment in the other two phases, and its path and value will best be shown in the following diagram, in which x may be taken as the middle collector-ring, and the maximum current to be flowing from x toward z. It will be seen that no current is coming in over the line y, but part of the current at z will have been induced in branches b and c.

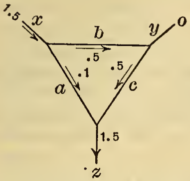


FIG. 62. Path and Value of Current in Delta-connected Armature.

Most three-phase windings can be connected either in Y or delta; but it must be borne in mind that with the same windings the delta-connection will stand 1.732 times as much current as the Y-connection, but gives only $\frac{1}{1.732}$ as much voltage.

Heating of Armatures.

The temperature an armature will attain during a long run depends on its peripheral speed, the means adopted for ventilation, the heating of the conductors by eddy currents, the heating of the iron core by hysteresis and eddy currents, the ratio of the diameter of the insulated conductor to that of its copper core, the current density in the conductor, the radial depth of winding, whether the armature is of cylinder or drum type, and the amount and character of the cooling surface of the wound armature.

The higher the peripheral speed of the armature the less is the rise of temperature in it. Mr. Esson gives, as the result of some experiments on armatures with smooth cooling surfaces, the following approximate rule:

$$C^\circ = \frac{55\ W}{S\,(1 + 0.00018\ V)} = \frac{350\ W}{S'\,(1 + 0.00059\ V')},$$

where $C^\circ =$ difference of temperature between the hottest part of the armature and the surrounding air in degrees, Centigrade,

$W =$ watts wasted in armature,

$S =$ active cooling surface in square inches,

$S' =$ active cooling surface in square centimeters,

$V =$ peripheral speed of armature in feet per minute,

$V' =$ peripheral speed in meters per minute

The more efficient the means adopted for ventilating the armature by currents of air, the smaller is the temperature rise. Some makers leave spaces between the winding at intervals, thus allowing the air free access to the core and between the conductors. A draught of air through the interior of the armature assists cooling, and should be arranged for whenever possible.

For heavy currents it is sometimes necessary to subdivide the conductors to prevent eddy currents; stranded conductors, rolled or pressed hydraulically, of rectangular or wedge-shaped section, have been used. Such subdivision should be parallel to the axis of the conductor, and preferably effected by the use of stranded wires rather than laminæ. Few armature conductors of American dynamos of to-day are divided or laminated in any degree whatsoever. Solid copper bars of approximately rectangular cross-section are often used, and little trouble is found from Foucault currents.

The power wasted by eddy currents in an armature core is proportional to the square of the maximum magnetic induction and to the frequency of change of magnetic induction in the iron.

Mr. Kapp considers 1.5 square inches (9.7 square centimeters) of cooling surface per watt wasted in the armature, a fair allowance.

Esson gives the following for armatures revolving at 3000 feet per minute.

$W =$ watts wasted in heat in winding and core,

$S =$ cooling surface, exterior, interior, and ends, in square inches,

$S_1 =$ cooling surface, exterior, interior, and ends, in square centimeters,

$T =$ temperature difference between hottest part of armature and surrounding air in C°.

Then
$$T = \frac{35\ W}{S} \text{ or } \frac{225\ W}{S_1}$$

Specifications for standard electrical apparatus for U.S. Navy say, "No part of the dynamo, field, or armature windings shall heat more than 50° F. above the temperature of the surrounding air after a run of four hours at maximum rated output."

According to the British Admiralty specification for dynamos, the temperature of the armature one minute after stopping, after a six hours' run, must not exceed 30° F. above that of the atmosphere. In this test the thermometer is raised to a temperature of 30° F. above that of the atmosphere before it is placed in contact with the armature, and the dynamo complies (or does not comply) with the specification according as the thermometer does not (or does) indicate a further rise of temperature.

The best dynamo makers to-day specify 40° and 45° C. as the maximum rise in temperature of the hottest part of a dynamo, or 55° if the temperature of the commutator surface is to be measured.

Armature Reactions.

In continuous current dynamos, with no special devices for reversing the currents in the armature sections as they successively pass under the brushes, it is necessary, in order to avoid sparking, to give the brushes a forward lead; the lead usually varies with the output of the dynamo.

With the forward lead given to the brushes the effect of the armature current is to weaken and distort the magnetic field set up by the field-magnets; a certain number — depending on the lead of the brushes — of the armature ampere-turns directly oppose those on the field-magnets, and render a somewhat larger number of these ineffective, except as regards wasting power; the remaining armature ampere-turns tend to set up a magnetic field at right angles to the main field, with the result that the resultant field is rotated forward in the direction of motion of the armature, and that the field-strength is reduced in the neighborhood of every trailing pole-piece horn, and is increased in that of every leading pole-piece horn. When, therefore, the brushes have a forward lead each armature section as it comes under a brush enters a part of the field, of which the strength is reduced by the armature cross-induction; and, if this reduction is great, the field-strength necessary for reversing the current in the section (in the short time that the section is short-circuited under the brush) may not be obtained, and sparkless collection may thus be rendered impossible.

Various devices for reversing the currents in the armature sections, as they pass successively under the brushes, without giving a forward lead to the brushes, have been proposed; a number of these are described in the paper by Mr. Swinburne; an improvement of Mr. W. B. Sayers consists in interposing auxiliary coils between the joints of adjacent armature sections and the corresponding commutator bars. Each auxiliary coil is wound on the armature with a lead relatively to the two main armature sections and the commutator bar which it connects together. The result of this arrangement is that the difference between the E.M.F.s in the two auxiliary coils connecting any given armature section to the two corresponding commutator bars may be made sufficient to reverse the current in the armature section when short-circuited under a brush, even if the brush has a backward instead of a forward lead. Mr. Sayers's invention not only makes it possible to reduce the air-gap very considerably, but also, by enabling a backward lead to be given to the brushes, to make the armature winding assist that on the field-magnets in producing the required magnetic field for the armature. Both these results assist in reducing the weight and excitation of the field-magnets.

For a two-pole dynamo the back ampere-turns are given by the formula,

$$(A.T.)_b = \frac{\theta N I}{180}$$

where θ = angular lead of brushes in degrees,
N = number of conductors, counted round periphery of armature, in series,
I = armature current in amperes;

and, according to Prof. S. P. Thompson, the number of ampere-turns on the field-magnets required to compensate for the back ampere-turns on the armature is $v \times (A.T.)_b$, where v is the coefficient of magnetic leakage.

In the Thompson-Ryan dynamo the effects of armature reaction are neutralized by a special winding through slots across the faces of the pole-pieces, parallel with the axis of the armature; this winding is in series with the armature, and the same current flowing in both, but in such direction that all effects on the field magnets are neutralized, the ampere-turns of the shunt are therefore much less than in other dynamos, there is no sparking under any ordinary conditions of load, the brushes are placed permanently when the machine is set up, and the efficiency is high under a wide range.

This dynamo is not compound-wound in the usual meaning of the term, but the effects of compounding can be obtained by varying the position of the brushes, a backward lead, tending to raise the voltage by assisting the field magnets, as the current or load increases.

Drag on Armature Conductors.—In dynamos, each armature conductor has to be driven in opposition to an effort or drag proportional at every instant to the product of the current carried by the conductor into the strength of the magnetic field. This drag on a conductor varies, therefore, with the position of the conductor relatively to the field-magnet poles, and is a maximum when the conductor passes through that part of the air-gap at which the magnetic induction is greatest. The arrangements for driving the armature conductors must, of course, be adapted to the greatest value of the drag to which a conductor is exposed, and this is given for smooth core armatures by the formula below.

Let $I =$ current in amperes carried by each conductor,

$\mathcal{B} =$ maximum induction in air-gap per square centimeter,

$F =$ maximum drag on a conductor in lbs. per foot of length.

Then
$$F = \frac{I\mathcal{B}}{146{,}000} \text{ or } .00000685\, I\mathcal{B}$$

In slotted armatures the drag comes upon the core teeth instead of the conductors.

Current Density in Armature Conductors.—This should be determined so that the I^2r loss, plus the hysteresis loss in the armature, does not exceed the less of the two limiting values assigned by the conditions of efficiency and freedom from overheating respectively; in practice current densities of 2,000 to 3,000 amperes per square inch are common, and in drum armatures the current density is sometimes higher. American practice gives 600 to 800 circular mils per ampere.

FIELD MAGNETS.

Surface necessary for Safe Temperature.

Esson gives the following method of determining the surface necessary for a magnet coil to keep its heat within assigned limits.

Let $w =$ watts wasted in heating,

$s =$ cooling surface in square inches of coil, not including end flanges and interior,

$s_{\prime} =$ same as above in square centimeters,

$t =$ temperature of hottest part above surrounding air,

then
$$t\,\text{F}^\circ = 99\,\frac{w}{s} \text{ or } t\,\text{C}^\circ = 335\,\frac{w}{s_{\prime}}$$

$$\text{Maximum current} = \sqrt{\frac{degs.\ \text{F} \times sq.\ ins.}{99 \times hot\ r}}$$

Hot $r =$ cold $r + 1\%$ for each additional 4.5° F.

Table of Cooling Surfaces.

Excess temperature above surrounding air.		Cooling surface per watt in	
F.°	C.°	square inches.	sq. centimeters.
—	15	3.67	23.7
30	—	3.30	21.3
—	20	2.75	17.8
40	—	2.48	16.0
—	25	2.20	14.2
50	—	1.98	12.8
—	30	1.83	11.8
60	—	1.65	10.7
—	35	1.57	10.1
70	—	1.41	9.1
—	40	1.38	8.9

Notes. — The number of ampere-turns necessary to overcome an air-gap of one-half inch equals the number of lines of force per square centimeter. Approximate rule by G. Forbes.

Current Density.

(Esson.)

The current density per square centimeter section in the magnet winding of ordinary machines is about half the current density in the armature.

Safe Continuous Output of Dynamos and Motors.

(Albion Snell.)

$$\text{Dynamos}\begin{cases}\text{Drums} & \text{Watts} = ld^2n\ .015.\\ \text{Cylinders} & \text{Watts} = ld^2n\ .01.\end{cases}$$

$$\text{Motors}\begin{cases}\text{Drums} & \text{Brake H.P.} = ld^2n\ .000015.\\ \text{Cylinders} & \text{Brake H.P.} = .00001.\end{cases}$$

l = length of armature in inches,
d = diameter of armature in inches,
n = number of revolutions per minute.

Gyrostatic Action on Dynamos in Ships.

(Lord Kelvin.)

$$L = \frac{Wk^2\Omega\omega}{g} \text{ and } P = \frac{Wk^2\Omega\omega}{gl}$$

where
L = moment of couple on axis,
P = pressure on each bearing,
W = weight of armature,
k = radius of gyration about axis,
$\Omega = \frac{2\pi}{T}A$ = maximum angular velocity of dynamo in radians per second due to rolling of ship,
$A = \frac{\pi d}{180}$ = amplitude in radians per second,

(Radian is unit angle in circular measure.)

$d =$ degrees of roll from mean position.
$T =$ periodic time in seconds.
$\omega = 2\pi n =$ angular velocity of armature in radians per second.
$n =$ number of revolutions of armature per second.
$l =$ distance between bearings.
$g =$ acceleration due to gravity.

NOTE.—On applying the above formula to dynamos, where W, k, and ω are great, it will be found advisable to place their plane of rotation athwartships, in order to avoid as far as possible wear and tear of bearings due to the gyrostatic action.

SYNCHRONIZERS.

There are numerous methods of determining when alternators are in step, some acoustic, but mostly using incandescent lamps as an indicator.

In the United States it is most common to so connect up the synchronizer that the lamp stays dark at synchronism; in England it is more usual to have the lamp at full brilliancy at synchromism, and on some accounts the latter is, in the writer's opinion, the better of the two, as, if darkness indicates synchronism, the lamp breaking its filament might cause the machines to be thrown together when clear out of step; on the other hand, it is sometimes difficult to determine the full brilliancy.

The two following cuts show theory and practice in connecting synchronizers.

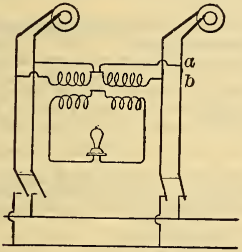


FIG. 63. Synchronizer Connections.

When connected as shown, the lamp will show full c. p. at synchronism. If a and b are reversed, darkness of lamp will show synchronism.

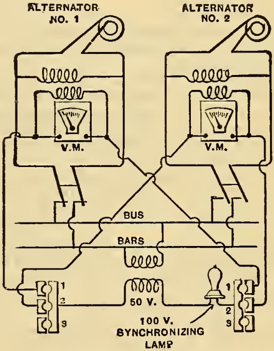


FIG. 64. Synchronizer Connections.

Lamp lights to full c.p. when dynamos are in synchronism.

Two transformers having their primaries connected, one to the loaded and the other to the idle dynamo, have their secondaries connected in series through a lamp; if in straight series the lamp is dark at synchronism; if the secondaries are cross-connected the lamp lights in full brilliance at synchronism.

Note on the Parallel Running of Alternators.—There is little if any trouble in running alternators that are driven by water-wheels, owing to the uniform motion of rotation. With steam-engine driven machines it is somewhat different, owing to more or less pulsation during a stroke of the engines, caused by periodic variations in the cut-off, which cause oscillations in the relative motion of the two or more machines, accompanied by periodic cross currents. Experiments have proved that a sluggish governor for engines driving alternators in parallel is more desirable than one that acts too quickly; and it is sometimes an advantage to apply a dashpot to a quick-acting governor, one that will allow of adjustment while running. It is quite desirable also that the governors of engines designed to drive alternators in parallel shall be so planned as to allow of adjustment of speed while the engine is running, so that engines as well as dynamos may be synchronized, and load may be transferred from one machine to the others in shutting down. Foreign builders apply a bell contact to the same part of all engines that are to be used in this way, and throw machines together when the bells ring at the same time. These bells would also serve to determine any variation, if not too small, in the speed of the machines, and assist in close adjustment.

Manufacturers do not entirely agree as to the exact allowance permissible for variation in angular speed of engines, some preferring to design their dynamos for large synchronizing power, and relatively wide variation in angular speed, while others call for very close regulation in angular variation of engine speed, and construct their dynamos with relatively little synchronizing power.

Dynamos of low armature reaction have large synchronizing power, but if accidentally thrown out of step are liable to heavy cross-currents. On the contrary, machines with high armature reaction have relatively little synchronizing power, and are less liable to trouble if accidentally thrown out of step.

The smaller the number of poles the greater may be the angular variation between two machines without causing trouble, thus low frequencies are more favorable to parallel operation than high; and this is especially so where the dynamos are used to deliver current to synchronous motors or rotary converters.

Specifications for engines should read in such a manner as to require not more than a certain stated angular variation of speed during any stroke of the machine, and this variation is usually stated in degrees departure from a mean speed.

The General Electric Company states it as follows: —

"We have . . . fixed upon two and one-half degrees of phase departure from a mean as the limit allowable in ordinary cases. It will, in certain cases, be possible to operate satisfactorily in parallel, or to run synchronous apparatus from machines whose angular variation exceeds this amount, and in other cases it will be easy and desirable to obtain a better speed control. The two and one-half degree limit is intended to imply that the maximum departure from the mean position during any revolution shall not exceed $\frac{2\frac{1}{2}}{360}$ of an angle corresponding to two poles of a machine. The angle of circumference which corresponds to the two and one-half degrees of phase variation can be ascertained by dividing two and one-half by one-half the number of poles; thus, in a twenty-pole machine, the allowable angular variation from the mean would be $\frac{2\frac{1}{2}}{10} = .25$ of one degree."

Some foreign builders of engines state the conditions as follows: Calling N the number of revolutions per minute, the weight of all the rotary parts of the engine should be such that under normal load the variation in speed during one revolution $\frac{N\,max. - N\,min.}{N\,average}$ will not exceed $\frac{1}{250}$. Some state $\frac{1}{200}$.

Oudin says: "The regulation of an engine can be expressed as a percentage of variation from that of an absolutely uniform rotative speed. A close solution of the general problem shows that $1\frac{1}{4}^\circ$ of phase displacement corresponds to a speed variation, or "pulsation," with an alternator of two n poles, as follows: —

In the case of a single cylinder or tandem compound engine $\frac{2.75\%}{n}$

A cross compound . . . . $\frac{5.5\%}{n}$

A working out of the problem also shows . . . that no better results are obtained from a three-crank engine than a two-crank.

The Westinghouse Company designs its machines with larger synchronizing effect by special construction between poles, and allows somewhat larger angular variation, stating it as follows: The variation of the fly-wheel through the revolution at any load not exceeding 25% overload, shall not exceed one-sixtieth of the pitch angle between two consecutive poles from the position it would have if the motion were absolutely uniform at the same mean velocity. The maximum allowable variation, which is the amount which the armature forges ahead plus the amount which it lags behind the position of absolute uniform motion is therefore one-thirtieth of the pitch angle between two poles.

The number of degrees of the circumference equal to one-thirtieth of the pitch angle is the quotient of 12 divided by the number of poles.

Alternators in Parallel.

To connect an idle alternator in parallel with one or more already in use: Excite the fields of the idle machine until at full speed the indicator shows bus bar pressure, or the pressure that may have been determined on as the best for connecting the particular design of alternator in circuit.

Connect in the synchronizer to show when the machines are in step, at which point the idle machine may be connected to the bus bars. The load will now be unequally divided, and must be equalized by increasing the driving-power of the idle dynamo until it takes on its proper part of the load.

Very little control over the load can be had from the field rheostats.

To disconnect an alternator fron the bus bars: Decrease its driving power slowly until the other machines have taken all the load from it, when its main switch may be opened and the dynamo stopped and laid off.

Current leads

from brushes to binding-posts, must be ample to produce no appreciable drop in voltage. The following table gives current densities, etc., for brush-holders, cables, conductor-rods, cable-lugs, binding-posts, and switches.

Average Current Densities for Cross-section and Contact Surface of Various Materials.

	Material.	Current density.	
		Square Mils per Ampere.	Amperes per Square Inch.
Cross section .	Copper wire . . .	500 to 800	1,200 to 2,000
	Copper rod	800 " 1,200	800 " 1,200
	Copper-wire cable .	600 " 1,000	1,000 " 1,600
	Copper casting . .	1,400 " 2,000	500 " 700
	Brass casting . . .	2,500 " 3,300	300 " 400
Brush contact.	Copper brush . . .	5,700 " 6,700	150 " 175
	Carbon brush . . .	28,500 " 33,500	30 " 35
Sliding contact	Copper — copper . .	10,000 " 15,000	67 " 100
	Brass < copper . brass . .	20,000 " 25,090	40 " 50
Screwed contact	Copper — copper .	5,000 " 8,000	120 " 200
	Brass < copper . brass . .	10,000 " 15,000	67 " 100

Gano S. Dunn says, in brushes of soft carbon ⅜ square inch will stand 60 amperes maximum.

MOTORS.

CONTINUOUS CURRENT.

Theory.

THE revolution of a motor armature in its field develops an E.M.F. which is counter to or opposes the impressed E.M.F., and therefore acts like resistance to reduce the amount of current flowing; it is called the *counter E.M.F.*

Let $E =$ applied E.M.F. at motor terminals,
$e =$ counter E.M.F.,
$R =$ resistance of motor armature,

then

$$I = \frac{E - e}{R}$$

and

$$\text{Total watts } W = EI = E\,\frac{E - e}{R}$$

$$\text{Useful watts } w = eI = e\,\frac{E - e}{R}$$

$W = w +$ watts wasted in heat,

or $W = w + I^2R$

and

$$\frac{w}{W} = \frac{e\,(E - e)}{E\,(E - e)}$$

or

$$\frac{w}{W} = \frac{e}{E}$$

Now

$$w = E\,I - I^2R$$

and $I = \frac{1}{2}\,\frac{E}{R} =$ maximum value of w obtained by equating to 0 the differential coefficient of w with respect to I.

but $I = \frac{E}{R}$ when the armature is standing, and no counter E.M.F. is being developed; therefore the maximum rate of work will be obtained when the efficiency is 50%, and the speed of the armature is such as to produce

$$e = \frac{E}{2}$$

for

$$w = E\,I - I^2R$$

$$\frac{\delta\,w}{\delta\,I} = E - 2IR = 0$$

but

$$I\,R = E - e$$

$$E = 2E - 2e,$$

or

$$e = \frac{E}{2}\ ;\ \text{and } c = \frac{E}{2R}$$

and the efficiency

$$\frac{w}{W} = \frac{1}{2}$$

Theoretically, and neglecting all losses but the one above mentioned, the motor will be at its maximum efficiency when it is run at the required speed, and produces the required power, and e is maximum, or as nearly equal to E as can be obtained.

Speed and Torque.

Let $\omega = 2\pi$ rev. $= 2\pi \times$ rev. per sec. $=$ angular velocity.
$T =$ torque,
then $\omega T =$ power (mechanical) in foot-pounds per sec.,
and $e\,I =$ electric power in watts.
If $Ia =$ current in armature,

then $w = e\,Ia = \omega\, T \times \frac{746}{550} = 2\pi \times rev. \times T\,\frac{746}{550}$

and, as $e = \frac{rev. \times n \times \Phi}{10^8}$

where $n =$ number of wires on the periphery of the armature,
and $\Phi =$ flux in the armature core,

hence $2\pi \times rev. \times T \times \frac{746}{550} = \frac{Ia \times rev. \times \Phi \times n}{10^8}$

and $2\pi\, T = n\,\Phi\, Ia \times \frac{550}{746 \times 10^8}$

Torque in pounds at 1 foot radius will then be

$$T = Ia\,\frac{n\,\Phi}{2\,\pi} \div 13.56 \times 10^7$$

If Φ is constant T will be proportional to Ia, and T will be greatest, therefore, when the armature is standing, and $Ia = \frac{E}{R}$.

If $r =$ resistance of the armature,

then $Ia = \frac{E - e}{r}$

and $T = \frac{n\,\Phi}{2\,\pi} \times \frac{E - \frac{rev. \times n \times \Phi}{10^8}}{r \times 13.56 \times 10^7}$

or $T = O$, when $rev.\ n\,\Phi = E \times 10^8$.

Speed in rev. per sec. $= \frac{E \times 10^8}{n \times \Phi} - \frac{2\pi \times T \times 13.56 \times r \times 10^{15}}{n^2\,\Phi^2}$

If r is small and Φ is relatively large, the second term may be neglected.

The stronger the field, i.e., the Φ, the slower will be the speed; and if Φ is constant the speed is proportional to E.

Series-Wound Motor.

Values in C. G. S. units.

In a series motor $R = ra + rm$ where $ra =$ resistance of the armature, and $rm =$ resistance of the fields:

Let $\Phi\ sat. =$ complete saturation of field magnets,
and $I' =$ *diacritical* current, or current at half saturation,

then $\Phi = \Phi\ sat \times \frac{I}{I + I'}$

Writing Y for $\frac{n\,\Phi\ sat.}{2\pi}$

a $T = Y\,\frac{I^2}{I + I'} \div 13.56 \times 10^7 =$ torque in pounds at 1 ft. radius.

b $I = \frac{T}{2\,Y}$ in C. G. S. units.

c $rev. = \frac{E\,I}{2\pi\ T} - \frac{R\,I^2}{2\pi\ T}$ in C. G. S. units.

In a series motor the current is the same under the same load at any speed. In other words, the torque is almost directly proportional to the current. The following curves show the speed and torque curves for a series motor on a constant potential circuit.

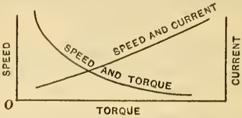


FIG. 65.

Shunt-Wound Motor.

Values in C. G. S. units.

$$T = Ia \frac{n\,\Phi}{2\,\pi}$$

$Ia = I - Is$, where Is = current in the shunt field.

$\Phi = \Phi\, sat. \times \frac{E}{E + E'}$ — where E' is the E M F. to give half saturation in field magnets.

$$e = E\left(1 \times \frac{ra}{rs}\right) - ra\, I.$$

a $$T = \frac{n}{2\,\pi}\left(I - \frac{E}{rs}\right)\Phi\, sat. \times \frac{E}{E + E'}$$

and if $Y = \frac{n\,\Phi}{2\,\pi}$

b $$I = \frac{T}{Y} \times \frac{E + E'}{E} + \frac{E}{rs}$$

c $$rev. = \frac{1}{n\,\Phi}\left[E\left(1 + \frac{ra}{rs}\right) - ra\, I\right]$$

Brushes on a motor must be set *back* of the neutral point, or with a "backward lead." This tends to demagnetize the fields, and as weakening the fields of a motor tends to increase the speed, the increase of load on a shunt-wound motor tends to prevent the speed falling, and the shunt motor is very nearly self-regulating.

Leonard's System of Motor Control.

Wherever it becomes necessary to vary the speed and torque of a continuous current electric motor to any considerable degree, any of the rheostat methods introduce very considerable losses, and are apt to induce bad sparking at the commutator.

H. Ward Leonard, E.E., invented the method shown in Fig. 66, which gives most excellent results, although to some extent complicated, and is highly efficient.

The driving motor, or rather motor which it is wished to control, is provided with a separately excited field, which can be varied by its rheostat to produce any rate of speed, from just turning to the full speed of which it may be capable. Current is supplied to its armature from a separate generator, and by varying the separately excited field of this generator, the amount of current supplied to the motor armature can be varied at will, and the torque therefore changed to suit the circumstances.

The generator is driven at constant speed by direct connection to a motor which gets its current from an outside source, or to another generator driven by some other motive power, say a steam engine. This driven generator supplies current for exciting the fields of the secondary generator and main motor.

By reversing the field of the generator, the current in its armature is reversed, and therefore so is the direction of rotation of the motor armature.

Fig. 67 shows the Leonard system adapted to electric street railway motor control.

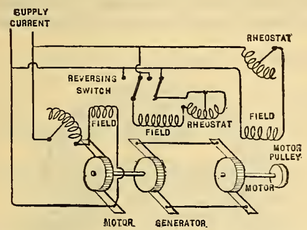


FIG. 66. Leonard's System of Motor Control.

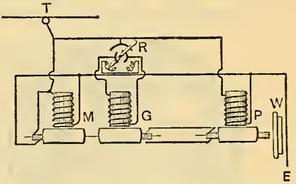


FIG. 67. Leonard's System of Electric Propulsion.

ALTERNATING CURRENT MOTORS.

While the single-phase alternating current motor has been quite well developed during the last few years, it has as yet come but little into use, owing largely to its inductive effect on the line, and poor efficiency and unsatisfactory operation. On the contrary, the multiphase motor has been so far developed as to bring it into very strong competition with the direct current motor, owing probably to its extreme simplicity, lacking all brushes, commutators, and other troublesome attachments.

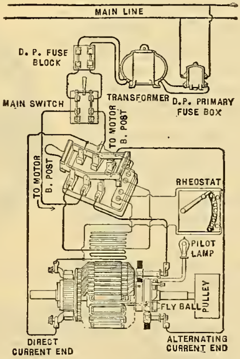


FIG. 68. Connections for Standard S. P. A. C. Motor of the Fort Wayne Electric Corporation.

Only the most elementary formulæ will be given here, and the reader is referred to the numerous books treating on the subject; among others, S. P. Thompson, Steinmetz, Jackson, Kapp, and others.

Following is a statement of the theory of the multiphase motor, condensed from a pamphlet of the Westinghouse Electric and Manufacturing Company.

Elementary Theory of the Multiphase Induction Motor.

If a horse-shoe magnet be held over a compass the needle will take a position parallel to the lines of force which flow from one pole to the other. It is perfectly obvious that if the magnet be rotated the needle will follow.

If a four-pole electromagnet be substituted for the horse-shoe, and current be made to flow about either one of the sets of poles separately, the needle will take its position parallel with the lines of force that may be flowing, as will be seen by the following figures.

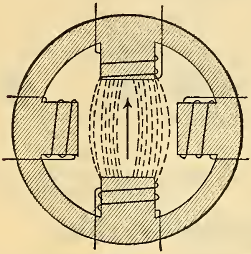


FIG. 69.

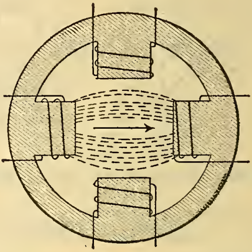


FIG. 70.

If the two sets of poles are excited at the same time by currents of equal strength, then the needle will take its position diagonally, half way between the two sets of poles, as will be seen by the following diagram.

It is now easily conceivable that if one of these currents is growing stronger while the other is at the same time becoming weaker, the needle will be attracted toward the former until it reaches its maximum value, when if the currents are alternating, the strong current having reached its maximum begins to weaken, and the other current having not only reversed its direction but begun to grow strong, attracts the needle away from the first current and in the same direction of rotation. If this process be continually repeated, the needle will continue to revolve, and its direction of rotation will be determined by the phase relation of the two currents, and the direction of rotation can be reversed by reversing the leads of one phase.

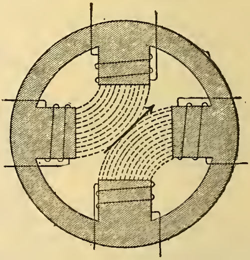


FIG. 71.

If the compass needle be replaced by an iron core wound with copper conductors, secondary currents will be induced in these windings, which will react on the field windings, and rotation will be produced in the core just as it was in the compass needle. Two cranks at right angles on an engine shaft are analogous with the quarter-phase motor, and three to the three-phase motor, which depends on the same principle for its working.

Theory of Multiphase Induction Motor.

Condensed from C. P. Steinmetz.

The following names and symbols are used for designating the parts and properties of the induction motor: —

Stator = stationary part, nearly always corresponding to the field.
Rotor = rotating part, corresponding to the armature of the d.c. motor.
Ω = angular speed of the rotating magnetic field $= 2\pi\, rev. \div m$, where m = number of pairs of poles.
ω = angular speed of *rotor* $= 2\pi\, rev._2 \div m$, where $rev._2$ = number of revolutions per second.
T = torque between the *stator* and *rotor*.

Analytical Theory of Polyphase Induction Motors.

Let r = resistance per circuit of *primary*.
$r_{,}$ = resistance per circuit of *secondary*,
being reduced to primary system by square of the ratio of turns.

Let d = number of poles,
x = reactance of *primary*, per circuit,
$x_{,}$ = reactance of *secondary*, per circuit,
reduced to primary system by square of the ratio of turns.

Let S = per cent of slip,
I = current per circuit of *primary*.
E = applied E.M.F. per circuit,
Z = impedance of whole motor per circuit,
N = frequency of applied E.M.F.
Let the primary and secondary consist of p. circuits on a p. phase system.

n = primary turns per circuit,
$n_{,}$ = secondary turns per circuit,

Let $a = \dfrac{n}{n_{,}}$ ratio of transformation,

Then

$$I \text{ (neglecting ex. current)} = \frac{S\,E}{\sqrt{(r_{,} + Sr)^2 + S^2\,(x + x_{,})^2}}$$

$$\text{Torque } T = \frac{d\,p\,r_{,}\,E^2\,S}{4\pi\,N\,[(r_{,} + Sr)^2 + S^2\,(x_{,} + x)^2]}$$

$$\text{Power} = \frac{p\,r_{,}\,E^2\,S\,(1 - S)}{(r_{,} + Sr)^2 + S^2\,(x_{,} + x)^2}$$

$$\text{Max. torque} = \frac{d\,p\,E^2}{8\pi\,N\,[r + \sqrt{r^2 + (x_{,} + x)^2}]}$$

$$\text{Max. power} = \frac{p\,E^2}{2\,[r + r_{,} + Z]} \text{ at the slip } S = \frac{r_{,}}{r_{,} + Z}$$

$$\text{Starting current} = i = \frac{E}{Z}$$

$$\text{Starting torque} = \frac{d\,p\,E^2}{4\pi\,N} \times \frac{r_{,}}{Z^2}$$

Note that the maximum torque is independent of *secondary resistance* $r_{,}$, and thus the speed at maximum torque depends on the *secondary resistance*. Current at maximum torque is also independent of *secondary resistance*.

The maximum torque occurs at a lower speed than the maximum output. A resistance can be chosen that when inserted in the secondary, the maximum torque will be obtained at starting; that is, the speed at which maximum torque occurs can be regulated by the resistance in the rotor.

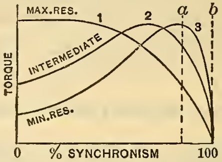


FIG. 72. Torque curves for Polyphase Induction Motor.

Curves 1, 2, and 3 show the effect of successive increases of rotor resistance, rotor run on part of curve *a*—*b*; for here a decrease of speed due to load increases the torque.

Speed of Induction Motor.—The speed or rotating velocity of the magnetic field of an induction motor depends upon the frequency (cycles per second) of the alternating current in the field, and the number of poles in the field frame, and may be expressed as follows:—

rev. = revolutions per minute of the magnetic field,
p = number of poles,
f = frequency; then

$$rev. = 120\,\frac{f}{p}$$

The actual revolutions of the *rotor* will be less than shown by the formula, owing to the *slip* which is expressed in a percentage of the actual revolutions; therefore the actual revolutions at any portion of the load on a motor will be

rev. × *slip* due to the part of the load actually in use.

actual speed = *rev.* (1 — % of slip.)

The following table by Wiener, in the *American Electrician*, shows the speeds due to different numbers of poles at various frequencies.

Speed of Rotary Field for Different Numbers of Poles and for Various Frequencies.

Number of Poles.	Speed of Revolving Magnetism, in Revolutions per Minute, when Frequency is:											
	25	30	$33\frac{1}{3}$	40	50	60	$66\frac{2}{3}$	80	100	120	125	$133\frac{1}{3}$
2	1500	1870	2000	2400	3000	3600	4000	4800	6000	7200	7500	8000
4	750	900	1000	1200	1500	1800	2000	2400	3000	3600	3750	4000
6	500	600	667	800	1000	1200	1333	1600	2000	2400	2500	2667
8	375	450	500	600	750	900	1000	1200	1500	1800	1875	2000
10	300	360	400	480	600	720	800	960	1200	1440	1500	1600
12	250	300	333	400	500	600	667	800	1000	1200	1250	1333
14	214	257	286	343	428	514	571	686	857	1029	1071	1143
16	188	225	250	300	375	450	500	600	750	900	938	1000
18	167	200	222	267	333	400	444	533	667	800	833	889
20	150	180	200	240	300	360	400	480	600	720	750	800
22	136	164	182	217	273	327	364	436	545	655	682	720
24	125	150	167	200	250	300	333	400	500	600	625	667

Slip.—The slip, or difference in rate of rotation between rotating field and *rotor*, is due to the resistance opposed to rotor current.

Slip varies from 1 per cent in a motor designed for very close regulation to 40 per cent in one badly designed, or designed for some special purpose.

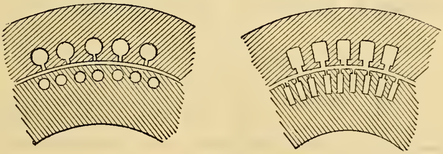
Weiner gives the following table as embodying the usual variations :

Slip of Induction Motors.

Capacity of Motor, H.P.	Slip, at full load, per cent.	
	Usual limits.	Average.
$\frac{1}{8}$	20 to 40	30
$\frac{1}{4}$	10 " 30	20
$\frac{1}{2}$	10 " 20	15
1	8 " 20	14
2	8 " 18	13
3	8 " 16	12
5	7 " 15	11
$7\frac{1}{2}$	6 " 14	10
10	6 " 12	9
15	5 " 11	8
20	4 " 10	7
30	3 " 9	6
50	2 " 8	5
75	1 " 7	4
100	1 " 6	3.5
150	1 " 5	3
200	1 " 4	2.5
300	1 " 3	2

Core of Stator and Rotor.—Both the field-frame core, or *Stator*, and the armature core, or *Rotor*, are built up of laminated iron punchings in much the same manner as are the armature cores of ordinary dynamos.

The windings in both cases are laid in slots across the face of either part, and for this reason both parts are punched in a series of slots or holes for the reception of the windings. The following cuts, taken from the "American Electrician," show the usual form of slots used.



FIGS. 73 and 74. Forms of Punchings of Induction Motors.

The number of slots in the *stator* must be a multiple of the number of poles and number of phases, and Weiner gives the following table, in the "American Electrician," as showing the proper number to be used in various cases, both for two- and three-phase machines. In practice the number of poles is determined by the speed required and the available frequency ; then the number of slots is so designed as to be equally spaced about the whole inner periphery of the stator.

Number of Slots in Field-Frame of Induction Motors.

Capacity of Motor.	Number of Poles.	Slots per Pole.	Slots per Pole per Phase.	
			Two-Phase.	Three-Phase.
⅛ H.P. to 1 H.P.	4 to 8	3 4	1½ 2	1 —
½ H.P. to 1 H.P.	4 to 6	5 6	2½ 3	— 2
2 H.P. to 5 H.P.	4 to 10	5 6	2½ 3	— 2
	4 to 6	7 8 9	3½ 4 4½	— — 3
6 H.P. to 50 H.P.	6 to 12	7 8 9	3½ 4 4½	— — 3
	4 to 8	10 11 12	5 5½ 6	— — 4
50 H.P. to 200 H.P.	10 to 20	7 8 9	3½ 4 4½	— — 3
	8 to 12	10 11 12 13	5 5½ 6 6½	— — 4 —
	6 to 10	14 15 16	7 7½ 8	— 5 —

The number of slots per pole per phase in the *rotor* must be prime to that of the *stator* in order to avoid dead points in starting, and to insure smooth running, and commonly range from 7 to 9 times the number of poles, or any integer not divisible by the number of poles, in the squirrel cage or single conductor per slot windings. The proper number of slots may be taken from the following table by Weiner:

Number of Rotor Slots for Squirrel-Cage Induction Motors up to 5 H.P. Capacity.

Number of Poles, p.	Limits of Slots, Number 7 p. to 9 p.	Number of Rotor Slots.
4	28 to 36	29, 30, 31, 33, 34, 35, 37.
6	42 " 54	43, 44, 45, 46, 47, 49, 50, 51, 52, 53.
8	56 " 72	57, 58, 59, 60, 61, 62, 63, 65, 66, 67, 68, 69, 70, 71.

In large machines, where there is more than one conductor in each slot and in which the winding is connected in parallel, the number of slots in the *rotor* must be a multiple of both the number of phases and the number of pairs of poles.

The following table gives numbers of slots for various field-slots :

Number of Rotor-Slots for Induction Motors of Capacities over 5 H.P.

Number of Field-Slots per Pole.	Number of Rotor-Slots. (n_s = number of Field-Slots.)
8	$\frac{5}{4}n_s$. or $\frac{3}{2}n_s$.
9	$\frac{4}{3}n_s$.
10	$\frac{6}{5}n_s$. " $\frac{3}{2}n_s$.
12	$\frac{5}{4}n_s$. " $\frac{4}{3}n_s$.
14	$\frac{9}{7}n_s$. " $\frac{3}{2}n_s$.
15	$\frac{6}{5}n_s$. " $\frac{4}{3}n_s$.
16	$\frac{9}{8}n_s$. " $\frac{5}{4}n_s$.

Flux Density. — This must be settled for each particular case, as it will be governed much by the quality of iron and the particular design of the motor.

Hysteresis loss increases as the 1.6 power of the flux density ; and eddy current losses are proportional to the square of the density and also to the square of the frequency.

The following table shows practical values :

Flux-Densities for Induction Motors.

(Wiener.)

Capacity of Motor, H.P.	Flux-Density, in Lines of Force per Square Inch.					
	For Frequencies from 25 to 40.		For Frequencies from 60 to 100.		For Frequencies from 120 to 180.	
	Practical Values.	Aver-age.	Practical Values.	Aver-age.	Practical Values.	Aver-Age.
$\frac{1}{8}$	12000 to 18000	15000	10000 to 15000	12500	7000 to 11000	9000
$\frac{1}{4}$	15000 " 25000	20000	12000 " 18000	15000	7500 " 12500	10000
$\frac{1}{2}$	18000 " 32000	25000	15000 " 25000	20000	8000 " 17000	12500

Flux-Densities for Induction Motors—(*Continued*).

Capacity of Motor, H.P.	Flux-Density, in Lines of Force per Square Inch.					
	For Frequencies from 25 to 40.		For Frequencies from 60 to 100.		For Frequencies from 120 to 180.	
	Practical Values.	Average.	Practical Values.	Average.	Practical Values.	Average.
1	20000 to 40000	30000	18000 to 32000	25000	9000 to 21000	15000
2	25000 " 45000	35000	20000 " 40000	30000	10000 " 25000	17500
5	30000 " 50000	40000	25000 " 45000	35000	11000 " 29000	20000
10	40000 " 60000	50000	30000 " 50000	40000	12500 " 32500	22500
20	50000 " 70000	60000	35000 " 55000	45000	15000 " 35000	25000
50	60000 " 80000	70000	40000 " 60000	50000	17500 " 37500	27500
100	70000 " 90000	80000	45000 " 65000	55000	20000 " 40000	30000
150	80000 " 100000	90000	50000 " 70000	60000	25000 " 45000	35000
200†	90000 " 110000	100000	60000 " 80000	70000	30000 " 50000	40000

† And over.

In the earlier induction motors it was considered the most efficient method to connect the driving current to the revolving part or *rotor;* and as it is highly important that the number of windings on the *rotor* be *prime* to that of the *stator*, Fig. 75 shows a winding with an odd combination of conductors, being 51, or three times 17.

The *stator* windings would then be bars, connected at either end to a heavy copper ring, this forming a sort of "squirrel-cage."

In the modern machines the winding shown would be in coils on the stator, the three ends being carried to terminal blocks on the outside of the machine instead of to rings as shown, and the "squirrel-cage" would then be placed on the *rotor* and be made of bars as mentioned.

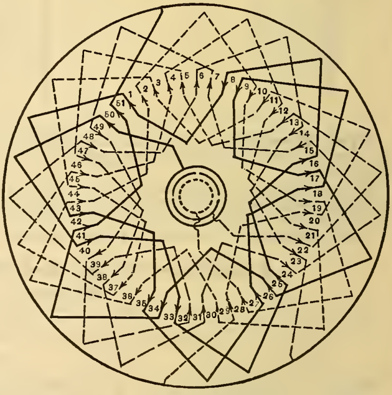


FIG. 75.

Starting and Regulating Devices.—Small induction motors, up to about 5 h. p. capacity, are started by closing the circuit directly to the motor. In large machines this would not be safe, as the *rotor* is standing, and would act in a lesser degree as the short-circuited secondary of a static transformer, and cause a heavy rush of current.

Resistance in Rotor.—This is a favorite method with the General Electric Company. A set of strongly constructed resistances is secured inside the rotor ring, and so arranged with a lever that they may be closed or short-circuited after the motor has reached its full speed. These resistances are in the armature circuits. In order to give maximum starting torque total armature resistance should be

$$r_1 = \sqrt{r^2 + (x_1 + y)^2}$$

Where r_1 = rotor resistance per circuit reduced to field system.
x_1 = rotor reactance per circuit reduced to field system.
r = resistance per field circuit.
γ = reactance per field circuit.

This method serves the double purpose of keeping down the starting current and increasing the starting torque.

Resistances in Stator. — Resistance boxes may be connected in the circuits supplying induction motors; three separate resistances in three-phase circuits, and two separate resistances in two-phase circuits. They must be all connected in such a manner as to be operated in unison. Under these conditions the pressure at the field terminals is reduced, as is of course the starting current and the starting torque. In order to start a heavy load, under this arrangement, a heavy starting-current is necessary.

Compensators or Auto-Transformers. — This method is greatly favored by the Westinghouse Electric and Manufacturing Company, is used to some extent by the General Electric Company, and consists of introducing an impedance coil across the line terminals, the motor being fed, in starting, from some point on the winding where the pressure is considerably less than line pressure. This avoids heavy drafts of current from the line, thus not disturbing other appliances attached thereto, but as regards starting-current and torque has the same effect as resistances directly in the line; that is, greatly reduces both.

Rotor Windings Commutated. — In this arrangement all or a part of the rotor windings are designed to be connected in series when starting, and are thrown in parallel after standard speed is attained. Another design has part of the conductors arranged in opposition to the remainder in starting, but all are thrown in parallel in regular order when running at standard speed. These commutated arrangements have not been much used in the United States.

SYNCHRONOUS MOTORS.

Alternators are convertible into motors; and one alternator will run in synchronism with another similar machine after it is brought to the same speed, or, if of unlike number of poles, to some multiple of the speed of the driven dynamo, provided the number of pairs of poles on the motor is divisible into the multiple. Such motors will run as if geared to the driven dynamo even up to two or three times its normal full torque or capacity. Single-phase synchronous motors have no starting-torque, but synchronous motors for multiphase circuits will come up to synchronism without much load, giving about 25 % starting-torque, starting as induction motors, with the d. c. field open.

When connected to lines on which are connected induction motors that tend to cause lagging currents and low-power factor of the line, over excitation of the synchronous motor fields acts in the same manner as a condenser introduced in the line, and tends to restore the current to phase with the impressed E.M.F., and therefore to do away with inductive disturbances.

It is necessary to provide some source from which may be obtained continuous current for exciting the fields of the synchronous motor; and this is oftenest done by the use of a small d. c. dynamo belted from the motor-shaft, the exciting current not being put into use until the motor armature reaches synchronism.

In starting a synchronous motor the field is open-circuited, and current is turned on the armature. In practice, field coils are connected in various ways to obviate the dangers of induced voltage, and a low resistance coil similar to the series winding of the d. c. machine is sometimes so arranged on the field poles as to give the necessary reaction for starting. Another way is to use a low-pressure excitation. and therefore few turns on the field coils; also the field coils are "split up" by a switch at starting. The field excitation is thrown on after the rotating part approaches synchronism, which may be indicated by a lamp or other suitable device at the operating switchboard.

Considerable care must be exercised in the use of synchronous motors, and their best condition is where the load is quite steady, otherwise they introduce inductive effects on the line that are quite troublesome. The field of such a motor can be adjusted for a particular load, so there will be neither leading nor lagging current, but unity power factor. If the load changes, then the power factor also changes, until the field is readjusted; if the load has been lessened the current will lead, and if it increases the current will lag. If induction motors are connected to the same line, with a synchronous motor that has a steady load, then the field of the synchronous motor can be over-excited to produce a *leading* current, which will counteract the effect of the *lagging* currents induced by the induction motors. If two or more synchronous motors are connected to the same circuit, and the load on one of them is quite variable, and its field is not changed to meet such changing conditions, a pumping effect is liable to take place in the other motors, unless especial provision has been made in the design of the motors to prevent it. It is only necessary to arrange one of the motors of the number for preventing this trouble, but better to make all alike. A copper shield between pole-pieces, and covering a portion of the pole-tip, will prevent the trouble; and the Westinghouse Electric and Manufacturing Company use a heavy copper strap around each pole-piece, with a shoe covering part of the pole-tip in the air-gap.

THEORY OF THE SYNCHRONOUS MOTOR.

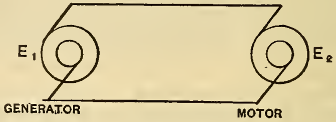


FIG. 76.

Let R = resistance of whole circuit.
L = self-inductance of whole circuit.

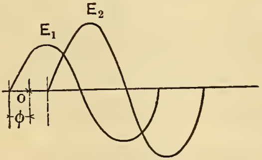


FIG. 77.

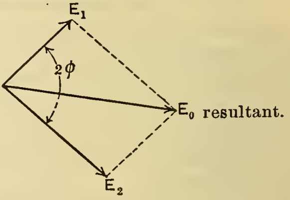


FIG. 78.

Take the origin at 0.
Let E represent maximum value.

$$e = \text{instantaneous value},$$
$$e_1 = E_1 \sin(\text{pt.} + \phi),$$
$$e_2 = E_2 \sin(\text{pt.} - \phi),$$

where $p = 2\pi\, n$, and n number of complete periods per second.

$$e = E_0 \sin(\text{pt.} - \psi)$$

where ψ = angle of lag of E_0 with respect to the origin.

$$E_0^2 = E_1^2 + E_2^2 + 2E_1\, E_2 \cos 2\,\phi,$$

$$\text{For}\qquad \begin{array}{ll} E_2 > E_1\,, & E_0 \text{ leads},\\ E_2 < E_1\,, & E_0 \text{ lags},\end{array}\left\{\begin{array}{l} \cos\psi = \dfrac{E_1 - E_2}{E_0}\cos\phi \\ \tan\psi = \dfrac{E_2 - E_1}{E_2 + E_1}\tan\phi \\ \sin\psi = \dfrac{(E_1 + E_2)}{E_0}\cos\phi \end{array}\right.$$

E_0 and ϕ are known.

Energy. Shifts the origin by the angle ψ.

$$e_1 = E_1 \sin(\text{pt.} + \phi + \psi).$$
$$e_2 = E_2 \sin(\text{pt.} - \phi + \psi).$$

Now
$$I = \frac{E_0}{\sqrt{R^2 + p^2 L^2}}$$

and I lags behind E_0 by the angle δ where

$$\tan\delta = \frac{L\,p}{R}.$$

By introducing the angle ψ we are referring the E.M.F.'s of both machines to the zero point of the resultant wave as origin.

In general

$$\omega = \frac{1}{T}\int_0^T e\,i\,dt = \frac{E\,I}{2}\cos\Theta$$

where $\omega =$ the energy in watts, and
$\Theta =$ lag or lead of I with respect to E.
E and I are maximum values.

$$T = \frac{1}{n}\text{, or the periodic time.}$$

Let $\omega_1 =$ energy given to the circuit by the generator,
$\omega_2 =$ energy absorbed from the circuit by the motor.

$$\omega_1 = \frac{1}{T}\int_0^T e,\,i\,dt =$$

$$\frac{E_1}{2}\,\frac{E_0}{\sqrt{R^2 + p^2 L^2}}\cos(\phi + \psi + \delta$$

$$[i = I\sin(\text{pt} - \delta)]$$

$$\omega_1 = \frac{E_1}{2}\,\frac{E_0}{\sqrt{R^2 + p^2 L^2}}\,[\cos(\phi + \psi)\cos\delta - \sin(\phi + \psi)\sin\delta]$$

$$\sin\delta = \frac{L\,p}{\sqrt{R^2 + L^2 p^2}} \qquad \cos\delta = \frac{R}{\sqrt{R^2 + p^2 L^2}}$$

$$\therefore\ \omega_1 = \frac{E_1 E_0}{2(R^2 + p^2 L^2} \left\{ R\cos(\phi + \psi) - L\,p\sin(\phi + \psi) \right\}$$

and substituting $-\phi$ for $+\phi$ we get

$$\omega_2 = \frac{E_2 E_0}{2(R^2 + p^2 L^2)} \left\{ R\cos(\phi - \psi) + Lp\sin(\phi - \psi) \right\}$$

$$\text{Now } \sin\psi = \frac{-(E_1 + E_2)}{E_0}\sin\phi$$

$$\cos\psi = \frac{E_1 - E_2}{E_0}\cos\phi$$

Substituting and reducing

$$\omega_2 = \frac{1}{2}\,\frac{E_2}{R^2 + p_2 L^2} \left\{ E_1(R\cos 2\phi + L\,p\sin 2\phi) - E_2 R \right.$$

An angle ϕ^1 is introduced such that

$$\sin 2\,\phi^1 = \frac{R}{\sqrt{R^2 + p^2 L^2}}$$

$$\cos 2\phi^1 = \frac{L\,p}{\sqrt{R^2 + p^2 L^2}}$$

Substitute in ω_2, and

$$\omega_2 = \frac{1}{2}\,\frac{E_2}{R^2+p^2L^2}\left\{E_1\sqrt{R^2+p^2L^2}\,\sin(2\phi+2\phi^1)-E_2R\right\}$$

ω_2 is a maximum when

$2\phi + 2\phi^1 = 90^\circ$ or

$$\phi + \phi^1 = \frac{\pi}{4};$$

that is, the "sine term" = unity.

ω_2 is positive provided

$$\frac{E_1}{E_2} > \frac{R}{\sqrt{R^2+p^2L^2}}$$

which shows that it is possible to have E_2 greater than E_1 if there is the proper ratio of resistance and reactance in the circuit.

Now, if we plot from an actual motor the armature current and the field excitation we get a curve shown in Fig. 79.

This shows that the armature current varies with the excitation for a given load. The flatter curves are for increase of load.

Point a shows under excitation,
b shows over excitation,
c shows the excitation which makes the power factor unity; it is well from the point of stability of operation to slightly over excite, and this makes $E_2 > E_1$, and also counteracts the inductive drop in the line, thus showing that the action of an over excited synchronous motor is similar to a condenser.

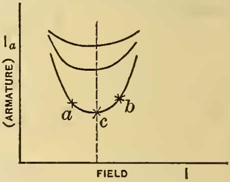


FIG. 79.

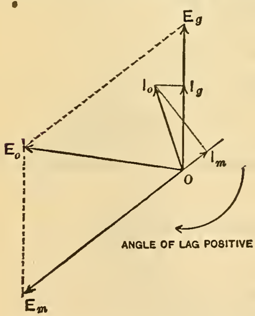


FIG. 80.

Graphical treatment.

E_g = generator E.M.F.
E_m = motor E.M.F.
E_o = resultant E.M.F.
I_o = resultant current.
$O\,I_g$ = projection of I_o on $O\,E_g$.
$O\,I_m$ = projection of I_o on $O\,E_m$.
$O\,I_g \cdot O\,E_g = \omega_g$ = energy given up by the generator.
$O\,I_m \cdot O\,E_m = \omega_m$ = energy absorbed by the motor from the circuit.

ω_m is negative, which shows that ω_m is the motor, because it is taking energy from the circuit; and similarly ω_g is the generator, because $O\,E_g \cdot O\,I_g$ is positive, and gives up energy to the circuit.

[For further discussion see Jackson's *Alternating Current* and *Alternating Current Machines;* also *Electrical World* for March 30 and April 6, 1895, by Bedell and Ryan. The latter is the classic paper on the subject.]

MOTOR GENERATORS OR DYNAMOTORS.

These are of two styles, one for transforming continuous current of one voltage into continuous current of a different voltage, and usually called in America *motor-generators;* the second class transforms alternating current into continuous current, or *vice versa*, the voltage not being changed excepting from A.C. $\sqrt{\text{mean}^2}$ values to d.c. values equal to the top of the A.C. wave; these latter machines are now called *rotary converters*, and are largely used in connection with the circuits of the Niagara Falls Power Company and other power transmission stations.

Motor-generators are now largely used in telegraph offices for reducing the pressure of the supply current to voltages suitable for use in telegraphy and for ringing and charging generators in telephone offices.

Theory. Let

$E =$ voltage at motor terminals.
$e =$ voltage at generator end terminals.
$I =$ current in motor armature.
$r =$ resistance of motor armature.
$n =$ number of conductors in motor armature.
$I_1 =$ current in generator armature part.
$r_1 =$ resistance of generator armature part.
$n_1 =$ number of conductors in generator armature part.
$\frac{n}{n_1} = k =$ coefficient of transformation.
$E =$ induced E.M.F. in motor part.
$E_1 =$ induced E.M.F. in generator part.
$E = rev. \times n \times \phi.$
$E_1 = rev. = n_1 \times \phi.$
$E = E - r\, I$
$E_1 = e + r_1 I_1.$
$ke = E = r\, I - kr_1\, I_1.$

If it be assumed that losses by hysteresis and eddy currents be negligible, or that $E\, I = E_1\, I_1$ whence $I_1 = k\, I$, then

$$e = \frac{E}{k} - \left(r_1 + \frac{r}{k^2}\right) I_1$$

Such machines run without sparking at the commutator, as all armature reactions are neutralized.

Continuous Current Boosters.

This is a type of *motor generator* much in use for *raising* or *lowering* the pressure on long feeders on the low-pressure system of distribution, and is to be found in most of the larger stations of the Edison companies. It is also much used in connection with storage-battery systems in charging cells.

The "*booster*" consists of a series generator driven by a motor direct connected to its armature shaft. The terminals of the generator are connected in series with one leg of the feeder ; and it is obvious that the current in the feeder will excite the series field just in proportion to the current flowing, provided the design of the iron magnetic circuit is liberal enough so that the field is way below saturation (on the straight part of the iron curve way below the knee). As the armature is being independently rotated in this field, it will produce an E.M.F. approximately in proportion to such excitation, which E.M.F. will be added to that of the feeder or will oppose that E.M.F., according as the terminal connections are made. On three-wire systems two generators are direct connected to one motor, and for convenience on one bed-plate.

Such a booster can be so adjusted as to make up for line loss as it increases with the load.

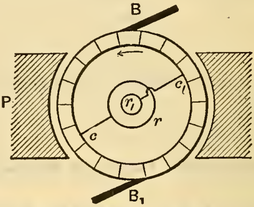
One danger of a booster that is not always taken into account is, that if the shunt of the driving-motor should happen to open, or, in fact, anything should happen to the driving-motor that would result in its losing its power, the generator would immediately become a series motor, taking current from the line to which it is connected, and by its nature would reverse in direction of rotation, and increase in speed enormously, and if not disconnected from its circuits in time would result in a complete wreck of the machine. It is always safest to have the generator terminals connected to their line through some automatic cut-out, so arranged that should the shunt break, as suggested, it would actuate the device, and automatically detach the booster from the circuit before harm could be done.

ROTARY CONVERTERS.

A *rotary converter* is the name given to a machine designed for changing alternating currents into continuous currents. If the same machine be used inverted, i.e., for changing continuous currents into alternating, it is sometimes known as an *inverted converter*. Again, if the same machine be driven by outside mechanical power, both alternating and continuous currents may be taken from it, and it then becomes known as a *double current generator*.

Theoretically the *rotary converter* is a continuous current dynamo with collector rings added, which are connected by leads to certain parts of the armature windings, sometimes at the commutator segments.

In the following figure, which represents in diagram the *single-phase rotary converter*, the collector rings r and r_1 are connected by leads to diametrically opposite segments or coils of the armature at c and c_1. It is obvious that as the armature revolves the greatest difference of potential between the rings, or maximum E.M.F., will be at the instant the segments c and c_1 pass under and coincide with the brushes B and B_1; and this E.M.F. will decrease as the rotation continues, until the lowest E.M.F. will occur when the segments c and c_1 are directly opposite the centre of the pole-pieces P and P_1.



SINGLE PHASE ROTARY CONVERTER

FIG. 81.

The maximum alternating E.M.F. will be equal to the continuous current voltage at the brushes B and B_1, and if the machine be designed to produce a sinusoidal curve of E.M.F., then the alternating E.M.F., that is, the $\sqrt{\text{mean}^2}$ or effective E.M.F., will be,

$$e = E \sin 2\pi\, Nt. \quad \text{or } e = \frac{E}{\sqrt{2}} = .707\, E$$

Where $e = \sqrt{\text{mean}^2}$ or effective voltage,
$E =$ continuous current voltage, or maximum,
$Nt =$ frequency of rotation.

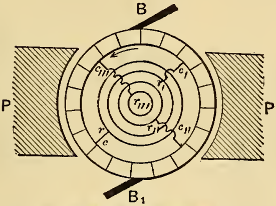
In a bipolar machine the frequency is t, and in a machine with p poles the frequency will be $\frac{p}{2}\, t$.

Neglecting losses and phase displacement the supply of alternating current to the rings must be $I \sqrt{2} = 1.414\, I$ where I is the continuous current output.

If, as shown in Fig. 82, another pair of rings be added, and connected to points on the winding at right angles to the first, then another and similar

E.M.F. will be produced, but in quadrature to the first. The E.M.F. will be the same for each phase as in the single-phase connection previously shown, and still neglecting phase displacement and losses the current will be for each of the two phases

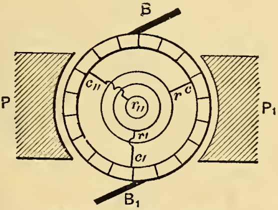
$$\frac{I}{\sqrt{2}} = .707\ I.$$



TWO PHASE, OR QUARTER PHASE ROTARY CONVERTER

FIG. 82.

If three equidistant points on the armature windings be connected to three rings, as shown in the following diagram, a *three-phase* converter is produced.



THREE PHASE ROTARY CONVERTER

FIG. 83.

As the connections of a *three-phase rotary* are always delta, the E.M.F.'s as compared with the continuous current E.M.F. E have the following value:

Voltage between collector ring and neutral point $e = \frac{E}{2\sqrt{2}} = .354\ E.$

Voltage between collector rings $e^1 = \frac{E\sqrt{3}}{2\sqrt{2}} = .612\ E.$

Alternating current input $= i = \frac{I\ E}{3\ e} = \frac{2\ I\sqrt{2}}{3} = .943\ I.$

Steinmetz, in the *Electrical World* of Dec. 17, 1898, gives the following table of values of the alternating E.M.F. and current in units of continuous current.

Value of A. C. Voltage and Current in Terms of D. C.

	Continuous Current	Single-phase.	Three-phase.	Two-phase.	Six-phase.	Twelve-phase.	n phase.
Volts between collector ring and neutral point . .	1	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = 354$	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = .354$
Volts between adjacent collector rings	1	$\frac{1}{\sqrt{2}} = .707$	$\frac{\sqrt{3}}{2\sqrt{2}} = .612$	$\frac{1}{2} = .5$	$\frac{1}{2\sqrt{2}} = .354$	.183	$\frac{1}{\sqrt{2} \sin \frac{\pi}{n}}$
Amperes per line .	1	$\sqrt{2} = 1.414$	$\frac{2\sqrt{2}}{3} = .943$	$\frac{1}{\sqrt{2}} = .707$	$\frac{\sqrt{2}}{3} = .472$	.236	$\frac{2\sqrt{2}}{n}$
Amperes between adjacent lines .	1	$\sqrt{2} = 1.414$	$\frac{2\sqrt{2}}{3\sqrt{3}} = .545$	$\frac{1}{2} = .5$	$\frac{\sqrt{2}}{3} = .472$	.455	$\frac{\sqrt{2}}{n \sin \frac{\pi}{n}}$

The values of E.M.F. and of current stated above are theoretical, and are varied in practice by reason of drop in armature conductors and phase displacement. In converting from a.c. to d.c., if the current in the rotary is in phase with the impressed E.M.F., armature self-induction has little effect; but with a *lagging* current, which may be due to under-excitation, the induced d.c. E.M.F. is somewhat reduced; and if the machine be over-excited, thus producing a *leading* current, the induced d.c. E.M.F. will be raised. The same is the case in converting from d.c. to a.c., the a.c. volts being down on a lagging circuit.

The corrections for the theoretical ratios of voltages as shown are, first for drop in the armature; and second, they have to be multiplied by the factors shown above.

Steinmetz says that the current flowing in the armature conductors of a rotary is the difference between the alternating current input and the continuous current output. The armature heating is therefore relatively small, and the practical limit of overload is limited by the commutator, and is usually far higher than in the continuous current generator.

In six-phase rotaries the I^2R losses of the armature are but 29 % of the regular I^2R loss in the armature as used for d.c. dynamo.

Kapp shows that width of pole-face has a bearing on the increase in output of a rotary converter over the same machine used as a continuous current dynamo. He compares the output of two converters, one in which the pole-face is two-thirds the pole distance, and another in which it is one-half the pole distance. In single-phase converters the output is not equal to that of the d.c. dynamo, and two- and three-phase machines are much different.

He gives, in the following table, the percentage of d.c. output of what would be the output of the same machine used as a d.c. dynamo.

		Pole-width.	
		$\frac{2}{3}$	$\frac{1}{2}$
Single-phase	Cos = 1.	88%	95%
	Cos = .9	81	88
	Cos = .8	73	80
	Cos = .7	63	70
Three-phase	Cos = 1.	138	144
	Cos = .9	128	137
	Cos = .8	117	126
Two- or four-phase	Cos = 1.	167	170
	Cos = .9	160	167
	Cos = .8	144	153

To find the voltage required between collector rings on rotary converters, when

T = number of turns in series between collector rings,
n = flux from one pole-piece into the armature,
n = cycles per second,
E = required E.M.F.

Then

For single-phase and two-phase machines

$$E = 2.83\ T n \Phi\ 10^{-8},$$

For three-phase machines

$$E = 3.69\ T n \Phi\ 10^{-8}.$$

The single-phase *rotary* has to be turned up to synchronous speed by some external power, as it will not start itself.

The polyphase *rotary* will start itself from the a.c. end, but takes a tremendous lagging current, and therefore, where possible, it should be started from its d.c. side.

The starting of rotaries that are connected to lines having lights also connected, should *always* be done from the d.c. side, as the large starting current taken at the moment of closing the switch will surely show in the lamps. Polyphase rotaries are sometimes started, as are induction motors, by use of a "compensator."

In starting a *rotary*, the field circuit must be opened until synchronism is reached, after which it is closed. The d.c. side must also be disconnected from its circuit, as it is obvious that the current produced is alternating until synchronism is reached. Care must be taken to keep the field circuit closed when the d.c. side is connected in parallel with other machines, and the a.c. side open, or the armature will run away and destroy itself.

As the change in excitation of the field of a rotary changes the d.c. voltage but little, and on the other hand produces wattless currents, the regulation of E.M.F. must be accomplished by some other method. This can be done by changing the ratio of the static transformer by cutting in and out turns as its primary, or by the introduction of self-induction coils in the a.c. leads to the *rotary*.

The first introduces a complicated set of connections and contacts, but is unlimited in range.

The second method seems especially suited for the purpose, but is somewhat limited in range. Theoretically the action is as follows: Suppose the excitation to be low enough so that the current lags 90° behind the impressed E.M.F., the E.M.F. of self-induction lags 90° behind the current, and is therefore 180° behind the impressed E.M.F., and therefore in opposition to it. On the other hand, if the excitation is large, and produces a leading current of 90°, the E.M.F. of self-induction is in phase with the impressed E.M.F. and adds itself to it. Therefore, with self-induction introduced in the a.c. lines, it is only necessary to vary the excitation in order to change the continuous current E.M.F. A *rotary* can thus be compounded by using shunt and series field, to maintain a constant E.M.F. under changes of load, the compounding taking place, of course, in the a.c. lines and not in the field of the machine, as usual in d.c. dynamos.

In handling the *inverted* converter care must be exercised in starting it under load, as it is apt to run away if not connected in parallel with other alternators. If they are started from the d.c. side, and have lagging currents flowing from a.c. side, this current will tend to demagnetize or weaken the fields, and the speed of the armature is liable to accelerate to the danger limit.

A lagging current taken from an inverted rotary, even after having reached synchronism, will cause an immediate increase in speed, and if enough lagging will cause an approach to the danger point.

Running as a rotary, and converting from a.c. to d.c., the phase of the entering current has no effect on the speed, this being determined by the cycles of the driving generator, nor upon the commutation, simply influencing the heat in the armature and ratio of voltages slightly.

Double-current generators are useful in situations where continuous current can be used for a portion of the day and the current transferred through the a.c. side to some other district for use in another portion of the day, thus keeping the machine under practically constant load.

The size of *double-current generators* is limited by the size of the d.c. generator that can be built with the same number of poles as a good alternator. The heating of the armature depends upon the sum and not the difference of the currents, as in the *rotary*, and the capacity is therefore no greater than a d.c. machine of the same total output.

Automatic compounding of *double current generators* is scarcely feasible in practice, and the field must be very stable, as the demagnetizing effect of the lagging a.c. currents tends to drop the excitation entirely. Such machines run better separately excited.

CONVERTER ARMATURE WINDINGS.

Two-Circuit Winding for Two-Phase Rotary Transformers.

The following diagram shows the connections of the four rings to the different sections of the armature. The connections are made at the commutator segments at four points, although there are six poles.

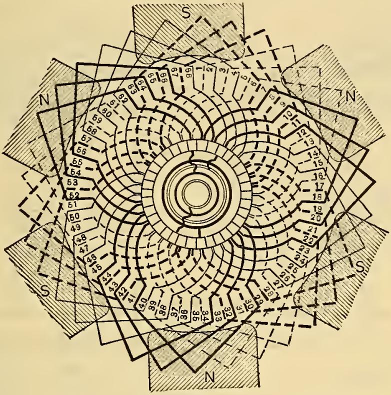


FIG. 84.

Two-Circuit Winding for Three-Phase Rotary Transformers.

The following diagram shows the connections of the three collector rings to the continuous current winding of a six-pole dynamo. As in the last figure, the rings are connected to points on the commutator at nearly equidistant points.

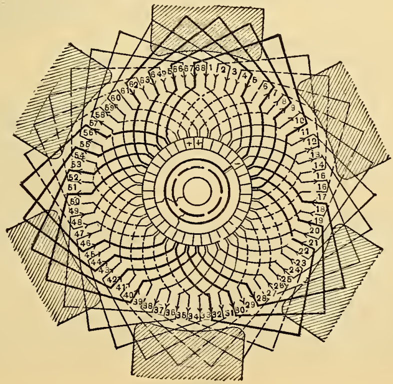


FIG. 85.

Note.—Connection of Static Transformers and Rotary Converters.

In the use of rotary transformers two or more of these machines are sometimes connected in multiple to the secondary of the static transformers, and their direct current leads then connected in multiple to a common bus bar circuit, as shown in Fig. 86.

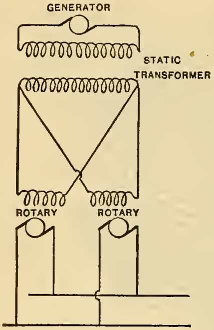


Fig. 86.

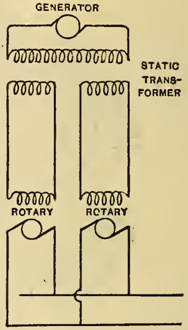


Fig. 87.

With the above connections currents are often formed in the rotaries that disturb the point of commutation, and it becomes practically impossible to adjust the brushes so they will not spark. Rather than connect across in the above manner, it is better that each rotary have its own transformer, or at least its own secondary on the static transformer, as shown in Fig. 87.

REPORT OF THE COMMITTEE ON STANDARDIZATION.

[ADOPTED AT THE 19TH ANNUAL CONVENTION AT GREAT BARRINGTON, MASS., JUNE 20, 1902.]

Reprinted from Vol. XIX. of the Transactions.

To the Council of The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

GENTLEMEN : Your Committee on Standardization begs to submit the following revised series of recommendations, which embraces the Committee's report of 1899, amended in view of such suggestions and extensions as experience and practice have since indicated to be desirable.

The subjects discussed in these recommendations are such as call for extension and revision from time to time, in view of the rapid advance of electrical engineering.

Yours respectfully,
FRANCIS B. CROCKER, *Chairman*,
A. E. KENNELLY,
JOHN W. LIEB, Jr.,
C. O. MAILLOUX,
CHARLES P. STEINMETZ,
LEWIS B. STILLWELL,
ELIHU THOMSON.

GENERAL PLAN.

Efficiency. **Sections 1 to 25.**

(I)	Commutating Machines,	Sections 7 to 10
(II)	Synchronous Machines,	" 11 to 12
(III)	Synchronous Commutating Machines,	" 13 to 16
(IV)	Rectifying Machines,	" 17 to 18
(V)	Stationary Induction Apparatus,	" 19 to 20
(VI)	Rotary Induction Apparatus,	" 21 to 24
(VII)	Transmission Lines,	" 25

Rise of Temperature. Sections 26 to 35.
Insulation. Sections 36 to 49.
Regulation. Sections 50 to 71.
Variation and Pulsation. Sections 72 to 74.
Rating. Sections 75 to 82.
Classification of Voltages and Frequencies. Sections 83 to 88.
Overload Capacities. Sections 89 to 92.
Luminous Sources. Sections 93 to 98.
Appendices.
- (I) Efficiency.
- (II) Apparent Efficiency.
- (III) Power Factor and Inductance Factor.
- (IV) Notation.
- (V) Table of Sparking Distances.

Preliminary Definitions:

A direct current is a unidirectional current.

A continuous current is a steady, or non-pulsating, direct current.

An alternating current is a current of equal half-waves in successively opposite directions.

An oscillating current is a current alternating in direction, and of decreasing amplitude.

Electrical Apparatus will be treated under the following heads :

I. Commutating Machines, which comprise a constant magnetic field, a closed-coil armature, and a multi-segmental commutator connected thereto.

Under this head may be classed the following: Continuous-current generators ; continuous-current motors ; continuous-current boosters ; motor-generators ; dynamotors ; converters and closed-coil arc machines.

A booster is a machine inserted in series in a circuit to change its voltage, and may be driven either by an electric motor, or otherwise. In the former case it is a motor-booster.

A motor-generator is a transforming device consisting of two machines, a motor and a generator, mechanically connected together.

A dynamotor is a transforming device combining both motor and generator action in one magnetic field, with two armatures, or with an armature having two separate windings.

For converters, see III.

II. Synchronous Machines, which comprise a constant magnetic field, and an armature receiving or delivering alternating currents in synchronism with the motion of the machine; i.e., having a frequency equal to the product of the number of pairs of poles and the speed of the machine in revolutions per second.

III. Synchronous Commutating Machines.—These include: 1. Synchronous converters, commonly called "converters"; i.e., converters from alternating to direct, or from direct to alternating current; and 2 Double-current generators; i.e., generators producing both direct and alternating currents.

A converter is a machine employing mechanical momentum in changing electric energy from one form into another.

A converter may be either:

a. A direct-current converter, converting from a direct current to a direct current, or

b. A synchronous converter, formerly called a rotary converter, converting from an alternating to a direct current, or vice-versa.

Phase converters are converters from an alternating-current system to an alternating-current system of the same frequency but in different phase.

Frequency converters are converters from an alternating-current system of one frequency to an alternating-current system of another frequency, with or without change in the number of phases.

IV. Rectifying Machines, or Pulsating-Current Generators, which produce a unidirectional current of periodically varying strength.

V. Stationary Induction Apparatus, i.e., stationary apparatus changing electric energy to electric energy through the medium of magnetic energy. These comprise:

a. Transformers, or stationary induction apparatus in which the primary and secondary windings are electrically insulated from each other.

b. Auto-transformers, also called compensators; i.e., stationary induction apparatus, in which part of the primary winding is used as a secondary winding; or conversely.

c. Potential regulators, or stationary induction apparatus having a coil in shunt, and a coil in series with the circuit, so arranged that the ratio of transformation between them is variable at will.

These may be divided into the following types, or combinations thereof:

1. Compensator potential-regulators, in which the number of turns of one of the coils is changed.

2. Induction potential-regulators, in which the relative positions of primary and secondary coils is changed.

3. Magneto potential-regulators, in which only the direction of the magnetic flux with respect to the coils is changed.

d. Reactors, or Reactance coils, formerly called choking coils; i.e., stationary induction apparatus used to produce impedance or phase displacement.

VI. Rotary Induction Apparatus, which consist of primary and secondary windings rotating with respect to each other. They comprise:

a. Induction motors.
b. Induction generators.
c. Frequency converters.
d. Rotary phase converters.

EFFICIENCY.

1. The "efficiency" of an apparatus is the ratio of its net power output to its gross power input.*

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* An exception should be noted in the case of storage batteries or apparatus for storing energy in which the efficiency, unless otherwise qualified, should be understood at the ratio of the energy output to the energy intake in a normal cycle.

2. The efficiency of all apparatus, except such as may be intended for intermittent service, should be either measured at, or reduced to, the temperature which the apparatus assumes under continuous operation at full rated load, referred to a room temperature of 25° C.

With apparatus intended for intermittent service, the efficiency should be determined at the temperature assumed under specified conditions.

3. Electric power should be measured at the terminals of the apparatus.

4. In determining the efficiency of alternating-current apparatus, the electric power should be measured when the current is in phase with the E.M.F., unless otherwise specified, except when a definite phase difference is inherent in the apparatus, as in induction motors, induction generators, frequency converters, etc.

5. Mechanical power in machines should be measured at the pulley, gearing, coupling, etc., thus excluding the loss of power in said pulley, gearing, or coupling, but including the bearing friction and windage. The magnitude of bearing friction and windage may be considered as independent of the load. The loss of power in the belt and the increase of bearing friction due to belt tension, should be excluded. Where, however, a machine is mounted upon the shaft of a prime mover, in such a manner that it cannot be separated therefrom, the frictional losses in bearings and in windage, which ought, by definition, to be included in determining the efficiency, should be excluded, owing to the practical impossibility of determining them satisfactorily. The brush friction, however, should be included.

Where a machine has auxiliary apparatus, such as an exciter, the power lost in the auxiliary apparatus should not be charged to the machine but to the plant consisting of machine and auxiliary apparatus taken together. The plant efficiency in such cases should be distinguished from the machine efficiency.

6. The efficiency may be determined by measuring all the losses individually, and adding their sum to the output to derive the input, or subtracting their sum from the input to derive the output. All losses should be measured at, or reduced to, the temperature assumed in continuous operation, or in operation under conditions specified. (See Sections 26 to 35.)

In order to consider the application of the foregoing rules to various machines in general use, the latter may be conveniently divided into classes as follows:

I. Commutating Machines.

7. In commutating machines the losses are:

a. Bearing friction and windage. (See Section 5.)

b. Molecular magnetic friction, and eddy currents in iron and copper, also I^2r losses in cross-connections of cross-connected armatures. These losses should be determined with the machine on open circuit, and at a voltage equal to the rated voltage $+ Ir$ in a generator, and $- Ir$ in a motor, where I denotes the current strength and r denotes the internal resistance of the machine. They should be measured at the correct speed and voltage, since they do not usually vary in any definite proportion to the speed or to the voltage.

c. Armature resistance losses. I^2r', where I is the current strength in the armature, and r' is the resistance between armature brushes, excluding the resistance of brushes and brush contacts.

d. Commutator brush friction.

e. Commutator brush-contact resistance. It is desirable to point out that with carbon brushes the losses (*d*) and (*e*) are usually considerable in low-voltage machines.

f. Field excitation. With separately excited fields, the loss of power in the resistance of the field coils alone should be considered. With shunt fields or series fields, however, the loss of power in the accompanying rheostat should also be included, the said rheostat being considered as an essential part of the machine, and not as separate auxiliary apparatus.

(*b*) and (*c*) are losses in the armature or "armature losses"; (*d*) and (*e*) "commutator losses"; (*f*) "field losses."

8. The difference between the total losses under load and the sum of the losses above specified, should be considered as "load losses," and are usually trivial in commutating machines of small field distortion. When the field distortion is large, as is shown by the necessity for shifting the brushes between no load and full load, or with variations of load, these load losses may be considerable, and should be taken into account. This applies especially to constant-current arc-light generators. In this case the efficiency may be determined either by input and output measurements, or the load losses may be estimated by the method of Section II.

9. Boosters should be considered and treated like other direct-current machines in regard to losses.

10. In motor-generators, dynamotors, or converters, the efficiency is the electric output divided by the electric input.

II. Synchronous Machines.

11. In synchronous machines the output or input should be measured with the current in phase with the terminal E.M.F., except when otherwise expressly specified.

12. The losses in synchronous machines are:

a. Bearing friction and windage. (See Section 5.)

b. Molecular magnetic friction, and eddy currents in iron, copper, and other metallic parts. These losses should be determined at open circuit of the machine at the rated speed and at the rated voltage, $+ I r$ in a synchronous generator, $- I r$ in a synchronous motor, where $I =$ current in armature, $r =$ armature resistance. It is undesirable to compute these losses from observations made at other speeds or voltages.

These losses may be determined either by driving the machine by a motor, or by running it as a synchronous motor, and adjusting its fields so as to get minimum current input, and measuring the input by wattmeter.

In the latter case, with polyphase machines, several wattmeters must be used, arranged so as to measure unbalanced load. The former method is preferable, since the latter is liable to error caused by acceleration and retardation due to a pulsation of frequency or an inherent tendency to surging.

c. Armature-resistance loss, which may be expressed by $p I^2 r$; where r = resistance of one armature circuit or branch, $I =$ the current in such armature circuit or branch, and $p =$ the number of armature circuits or branches.

d. Load losses as defined in Section 8. While these losses cannot well be determined individually, they may be considerable, and, therefore, their joint influence should be determined by observation. This can be done by operating the machine on short circuit and at full-load current; that is, by determining what may be called the "short-circuit core loss." With the low field intensity and great lag of current existing in this case, the load losses are usually greatly exaggerated.

One-third of the short-circuit core loss may, as an approximation, and in the absence of more accurate information, be assumed as the load loss.

e. Collector-ring friction and contact resistance. These are generally negligible, except in machines of extremely low voltage.

f. Field excitation. In separately-excited machines, the $I^2 r$ of the field coils proper should be used. In self-exciting machines, however, the loss in the field rheostat should be included. (See Section 7*f.*)

III. Synchronous Commutating Machines.

13. In converters, the power on the alternating-current side is to be measured with the current in phase with the terminal E.M.F., unless otherwise specified.

14. In double-current generators, the efficiency of the machine should be determined as a direct-current generator in accordance with Section 7, and as an alternating-current generator in accordance with Section 12. The two values of efficiency may be different, and should be clearly distinguished.

15. In converters the losses should be determined when driving the machine by a motor. These losses are:

a. Bearing friction and windage. (See Section 5.)

b. Molecular magnetic friction, and eddy currents in iron, copper, and metallic parts; also, $I^2 r$ loss, due to cross-current in cross-connected armatures. These losses should be determined at open circuit and at the rated terminal voltage, no allowance being made for the armature resistance, since the alternating and the direct currents flow in opposite directions.

c. Armature resistance. The loss in the armature is $q\ I^2 r$, where $I =$ direct current in armature, $r =$ armature resistance, and q, a factor which is equal to 1.47 in single-circuit single-phase, 1.15 in double-circuit single-phase, 0.59 in three-phase, 0.39 in quarter-phase, and 0.27 in six-phase converters.

d. Load losses. The load losses should be determined in the same manner as described in Section 12 *d*, with reference to the direct-current side.

e and *f*. Losses in commutator and collector friction and brush contact resistance. (See Sections 7 and 12.)

g. Field excitation. In separately-excited fields, the $I^2 r$ loss in the field coils proper should be taken, while in shunt and series fields the rheostat loss should be included, except where fields and rheostats are intentionally modified to produce effects outside of the conversion of electric power, as for producing phase displacement for voltage control. In this case 25 per cent of the $I^2 r$ loss in the field proper at non-inductive alternating circuit should be added as proper estimated allowance for normal rheostat losses. (See Section 7 *f*.)

16. Where two similar synchronous machines are available, their efficiency can be determined by operating one machine as a converter from direct to alternating, and the other as a converter from alternating to direct, connecting the alternating sides together, and measuring the difference between the direct-current input and the direct-current output. This process may be modified by returning the output of the second machine through two boosters into the first machine and measuring the losses. Another modification is to supply the losses by an alternator between the two machines, using potential regulators.

IV. Rectifying Machines, or Pulsating-Current Generators.

17. These include : Open-coil arc machines, constant-current rectifiers, constant-potential rectifiers.

The losses in open-coil arc machines are essentially the same as in Sections 7 to 10 (closed-coil commutating machines). In this case, however, the load losses are usually greater, and the efficiency should be measured by input-and-output test, using wattmeters for measuring the output. In alternating-current rectifiers, the output must be also measured by wattmeter, and not by voltmeter and ammeter ; since owing to the pulsation of current and E.M.F., a considerable discrepancy may exist between watts and volt-amperes, amounting to as much as 10 or 15 per cent.

18. In constant-current rectifiers, transforming from constant-potential alternating to constant direct current by means of constant-current transforming devices and rectifying commutators, the losses in the transformers are to be included in the efficiency, and have to be measured when operating the rectifier, since in this case the losses are generally greater than when feeding an alternating secondary circuit. In constant-current transforming devices, the load losses may be considerable, and, therefore, should not be neglected.

The most satisfactory method of determining the efficiency in rectifiers is to measure electric input and electric output by wattmeter. The input is usually inductive, owing to a considerable phase displacement, and to wave distortion. For this reason the apparent efficiency should also be considered, since it is usually much lower than the true efficiency. The power consumed by the synchronous motor or other source driving the rectifier should be included in the electric input.

V. Stationary Induction Apparatus.

19. Since the efficiency of induction apparatus depends upon the wave shape of E.M.F., it should be referred to a sine wave of E.M.F., except where expressly specified otherwise. The efficiency should be measured with non-inductive load, and at rated frequency, except where expressly specified otherwise. The losses are:

a. Molecular magnetic friction and eddy currents measured at open circuit and at rated voltage — Ir, where $I =$ rated current, $r =$ resistance of primary circuit.

b. Resistance losses, the sum of the I^2r in the primary and in the secondary windings of a transformer, or in the two sections of the coil in a compensator or auto-transformer, where $I =$ current in the coil or section of coil. $r =$ resistance.

c. Load losses, i.e., eddy currents in the iron, and especially in the copper conductors, caused by the current. They should be measured by short-circuiting the secondary of the transformer and impressing upon the primary an E.M.F. sufficient to send full-load current through the transformer. The loss in the transformer under these conditions measured by wattmeter gives the load losses $+ I^2r$ losses in both primary and secondary coils.

d. Losses due to the methods of cooling, as power consumed by the blower in air-blast transformers, and power consumed by the motor driving pumps in oil or water-cooled transformers. Where the same cooling apparatus supplies a number of transformers or is installed to supply future additions, allowance should be made therefor.

20. In potential regulators, the efficiency should be taken at the maximum voltage for which the apparatus is designed, and with non-inductive load, unless otherwise specified.

VI. Rotary Induction Apparatus.

21. Owing to the existence of load losses, and since the magnetic density in the induction motor under load changes in a complex manner, the efficiency should be determined by measuring the electric input by wattmeter, and the mechanical output at the pulley, gear, coupling, etc.

22. The efficiency should be determined at the rated frequency, and the input measured with sine waves of impressed E.M.F.

23. The efficiency may be calculated from the apparent input, the power factor, and the power output. The same applies to induction generators. Since phase displacement is inherent in induction machines, their apparent efficiency is also important.

24. In frequency converters, i.e., apparatus transforming from an alternating system to an alternating system of different frequency, with or without a change in the number of phases, and in phase converters, i.e., apparatus converting from an alternating system, usually single-phase, to another alternating system, usually polyphase, of the same frequency, the efficiency should also be determined by measuring both output and input.

VII. Transmission Lines.

25. The efficiency of transmission lines should be measured with non-inductive load at the receiving end, with the rated receiving pressure and frequency, also with sinusoidal impressed E.M.F.'s, except where expressly specified otherwise, and with the exclusion of transformers or other apparatus at the ends of the line.

RISE OF TEMPERATURE.

General Principles.

26. Under regular service conditions, the temperature of electrical machinery should never be allowed to remain at a point at which permanent deterioration of its insulating material takes place.

27. The rise of temperature should be referred to the standard conditions of a room-temperature of 25° *C.*, a barometric pressure of 760 mm. and normal conditions of ventilation; that is, the apparatus under test should neither be exposed to draught nor inclosed, except where expressly specified.

28. If the room-temperature during the test differs from 25° *C.*, the observed rise of temperature should be corrected by ½ per cent for each degree *C.* Thus with a room-temperature of 35° *C.*, the observed rise of temperature has to be decreased by 5 per cent, and with a room-temperature of 15° *C* the observed rise of temperature has to be increased by 5 per cent. The thermometer indicating the room-temperature should be screened from thermal radiation emitted by heated bodies, or from draughts of air. When it is impracticable to secure normal conditions of ventilation on account of an adjacent engine, or other sources of heat, the thermometer for measuring the air temperature should be placed so as fairly to indicate the temperature which the machine would have if it were idle, in order that the rise of temperature determined shall be that caused by the operation of the machine.

29. The temperature should be measured after a run of sufficient duration to reach practical constancy. This is usually from 6 to 18 hours, according to the size and construction of the apparatus. It is permissible, however, to shorten the time of the test by running a lesser time on an overload in current and voltage, then reducing the load to normal, and maintaining it thus until the temperature has become constant.

In apparatus intended for intermittent service, as railway motors, starting rheostats, etc., the rise of temperature should be measured after operation under as nearly as possible the conditions of service for which the apparatus is intended, and the conditions of the test should be specified.

In apparatus which by the nature of their service may be exposed to overload, as railway converters, and in very high voltage circuits, a smaller rise of temperature should be specified than in apparatus not liable to overloads or in low voltage apparatus. In apparatus built for conditions of limited space, as railway motors, a higher rise of temperature must be allowed.

30. In electrical conductors, the rise of temperature should be determined by their increase of resistance, where practicable. For this purpose the resistance may be measured either by galvanometer test, or by drop-of-potential method. A temperature coefficient of 0.42 per cent per degree *C.*, from and at 0° *C.*, may be assumed for copper.* Temperature elevations measured in this way are usually in excess of temperature elevations measured by thermometers.

When thermometers are applied to the free surface of a machine, it is desirable that the bulb of the thermometer should be covered by a pad of definite area. A convenient pad may be formed of cotton waste in a shallow circular box about one and a half inches in diameter, through a slot in the side of which the thermometer bulb is inserted. An unduly large pad over the thermometer tends to interfere with the natural liberation of heat from the surface to which the thermometer is applied.

31. With apparatus in which the insulating materials have special heat-resisting qualities a higher temperature elevation is permissible.

32. In apparatus intended for service, in places of abnormally high temperature, a lower temperature elevation should be specified.

33. It is recommended that the following maximum values of temperature elevation should not be exceeded:

Commutating machines, rectifying machines, and synchronous machines:
    Field and armature, by resistance, 50° *C.*
    Commutator and collector rings and brushes, by thermometer, 55° *C.*
    Bearings and other parts of machine, by thermometer, 40° *C.*
Rotary induction apparatus:
    Electric circuits, 50° *C.*, by resistance.
    Bearings and other parts of the machine, 40° *C.*, by thermometer.

In squirrel-cage or short-circuited armatures, 55° *C.*, by thermometer, may be allowed.

Transformers for continuous service — electric circuits by resistance,

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* By the formula

$$R_t = R_0 (1 + 0.0042\, t) \text{ and } R_{t+\theta} = R_0 [1 + 0.0042\, (t + \theta)$$

where R_t is the initial resistance at room-temperature t^0 *C.*
$R_{t+\theta}$ is the final resistance at temperature elevation $\theta°$ *C.*
R_0 is the inferred resistance at 0° *C.*

These combine into the formula

$$\theta = (238.1 + t) \left(\frac{R_{t+\theta}}{R_t} - 1 \right) \qquad \text{degrees } C.$$

50° *C.*, other parts by thermometer, 40° *C.*, under conditions of normal ventilation.

Reactors, induction- and magneto-regulators — electric circuits by resistance, 50° *C.*, other parts by thermometer, 40° *C.*

Where a thermometer, applied to a coil or winding, indicates a higher temperature elevation than that shown by resistance measurement, the thermometer indication should be accepted. In using the thermometer, care should be taken so to protect its bulb as to prevent radiation from it, and, at the same time, not to interfere seriously with the normal radiation from the part to which it is applied.

34. In the case of apparatus intended for intermittent service, except railway motors, the temperature elevation which is attained at the end of the period corresponding to the term of full load, should not exceed 50° *C.*, by resistance in electric circuits. In the case of transformers intended for intermittent service, or not operating continuously at full load, but continuously in circuit, as in the ordinary case of lighting transformers, the temperature elevation above the surrounding air-temperature should not exceed 50° *C.* by resistance in electric circuits and 40° *C.* by thermometer in other parts, after the period corresponding to the term of full load. In this instance, the test load should not be applied until the transformer has been in circuit for a sufficient time to attain the temperature elevation due to core loss. With transformers for commercial lighting, the duration of the full-load test may be taken as three hours, unless otherwise specified. In the case of railway, crane, and elevator motors, the conditions of service are necessarily so varied that no specific period corresponding to the full-load term can be stated.

35. The commercial rating of a railway motor should be the h. p. output giving 75° *C.* rise of temperature, above a room temperature of 25° *C.* after one hour's continuous run at 500 volts terminal pressure, on a stand, with the motor covers removed.

For determining the service temperature of a railway motor, the temperature rise should be determined by operating the motor on a straight and level track and under specified conditions: —

(1). As to the load carried in tons per motor.
(2). The schedule speed in miles per hour.
(3). The number of stops per mile.
(4). The duration in seconds of the stops.
(5). The acceleration to be developed in miles per hour per second.
(6). The braking retardation to be developed in miles per hour per second.

These specifications should be determined, or agreed upon, as equivalent to the actual service, and the motors to be closed or open, according to the way in which they are to be operated in service.

The tests should be made in both directions over the same track.

By a "level track" should be understood a track in which the gradient does not exceed one-half per cent at any point.

By a "straight track" should be understood a track in which the radius of curvature is nowhere less than the distance traveled by the car in 30 seconds, at the maximum speed reached during the run.

The wind velocity during a test should not exceed 10 miles per hour in any direction.

INSULATION.

36. The ohmic resistance of the insulation is of secondary importance only, as compared with the dielectric strength, or resistance to rupture by high voltage.

Since the ohmic resistance of the insulation can be very greatly increased by baking, but the dielectric strength is liable to be weakened thereby, it is preferable to specify a high dielectric strength rather than a high insulation resistance. The high-voltage test for dielectric strength should always be applied.

Insulation Resistance.

37. Insulation resistance tests should, if possible, be made at the pressure for which the apparatus is designed.

The insulation resistance of the complete apparatus must be such that the rated voltage of the apparatus will not send more than $\frac{1}{1,000,000}$ of the full-load current, at the rated terminal voltage, through the insulation. Where the value found in this way exceeds 1 megohm, 1 megohm is sufficient.

Dielectric Strength.

38. The dielectic strength or resistance to rupture should be determined by a continued application of an alternating E.M.F. for one minute. The source of alternating E.M.F. should be a transformer of such size that the charging current of the apparatus as a condenser does not exceed 25 per cent of the rated output of the transformer.

39. In alternating-current apparatus, the test should be made at the frequency for which the apparatus is designed.

40. The high-voltage tests should not be applied when the insulation is low, owing to dirt or moisture, and should be applied before the machine is put into commercial service.

The high potential test should be made at the temperature consumed under normal operation, as specified in Paragraph 2 under "Efficiency."

41. It should be pointed out that tests at high voltages considerably in excess of the normal voltages, to determine whether specifications are fulfilled, are admissible on new machines only.

42. The test for dielectric strength should be made with the completely assembled apparatus and not with its individual parts, and the voltage should be applied as follows*: —

1st. Between electric circuits and surrounding conducting material, and

2d. Between adjacent electric circuits, where such exist, as in transformers.

The tests should be made with a sine wave of E.M.F., or where this is not available, at a voltage giving the same striking distance between needle points in air, as a sine wave of the specified E.M.F., except where expressly specified otherwise. As needles, new sewing-needles should be used. It is recommended to shunt the apparatus during the test by spark gap of needle points set for a voltage exceeding the required voltage by 10 per cent.

A table of approximate sparking distances is given in Appendix V.

43. The following voltages are recommended for apparatus not including transmission lines or switchboards: —

Rated Terminal Voltage.	Rated Output.	Testing Voltage.
Not exceeding 400 volts	Under 10 k. w. .	1,000 volts.
" " " "	10 k. w. and over	1,500 "
400 and over, but less than 800 volts.	Under 10 k. w. .	1,500 "
" " " "	10 k. w. and over	2,000 "
800 " " 1,200 "	Any	3,500 "
1,200 " " 2,500 "	Any	5,000 "
2,500 " " 10,000 "	Any	Double the normal rated voltages.
10,000 " " 20,000 "	Any	10,000 volts above normal rated voltages.
20,000 "	Any	50 per cent above normal rated voltages.

Except that transformers of 5,000 volts or less, directly feeding consumption circuits, should be tested at 10,000 volts.

Synchronous motor fields and fields of converters started
from the alternating current side . . . . 5,000 volts.

Alternator field circuits should be tested under a breakdown test voltage corresponding to the rated voltage of the exciter, and referred to an out-

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* NOTE. — This Section (No. 42) was referred back by the Convention to the Committee with power to amend, and may be subsequently revised. — EDITOR.

put equal to the output of the alternator ; i.e., the exciter should be rated for this test as having an output equal to that of the machine it excites.

Condensers should be tested at twice their rated voltage and at their rated frequency.

The values in the table above are effective values, or square roots of mean square, reduced to a sine wave of E.M.F.

44. In testing insulation between different electric circuits, as between primary and secondary of transformers, the testing voltage must be chosen corresponding to the high-voltage circuit.

45. In transformers of 20,000 volts upwards, it should be sufficient to test the transformer by operating it at 50 per cent above its rated voltage ; if necessary, with sufficiently higher frequency to induce this voltage.

46. The test of the insulation of a transformer, if no testing transformer is available, may be made by connecting one terminal of the high-voltage winding to the core and low-voltage winding, and then repeating the test with the other terminal of the high-voltage winding so connected. The test of dielectric resistance between the low-voltage winding and the core should be in accordance with the recommendation in Section 43, for similar voltages and capacities.

47. High-voltage tests on transformers or other apparatus should be based upon the voltages between the conductors of the circuit to which they are connected.

48. When machines or apparatus are to be operated in series, so as to employ the sum of their separate E.M.F.'s, the voltage should be referred to this sum, except where the frames of the machines are separately insulated both from ground and from each other.

The insulation between machines and between each machine and ground should be tested, the former referred to the voltage of one machine, and the latter to the total voltage of the series.

49. Underground cables, and line switches, should be tested by the application of an alternating E.M.F. for one minute at twice the voltage at which the cable or switch is to be operated.

REGULATION.

50. The term "regulation" should have the same meaning as the term "inherent regulation," at present frequently used.

51. The regulation of an apparatus intended for the generation of constant potential, constant current, constant speed, etc., is to be measured by the maximum variation of potential, current, speed, etc., occurring within the range from full-load to no-load, under such constant conditions of operation as give the required full-load values, the condition of full-load being considered in all cases as the normal condition of operation.

52. The regulation of an apparatus intended for the generation of a potential, current, speed, etc., varying in a definite manner between full-load and no-load, is to be measured by the maximum variation of potential, current, speed, etc., from the satisfied condition, under such constant conditions of operation as give the required full-load values.

If the manner in which the variation in potential, current, speed, etc., between full-load and no-load, is not specified, it should be assumed to be a simple linear relation ; i.e., undergoing uniform variation between full-load and no-load.

The regulation of an apparatus may, therefore, differ according to its qualification for use. Thus, the regulation of a compound-wound generator specified as a constant-potential generator, will be different from that it possesses when specified as an over-compounded generator.

53. The regulation is given in percentage of the full-load value of potential, current, speed, etc., and the apparatus should be steadily operated during the test under the same conditions as at full-load.

54. The regulation of generators is to be determined at constant speed, of alternating apparatus at constant impressed frequency.

55. The regulation of a generator-unit, consisting of a generator united with a prime-mover, should be determined at constant conditions of the prime mover ; i.e., constant steam pressure, head, etc. It would include the inherent speed variations of the prime-mover. For this reason the regulation of a generator-unit is to be distinguished from the regulation of either the prime-mover, or of the generator contained in it, when taken separately.

56. In apparatus generating, transforming or transmitting alternating currents, regulation should be understood to refer to non-inductive load; that is, to a load in which the current is in phase with the E.M.F. at the output side of the apparatus, except where expressly specified otherwise.

57. In alternating apparatus receiving electric power, regulation should refer to a sine wave of E.M.F., except where expressly specified otherwise.

58. In commutating machines, rectifying machines, and synchronous machines, as direct-current generators and motors, alternating-current and polyphase generators, the regulation is to be determined under the following conditions:

a. At constant excitation in separately excited fields;

b. With constant resistance in shunt-field circuits; and

c. With constant resistance shunting series fields; i.e., the field adjustment should remain constant, and should be so chosen as to give the required full-load voltage at full-load current.

59. In constant-potential machines, the regulation is the ratio of the maximum difference of terminal voltage from the rated full-load value (occurring within the range from full load to open circuit) to the full-load terminal voltage.

60. In constant-current apparatus, the regulation is the ratio of the maximum difference of current from the rated full-load value (occurring within the range from full-load to short-circuit, or minimum limit of operation) to the full-load current at constant speed; or, in transformers, etc., at constant impressed voltage and frequency.

61. In constant-power apparatus, the regulation is the ratio of maximum difference of power from the rated full-load value (occurring within the range of operation specified) to the rated power.

62. In over-compounded machines, the regulation is the ratio of the maximum difference in voltage from a straight line connecting the no-load and full-load values of terminal voltage as function of the current, to the full-load terminal voltage.

63. In constant-speed continuous-current motors, the regulation is the ratio of the maximum variation of speed from its full-load value (occurring within the range from full-load to no-load) to the full-load speed.

64. In constant-potential non-inductive transformers, the regulation is the ratio of the rise of secondary terminal voltage from full-load to no-load (at constant primary impressed terminal voltage) to the secondary terminal voltage.

65. In induction motors, the regulation is the ratio of the rise of speed from full-load to no-load (at constant impressed voltage) to the full-load speed.

The regulation of an induction motor is, therefore, not identical with the slip of the motor, which is the ratio of the drop in speed from synchronism, to the synchronous speed.

66. In converters, dynamotors, motor-generators, and frequency-converters, the regulation is the ratio of the maximum difference of terminal voltage at the output side from the rated full-load voltage (at constant impressed voltage and at constant frequency), to the full-load voltage on the output side.

67. In transmission lines, feeders, etc., the regulation is the ratio of maximum voltage difference at the receiving-end, between no-load and full non-inductive load, to the full-load voltage at the receiving-end, with constant voltage impressed upon the sending end.

68. In steam engines, the regulation is the ratio of the maximum variation of speed in passing from full-load to no-load (at constant steam pressure at the throttle) to the full-load speed.

69. In a turbine or other water-motor, the regulation is the ratio of the maximum variation of speed from full-load to no-load (at constant head of water; i.e., at constant difference of level between tail race and head race), to the full-load speed.

70. In alternating-current apparatus, in addition to the non-inductive regulation, the impedance ratio of the apparatus should be specified; i.e., the ratio of the voltage consumed by the total internal impedance of the apparatus at full-load current, to its rated full-load voltage. As far as possible, a sinusoidal current should be used.

71. When in synchronous machines the regulation is computed from the terminal voltage and impedance voltage, the exciting ampere-turns corresponding to terminal voltage plus armature-resistance-drop, and the ampere turns at short-circuit corresponding to the armature-impedance-drop, should be combined vectorially to obtain the resultant ampere-turns, and the corresponding internal E.M.F. should be taken from the saturation curve.*

Variation and Pulsation.

72. In prime movers which do not give an absolutely uniform rate of rotation or speed, as in steam-engines, the "variation" is the maximum angular displacement in position of the revolving member expressed in degrees, from the position it would occupy with uniform rotation, and with one revolution as 360°; and the pulsation is the ratio of the maximum change of speed in an engine cycle to the average speed.

73. In alternators or alternating-current circuits in general, the variation is the maximum difference in phase of the general wave of E.M.F. from a wave of absolutely constant frequency, expressed in degrees, and is due to the variation of the prime-mover. The pulsation is the ratio of the maximum change of frequency during an engine cycle to the average frequency.

74. If $n =$ number of poles, the variations of an alternator is $n / 2$ times the variation of its prime-mover if direct connected, and $n / 2p$ times the variation of the prime-mover if rigidly connected thereto in the velocity ratio p.

RATING.

75. Both electrical and mechanical power should be expressed in kilowatts, except when otherwise specified. Alternating-current apparatus should be rated in kilowatts on the basis of non-inductive condition; i.e., with the current in phase with the terminal voltage.

76. Thus, the electric power generated by an alternating-current apparatus equals its rating only at non-inductive load; that is, when the current is in phase with the terminal voltage.

77. Apparent power should be expressed in kilovolt-amperes as distinguished from real power in kilowatts.

78. If a power-factor other than 100 per cent is specified, the rating should be expressed in kilovolt amperes, and power-factor, at full-load.

79 The full-load current of an electric generator is that current which with the rated full-load terminal voltage gives the rated kilowatts, but in alternating-current apparatus only at non-inductive load.

80. Thus, in machines in which the full-load voltage differs from the no-load voltage, the full-load current should refer to the former.

If $P =$ rating of an electric generator and $E =$ full-load terminal voltage, the full-load current is:

$I = \frac{P}{E}$ in a continuous-current machine or single-phase alternator.

$I = \frac{P}{E\sqrt{3}}$ in a three-phase alternator.

$I = \frac{P}{2E}$ in a quarter-phase alternator.

81. Constant-current machines, such as series arc-light generators, should be rated in kilowatts based on terminal volts and amperes at full-load.

82. The rating of a fuse or circuit-breaker should be the current strength which it will continually carry. In addition thereto, the current strength at which it will open the circuit should be specified.

Classification of Voltages and Frequencies.

83. In direct-current, low-voltage generators, the following average terminal voltages are in general use and are recommended:

125 volts.	250 volts.	550 to 600 volts.

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* NOTE. — This Section (No. 71) was referred back by the Convention to the Committee with power to amend, and may be subsequently revised.

84. In direct-current and alternating-current low-voltage circuits, the following average terminal voltages are in general use and are recommended:

110 volts. 220 volts.

In direct-current power circuits, for railway and other service, 500 volts may be considered as standard.

85. In alternating-current, constant-potential, primary-distribution circuits, an average E.M.F. of 2,200 volts, with step-down transformers of ratios 1 / 10 and 1 / 20, is in general use, and is recommended.

86. In alternating-current, constant-potential, high-pressure circuits, at the receiving end, the following voltages are in general use and are recommended:

6,000. 10,000. 15,000. 20,000. 30,000. 40,000. 60,000.

87. In alternating-current generators, or generating systems, a range of terminal voltage should be provided from no-load voltage to 10 per cent in excess thereof, to cover drop in transmission. If a greater range than ten per cent is specified, the generator should be considered as special.

88. In alternating-current circuits, the following approximate frequencies are recommended as desirable:

25 ∼ 60 ∼ 120 ∼.*

These frequencies are already in extensive use, and it is deemed advisable to adhere to them as closely as possible.

Overload Capacities.

89. All guarantees on heating, regulation, sparking, etc., should apply to the rated load, except where expressly specified otherwise, and in alternating-current apparatus to the current in phase with the terminal E.M.F., except where a phase displacement is inherent in the apparatus.

90. All apparatus should be able to carry the overload specified in Section 92, without self-destruction by heating, sparking, mechanical weakness, etc., and with an increase in temperature elevation not exceeding 15° C., above those specified for full loads, the overload being applied after the apparatus has acquired the temperature corresponding to full-load continuous operation. (See Sections 30 to 34.)

91. Overload guarantees should refer to normal conditions of operation regarding speed, frequency, voltage, etc., and to non-inductive conditions in alternating apparatus, except where a phase displacement is inherent in the apparatus.

92. The following overload capacities are recommended:

1st. In direct-current generators and alternating-current generators, 25 per cent for two hours.

2d. In direct-current motors, induction motors, and synchronous motors, not including railway motors and other apparatus intended for intermittent service, 25 per cent for two hours, and 50 per cent for one minute, for momentary overload capacity.

3d. Synchronous converters, 50 per cent for one-half hour.

4th. Transformers, 25 per cent for two hours. Except in transformers connected to apparatus for which a different overload is guaranteed, in which case the same guarantees shall apply for the transformers as for the apparatus connected thereto

5th. Exciters of alternators and other synchronous machines, 10 per cent more overload than is required for the excitation of the synchronous machine at its guaranteed overload, and for the same period of time.

6th. All exciters of alternating-current, single-phase or polyphase generators should be able to give, at constant speed, sufficient voltage to excite the alternator, at the rated speed, to the full-load terminal voltage, at the rated output in kilovolt-amperes and with 50 per cent power factor.

Luminous Sources.

93. It is customary in industrial practice at the present time to rate incandescent lamps upon the basis of their mean horizontal candle-power; but in comparing sources of light in which the relative distribution of

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* The frequency of 120∼ may be considered as covering the already existing commercial frequencies between 120∼ and 140∼.

luminosity differs considerably, the comparison should be based upon the total quantity of light, or total flux of light emitted by each source.

94. The mean spherical intensity of a luminous source is its total flux of light, expressed in lumens, divided by 4π. If the mean spherical intensity be expressed in British candles, the flux of light will be in British-candle lumens (B. C. Lumens). If the mean spherical intensity be expressed in Hefners, the flux of light will be expressed in Hefner lumens (H. Lumens).

95. The efficiency of a luminous source should be defined as the ratio of the light it emits to the power it consumes. In the case of an incandescent lamp, this ratio might be expressed in B. C. Lumens per watt at lamp terminals.

96. The specific consumption of a lamp should be the reciprocal of its efficiency, or the watts per B. C. Lumen.

97. The consumption per horizontal candle-power of a lamp is the ratio of power consumed at terminals to the mean horizontal candle-power, or watts per mean horizontal candle-power.

98. The Hefner-Alteneck amyl-acetate lamp is, in spite of its unsuitable color, the standard luminous source generally used in accurate photometric measurements. In comparing lamps with this standard, the ratio of the horizontal intensities of the Hefner and British candles may be accepted conventionally as follows: 1 Hefner under Reichsanstalt standard conditions = 0.88 British candle.

APPENDIX I.

Efficiency of Phase-Displacing Apparatus.

In apparatus producing phase displacement, as, for example, synchronous compensators, exciters of induction generators, reactors, condensers, polarization cells, etc., the efficiency should be understood to be the ratio of the volt-ampere activity to the volt-ampere activity plus power loss.

The efficiency may be calculated by determining the losses individually, adding to them the volt-ampere activity, and then dividing the volt-ampere activity by the sum.

1st. In synchronous compensators and exciters of induction generators, the determination of losses is the same as in other synchronous machines under Sections 11 and 12.

2d. In reactive coils the losses are molecular friction, eddy losses, and I^2r loss. They should be measured by watt-meter. The efficiency of reactive coils should be determined with a sine wave of impressed E.M.F., except where expressly specified otherwise. In reactive coils the load losses may be considerable.

3d. In condensers the losses are due to dielectric hysteresis and leakage, and should be determined by watt-meter with a sine wave of E.M.F.

4th. In polarization cells the losses are those due to electric resistivity and a loss in the electrolyte of the nature of chemical hysteresis, and are usually very considerable. They depend upon the frequency, voltage, and temperature, and should be determined with a sine wave of impressed E.M.F., except where expressly specified otherwise.

APPENDIX II.

Apparent Efficiency.

In apparatus in which a phase displacement is inherent to their operation apparent efficiency should be understood as the ratio of net power output to volt-ampere input.

Such apparatus comprise induction motors, reactive synchronous converters, synchronous converters controlling the voltage of an alternating-current system, self-exciting synchronous motors, potential regulators, and open magnetic circuit transformers, etc.

Since the apparent efficiency of apparatus generating electric power depends upon the power factor of the load, the apparent efficiency, unless otherwise specified, should be referred to a load-power factor of unity.

APPENDIX III.

Power Factor and Inductance Factor.

The power factor in alternating circuits or apparatus may be defined as the ratio of the electric power, in watts, to volt-amperes.

The inductance factor is to be considered as the ratiò of wattless volt-amperes to total volt-amperes.

Thus, if $p =$ power factor, $q =$ inductance factor,
then, with a sine wave of E.M.F. $p^2 = q^2 = 1$.

The power factor is the

$$\frac{\text{(energy component of current, or E.M.F.)}}{\text{(total current, or E.M.F.)}} = \frac{\text{true power}}{\text{volt-amperes}},$$

and the inductance factor is the

$$\frac{\text{(wattless component of current, or E.M.F.)}}{\text{(total current, or E.M.F.)}}.$$

Since the power-factor of apparatus supplying electric power depends upon the power-factor of the load, the power-factor of the load should be considered as unity, unless otherwise specified.

APPENDIX IV.

The following notation is recommended: —

E, e, voltage, E.M.F., potential difference,
I, i, current,
P, power,
ϕ, magnetic flux,
$\mathfrak{B}$, magnetic density,
R, r, resistance,
x, reactance,
Z, z, impedance,
L, l, inductance,
C, c, capacity,
Y, y, admittance,
b, susceptance,
g, conductance.

Vector quantities, when used, should be denoted by capital italics.

APPENDIX V.

Table of sparking distances in air between opposed sharp needle-points, for various effective sinusoidal voltages, in inches and in centimeters.

Kilovolts. Sq. Root of Mean Square.	Distance.		Kilovolts. Sq. Root of Mean Square.	Distance.	
	Inches.	Cms.		Inches.	Cms.
5	0.225	0.57	60	4.65	11.8
10	0.47	1.19	70	5.85	14.9
15	0.725	1.84	80	7.1	18.0
20	1.0	2.54	90	8.35	21.2
25	1.3	3.3	100	9.6	24.4
30	1.625	4.1	110	10.75	27.3
35	2.0	5.1	120	11.85	30.1
40	2.45	6.2	130	12.95	32.9
45	2.95	7.5	140	13.95	35.4
50	3.55	9.0	150	15.0	38.1

TESTS OF DYNAMOS AND MOTORS.

All reliable manufacturers of electrical machinery and apparatus are now provided with the necessary facilities for testing the efficiency and other properties of their output, and where the purchaser desires to confirm the tests and guaranties of the maker, he should endeavor to have nearly, and in some cases all such tests carried out in his presence at the factory, unless he may be equipped with sufficient facilities to enable him to carry out like tests in his own shops after the apparatus is in place.

Some tests, such as full load and overload, temperature, and insulation (except dielectric) tests are best made after the machinery has been installed and is in full running order.

Owing to the ease and accuracy with which electrical measurements can be made, it is always more convenient to make use of electrical driving power for dynamos, and electrical load for the dynamo output, and in the case of motors, a direct-current dynamo with electrical load makes the best load for belting the motor to.

No really accurate tests of dynamo efficiencies can be made with water-wheels, and only slightly better are those made by steam-engines, owing to unreliability of friction cards for the engine itself and the change of friction with load.

Where it is necessary to use a steam-engine for dynamo testing, all friction and low load cards should be taken with the steam throttled so low as to cut off at more than half stroke, and to run the engine at the same speed as when under load.

The tests of the engine as separated from the dynamo are as follows: —

a. Friction of engine alone.

b. Friction of engine and any belts and countershaft between it and the dynamo under test.

Consult works on indicators and steam-engines for instructions for determining power of engines under various conditions.

The important practical tests for acceptance by the purchaser, or to determine the full value of all the properties of dynamos and motors, are to learn the value of the following items: —

Rise of temperature under full load.
Insulation resistance.
Dielectric strength of insulation.
Regulation.
Overload capacity.
Efficiency, core loss.

Bearing friction, windage and brush friction.

I^2R loss in field and field rheostat,
I^2R loss in armature and brushes.

NOTE. — If a separate exciter goes with the dynamo, its losses will be determined separately as for a dynamo.

Methods of determining each of the above-named items will be described, and then the combinations of them necessary for any test will be outlined.

Temperature. — The rise of temperature in a dynamo, motor, or transformer, is one of the most important factors in determining the life of such piece of apparatus; and tests for its determination should be carried out according to the highest standards that can be specified, and yet be within reasonable range of economy. The A. I. E. E. standards state the allowable rise of temperature above surrounding air for most conditions, but special conditions must be met by special standards. For instance, no ordinary insulation ought to be subjected to a degree of heat exceeding 212° F., or 100° C. And yet in the dynamo-room of our naval vessels the temperature is said to at times reach 130° F., or even higher, which leaves a small margin for safety. It is obvious that specifications for dynamos in such locations should call for a much lower temperature rise in order to be safe under full load.

For all practical temperature tests it is sufficient to run a machine under its normal full-load conditions until it has developed its highest temperature, although at times a curve of rise of temperature may be desired at various loads.

All small dynamos, motors, and transformers, up to, say, 50 KW., will reach maximum temperature in five hours run under full load, if the temperature rise is normal; but larger machines sometimes require from 6 to 18 hours, although this depends quite as much on the design and construction of the apparatus as on size, as, for instance, the 5,000 h.p. Niagara Falls Generators reach full temperature in five hours. Temperature tests can be shortened by overloading the apparatus for a time, thus reaching full heat in a shorter period.

On dynamos and motors the temperatures of all iron or frame parts, commutators, and pole-pieces, have to be taken by thermometer laid on the surface and covered by waste. Note that when temperatures are taken with the machine running, care must be taken not to use enough waste to influence the machine's radiation. Where there are spaces, as air spaces, in armature cores or in the field laminations, that will permit the insertion of a thermometer, it should be placed there. Temperature of field coils should be taken by thermometer laid on the surface and covered with waste, and by taking the resistance of the coils first at the room temperature and again while hot immediately after the *heat run*. Temperature rise of armature windings can be taken by surface measurement and by the resistance method also; although being nearly always of low resistance, very careful tests by fine galvanometer and very *steady* current are required in order to get anything like accurate results.

The formula for determining the rise of temperature from the rise of resistance is as follows: —

Temperature by rise in resistance; for copper. — The increase in resistance due to increase in temperature is 0.4% for each degree Cent. above zero, the resistance at zero being taken as the base. If then

t_1 = temperature of copper when cold resistance is measured,
R_1 = resistance at temperature t_1,
t_2 = temperature of copper when hot resistance is taken,
R_2 = resistance at temperature t_2,

Then first reducing to zero degrees, we have

$$R_0 = \frac{R_1}{1 + .004\, t_1} \qquad (1).$$

The increase in resistance from 0 to t_2 degrees is $R_2 - R_0$, and hence we have for final temperature,

$$t_2 = \frac{R_2 - R_0}{R_0} \div .004 \qquad (2).$$

Substituting (1)

$$t_2 = \frac{R_2\,(1 + .004\, t_1) - R_1}{.004\, R_1} \qquad (3).$$

It is usually most convenient to correct all cold resistances to a temperature of 20° C., in which case we first reduce to zero and then raise to 20°. The general formula for obtaining the resistance at t degrees is

$$R_t = (1 + .004\, t)\; R_0.$$

Hence $R_{20} = 1.08\, R_0$ and in terms of the cold resistance at temperature t.

$$R_2 = \frac{(1.08\, R_0)}{(1 + .004\, t\,)} \qquad (4).$$

Formula (3) then becomes, when the cold resistance is at 20°,

$$t_2 = \frac{1.08}{.004} \times \frac{R_2}{R_{20}} - \frac{1}{.004} = 270\ \frac{R_2}{R_{20}} - 250 \qquad (5).$$

As the first formula requires but one setting of the slide rule, and the subtraction of the constant 250 can usually be done mentally, the advantage of the temperature equation in this form is very great as regards both speed and accuracy.

The temperature co-efficients most generally are

For copper 004
Resistivity of copper = .000001595 per cubic Cm.
Resistivity of G. S. = .00003468 per cubic Cm.

The following parts should be tested by the resistance method and the surface method also:

Field coils series, and shunt.

Armature coils. In 3-phase machines, take resistance between all three rings.

On transformers which are enclosed in a tank filled with oil, temperatures by thermometer should be taken on —

Outside case, in several places.
Oil, on top, and deeper by letting down thermometer.
Windings, by placing thermometer against same, even if under oil.
Laminations, by placing thermometer against same, even if under oil.
Terminals.
Room, as with dynamos and motors.
Also resistance measurements of primary and secondary windings, from which the temperature by resistance can be calculated as shown.

On transformers cooled by air forced through spaces between windings and spaces in laminations, temperatures by thermometer should be taken on —

Outside frame.
Air, outgoing from coils.
Air, outgoing from iron laminations.
Windings.
Terminals.
Room, in two or more places.
Also resistance measurements, hot and cold, should be taken, from which rise of temperature by resistance can be calculated.
Finally, the cubic feet of air, and pressure to force same through spaces (easily measured by "U" tube of water), should be measured.

When other fluids are used for cooling, such as water passing through piping submerged in oil, in which also the windings and core are submerged, or through windings of transformers themselves (made hollow for the purpose), the temperature of incoming and outgoing fluid should be measured, the quantity used and the pressure necessary to force it through the path arranged, besides the other points mentioned above.

The following parts should be tested by thermometer on the surface: —

Room, on side opposite from steam-engine, if direct connected, and always in two or more parts of the room, within six feet of machine.
Bearings, each bearing, thermometer held against inner shell, unless oil from the well is found to be of same temperature as the bearing.
Commutators and *collector rings.*
Brush-holders and *brushes*, if thought hotter than the commutator.
Pole-tips, leading and following.
Armature teeth, windings, and spider.
Field frame.
Terminal blocks, for leads to switch-board, and those for leads from the brushes.
Series shunt, if in a compound-wound machine.
Shunt field rheostat.

Careful watch of thermometers is necessary in all cases, as they will rise for a time and then begin to fall; and the maximum point is what is wanted.

British authorities state a definite time to read the thermometers after stopping the machine.

Care must also be taken to stop the machine rotating as soon as possible, so that it will not fan itself cool.

A handy method of constructing a curve showing the rise of temperature in the stationary parts of a machine at full load is to insert a small coil of fine iron wire in some crevice in the machine in the part of which the temperature is desired. Connect the coil with a mirror galvanometer and battery.

The temperature coefficient of iron is high, and the gradual increase in resistance of the coil will cause the readings on the galvanometer to grow gradually less; and readings taken at regular intervals of time can be plotted on cross-section paper to form a curve showing the changes in temperature.

Records of temperature test.—During all heat runs, which should be on non-inductive load, such as a water-box, readings should be taken every fifteen (15) minutes of the following items.

On direct and alternating current motors and generators—

Armature, Volts (between the various rings where machine is more than single-phase, in the case of alternators, and between brushes, in the case of a D. C. machine).
Amperes (in each line).
Speed.
Field, Volts.
Amperes.

On synchronous converters:—

Armature, Volts (between all rings on A. C. end, and between brushes on D. C. end).
Amperes, per line A. C. end, also D. C. end.
Speed.
Field, Volts.
Amperes.

On transformers, compensators, potential regulators:—

Volts, primary.
Volts, secondary.
Amperes, primary.
Amperes, secondary.
Cycles.
Amount and pressure of cooling-fluid (if any is used).

On induction motors:—

Volts, between lines.
Amperes, in line.
Speed.
Cycles.

Overload.—The A. I. E. E. standards contain suggestions for overload capacity (see page 303).

The writer has uniformly specified a standard overload of 25% for 3 hours, and there seems to be no especial difficulty in getting machines for this standard that do not heat dangerously under such conditions.

Insulation test.—Insulation resistance in ohms is of much less importance than resistance against breakdown of the insulation under a *strain* test, with alternating current of high pressure.

Make all insulation tests with a voltage as high, at least, as that at which the machine is to be worked.

The following diagram shows the connections to be made with E some external source of E.M.F. The formula used is

$R =$ resistance of voltmeter.
$E =$ E.M.F. across dynamo terminals.
$e =$ reading of voltmeter connected as in diagram.
$x =$ insulation resistance in ohms.

$$\text{Then } x = R\left(\frac{E}{e} - 1\right).$$

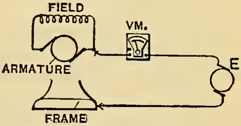

FIG. 1. Connections for voltmeter test of insulation resistance of a dynamo.

According to the A. I. E. E. standards, the insulation resistance must be such that the rated voltage of the machine will not send more than $\frac{1}{1000000}$ of the full-load current through the insulation. One megohm is usually considered sufficient, if found by such a test. Where one megohm is specified as sufficient, the maximum deflection that will produce that value, and that must not be exceeded in the test, may be found by the following variation of the above formula:

$$e = \frac{R \times E}{1{,}000{,}000 + R}$$

Strain test.—The dielectric strength of insulation should be determined by a continued application of an alternating E.M.F. for at least one (1) minute. The transformer from which the alternating E.M.F. is taken should have a current capacity at least four (4) times the amount of current necessary to charge the apparatus under test as a condenser. Strain tests should only be made with the apparatus fully assembled.

Connect on a D.C. machine as in the following diagram.

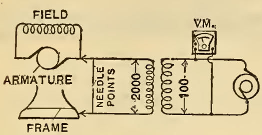

Fig. 2. Connections for strain test of dynamo or motor or transformer insulation.

Strain tests should be made with a sine wave of E.M.F., or with an E.M.F. having the same striking distance between needle points in air.

See article 40 A. I. E. E. standards for proper voltages.

Regulation.—The test for *regulation* in a dynamo consists in determining its change in *voltage* under different loads, or output of current, the speed being maintained constant.

The test for *regulation* in a motor consists in determining its change of *speed*, under different applied loads, when the voltage is kept constant.

Standards.—For full details of standards of regulation of different machines, see report of the Committee on Standardization of the A. I. E. E. at the beginning of this chapter.

Regulation Tests, Dynamos, Shunt or Compound, and Alternators.

The dynamo must be run for a sufficient length of time at a heavy load to raise its temperature to its highest limit; the field rheostat is then adjusted, starting with voltage a little low, and bringing up to proper value to obtain the standard voltage at the machine terminals, and since a constant temperature condition has been reached, must not again be adjusted during the test. Adjust the brushes, in the case of a D. C. machine, for full-load conditions, and they should not receive other adjustment during the test. This is a severe condition, and not all machines will stand it; but all good dynamos, with carbon brushes, will stand the test very well, provided the brushes are adjusted at just the non-sparking point at no load.

Load is now decreased by regular steps, and when the current has settled the following readings are taken:—

Speed of dynamo (adjusted at proper amount).
Current in output (a non-inductive load should be used).
If alternator, current in each line if more than single-phase.
Volts at machine terminals.
Amperes, field.
Volts, field.
Note sparking at the brushes (they should not spark any with carbon brushes).

Readings should be taken for at least ten intervals, from full load to open circuit (no load); and load should then be put on gradually and by the same steps as it was brought down; and the same records should be made back to full-load point, and beyond to 25% overload.

If the readings are to be plotted in curves, as they always should be, it will make little difference if the intervals or steps are not all alike; and should the steps be overreached in adjusting the load, the load must not, in any circumstances, be backed up or readjusted back to get regular intervals or a stated value, as the conditions of magnetization change, and throw the test all out. In case the current is broken, or the test has to be slowed down in speed or stopped, it must be commenced all over again. Finally, when the curves are plotted, draw, in the case of a compound-wound machine, a straight line joining the *no-load* voltage and the *full-load* voltage; and the ratio of the point of maximum departure of the voltage from this line to the voltage indicated by the line at the point will be the *regulation* of the machine.

The readings as obtained give what is called a field compounding curve. In the case of a shunt or separately excited machine, the procedure for the test is the same; but when the curve is plotted, the regulation is figured as equal to the difference between the no-load voltage and full-load voltage, divided by the full-load voltage. The curve is called a characteristic in this case.

Regulation Tests, Motors, Shunt, Compound, and Induction.

After driving the motor under heavy load for a length of time sufficient to develop its full heat, full-rated load should be applied, the field rheostat, if any is used, and brushes adjusted for the standard conditions; then the load should be gradually removed by regular steps, and the following readings be made at each such step:—

Amperes, input.
Volts at machine terminals (kept constant).
Watts, if induction motor.
Speed of armature.
Note sparking at brushes.
Amperes, field (in D. C. machines).

At least ten steps of load should be taken from full-rated load to no load.

The ratio of the maximum drop in speed between no-load and full-load, which will be at full-load, to the speed at full-load, is the *regulation* of the motor.

Efficiency Tests. Dynamos.

The term *efficiency* has two meanings as applied to dynamos; viz., *electrical* and *commercial.* The *electrical* efficiency of a dynamo is the ratio of electrical energy delivered to the line at the dynamo terminals to the total electrical energy produced in the machine. The *commercial* efficiency of a dynamo is the ratio of the energy delivered at the terminals of the machine to the total energy supplied at the pulley. Otherwise the *electrical* efficiency takes into account only electrical losses, while the *commercial* efficiency includes all losses, electrical, magnetic, and frictional.

Core-Loss Test, and Test for Friction and Windage.

These losses are treated together for the reason that all are obtained at the same time, and the first can only be determined after separating out the others.

A core-loss test is ordinarily run only on new types of dynamos and motors, but is handy to know of any machine, and if time and the facilities are available, should be run on acceptance tests by the consulting engineer. It consists in running the armature at open circuit in an excited field, driving it by belt from a motor the input to which, after making proper deductions, is the measure of the power necessary to turn the iron core in a field of the same strength as that in which it will work when in actual use.

Connect as in the following diagram, in which A is the dynamo or motor under test, and B is the motor driving the armature of A by means of the belt. The field of A must, of necessity, be separately excited, as its own armature circuit must be open so that there may be no current generated in its conductors.

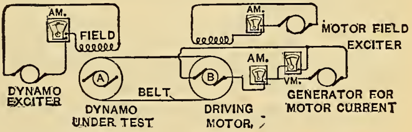

FIG. 3. Connections for a test of core loss.

The motor field is separately excited and kept constant, so that its losses and the core loss of the motor itself, being constant for all conditions of the test, may be cancelled in the calculations. The motor B should be thoroughly heated; and bearings should be run long enough to have reached a constant friction condition before starting this test, so that as little change as possible will take place in the different "constant" values. It is necessary to know accurately the resistance of the armature, B, in order to determine its I^2R loss at different loads, and to use copper brushes to practically eliminate the I^2R of brushes.

It is well to make a test run with the belt on in order to learn at what speed it is necessary to run the motor in order to drive the armature A at its proper and standard speed.

Friction, core loss, and windage of motor. — The speed having been determined, the belt is removed, and the motor field kept at its final adjustment, and enough voltage is supplied to the motor armature to drive it free at the standard speed. The watts input to the armature is then the measure of the loss (I^2R) in the motor armature plus the friction of its bearings, plus its windage, plus core loss, or the total loss in the motor at no load. This is called the "running light" reading.

Friction and windage of dynamo. — After learning the losses in the driving motor, the belt is put on and the dynamo is driven at its standard speed without excitation, and in order to be sure of this a voltmeter may be connected across the armature terminals; if the slightest indication of pressure is found, the dynamo field can be reversely excited, to be demagnetized, by touching its terminals momentarily to a source of E.M.F. Take a number of readings of the input to the motor in order to obtain a good mean, and the friction and windage of dynamo is then the input to the motor, less the "running light" reading previously obtained, the I^2R of motor armature having been taken out in each case.

Let $W_1 =$ watts input to motor,
$n_1 = I^2R$ in motor armature when driving dynamo,
$f =$ "running light" reading of motor,
$f_1 =$ friction and windage of dynamo armature,
$n_2 = I^2R$ of motor armature when "running light,"
then $f_1 = W_1 - (n_1 + f + f_1 + n_2)$.

Brush friction. — The friction of brushes is ordinarily a small portion of the losses; but when it is desirable that it should be separated from other losses, it can be done at the same time and in the same manner as the test for bearing friction. The brushes can be lifted free from the commutator or collector rings when the readings of input to the driving motor for bearing friction are taken; dropping the brushes again onto the commutator and taking other readings, the difference between these last readings and those taken with brushes off will be the value of brush friction. Note, that allowance must be made as before for increase of I^2R loss in the motor armature.

Test for core loss. — Having determined the friction and other losses that are to be deducted from the total loss, a current as heavy as will ever be used is put on the dynamo field, the motor is supplied with current enough to drive the dynamo at its standard speed, and the reading of watts and current input to the motor armature is taken.

The dynamo field current is now gradually decreased in approximately regular steps, readings of the input to the motor being taken at each such step until zero exciting current is reached, when the exciting current is reversed and the current increased in like steps until the highest current reading is again reached. This may now be again decreased by intervals back to zero, reversed and increased back to the starting-point, which will thus complete a cycle of magnetization; ordinarily this refinement is not, however, necessary.

This test must always be carried through without stop; and although it is desirable to make the step changes in field excitation alike, if the excitation be changed in excess of the regular step it must not be changed back for the purpose of making the interval regular, as it will change the conditions of the residual field. When the readings are plotted on a curve, regularity in intervals of magnetization is not entirely necessary.

The following ruling makes a convenient method of tabulation: —

DYNAMO.		MOTOR.			
Speed	amperes in field	Speed	amperes in field	amperes in armature i	volts in armature e
Constant		Constant.	Constant.		

COMPUTATIONS.

watts in armature belt on $W_{\prime\prime} = i\,e$	Running light reading f	I^2R in arm. belt on n_1	I^2R in arm. belt off n_2	Core loss $W_{\prime\prime} - (n_1 + f + f_1 + n_2)$

Plot on curve with exciting-current values on the horizontal scale, and the core loss on the vertical, and the usual core-loss curve is obtained.

Separation of core loss into Hysteresis and Eddy current loss.

Losses due to hysteresis and friction vary directly with the speed ; losses due to eddy currents vary as the square of the speed.

Current and voltage must now be applied to the dynamo armature to drive it as a motor at proper speed, with the current in the separately excited field kept constant at proper value. Drive the motor (dynamo) at say two different speeds, one of which may be K times the other ; let

L = total loss in watts,
f_1 = loss in friction,
H = loss by hysteresis,
D = loss by eddy currents, or

$$L = f_1 + H + D \text{ at the first speed,} \tag{1}$$

$$L_1 = Kf_1 + KH + K^2D \text{ at second speed,} \tag{2}$$

$$K \times (1) = KL = Kf_1 + kH + KD, \tag{3}$$

$$(2) - (3) = L_1 - KL = K^2D - KD, \tag{4}$$

$$L_1 - KL = KD\,(K - 1), \tag{5}$$

$$D = \frac{L_1 - KL}{K(K-1)}. \tag{6}$$

If $K = 2$, then

$$D = \frac{L_1 - 2L}{2\,(2-1)} = \frac{L_1}{2} - L.$$

Kapp and Housman separately devised the above method of separating the losses, but stated them somewhat differently.

With the field separately excited at a constant value, different values of current are supplied to the armature at different voltages, to drive it as a motor. The results are plotted in a curve which is a straight line, rising as the volts are increased.

The following diagram shows how the losses are plotted in curves. The test as a separately excited motor is run at a number of different values of voltage and current in the armature, and the results are plotted in a curve as shown in the following diagram. The line a, b, is plotted from the results of the current and volt readings.

The line a, c, is then drawn parallel to the base, and represents the sum of all the other losses, as shown by previous tests, and they may be further separated and laid off on the chart.

Foucault currents are represented in value by the triangle a, c, b.

If another run be made with a different value of excitation, a curve, a_1, b_1, or one below the original a, b, will be gotten, according to whether the total losses have been increased or decreased.

If the higher values of current tend to demagnetize, by reason of the eddy currents in the armature, the curve a, b, will curve upward somewhat at the upper end.

It is thus seen how to measure core-loss, and friction and windage of a dynamo; knowing this and the resistance of the various parts, the efficiency is quickly calculated, thus

Let W = core-loss + friction (obtained as shown),
V = voltage of armature,
I = current of dynamo armature,
I_1 = current of dynamo field,
R = resistance of armature and brushes,
R_1 = resistance of field.

Then considering the above as the only losses (i.e., neglecting rheostats, etc.),

$$\text{Efficiency} = \frac{Vc}{Vc + I^2R + I_1{}^2R_1 + W}$$

This is the simplest method of getting the efficiency, but does not take in "load losses" if any should exist.

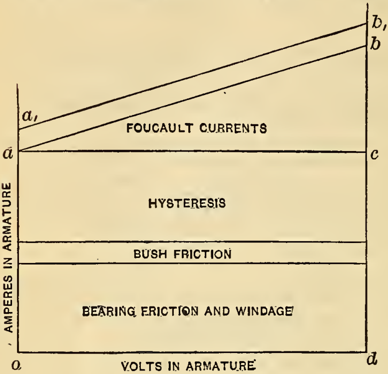

FIG. 4. Diagram showing separation of losses in dynamos.

Another test for efficiency. — If the dynamo under test is not of too large capacity, and a load for its full output is available, either in the form of a lamp bank, water rheostat, or other adjustable resistance, then one form of test is to belt it to a motor.

By separately exciting the motor fields, and running the motor free with belt off, its friction can be determined, and with the resistance of the armature known, the input to the motor in watts, less the friction and the I^2R loss in its armature at the given load, is a direct measure of the power applied at the pulley of the dynamo. The output in watts, measured at the dynamo terminals, then measures the efficiency of the machine. Let,

W = watts input to motor,
l = losses in motor, friction, I^2R, and core-loss,
W_1 = watts output at dynamo terminals.

$$\% \text{ of efficiency} = 100 \times \frac{W_1}{W - l} = \text{commercial efficiency.}$$

Knowing the current flowing in the armature and in the fields, and also knowing the resistance of the same, the I^2R losses in each may be calculated, which, added to the output at the dynamo terminals, shows the total electrical energy generated in the machine.

If m = the I^2R loss in the armature,
f = the I^2R loss in the fields,
The electrical efficiency will be

$$\% \text{ electrical efficiency} = 100 \times \frac{W_1}{W_1 + m + f}$$

The following diagram shows the connections for this form of test.

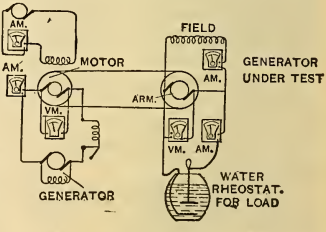

FIG. 5. Connections for efficiency test of a generator. Driven by an electric motor.

It must be obvious that a steam-engine, or other motive power that can be accurately measured, may be used in place of the electric motor; but measurements of mechanical power are so much more liable to error that they should be avoided where possible.

The only objection to this method is that the friction of the driving-motor varies with the load, and the loss in the belt is not considered.

Kapp's Test with two Similar Dynamos.

Where two similar dynamos are to be tested, and especially where their capacity is so great as to make it difficult to supply load for them, it is common to test them by a sort of opposition method; that is, their shafts are either coupled or belted together, the armature leads are connected in series, the field of one is weakened enough to make a motor of it; this motor drives the other machine as a generator, and its current is delivered to the motor. The difference in currents between the two machines, and for exciting the fields of each, is supplied by a separate generator.

The following diagram shows the method of connecting two similar dynamos for Kapp's test. D, is the dynamo; M, the machine with field weakened by the resistance R, that acts as a moter, and G, is the generator that supplies the energy necessary to make up the losses, excitation, and differences.

Start the combination and get them to standard voltage, as shown by the voltmeter; then take a reading of the current with the switch on *b*, and another with the switch on *a*. Let the first reading be *m*, and the second *d*, and let *x* be the efficiency of either machine, then

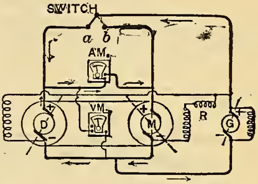

FIG. 6. Connections for Kapp's method of efficiency test of two similar dynamos.

$$\% \text{ efficiency of the combination} = 100 \times \frac{m}{d}, \text{ and}$$

$$x = \sqrt{\left(100 \times \frac{m}{d}\right)}$$

In using this formula the efficiency of the dynamo at its load is assumed the same as the motor at its simultaneous load, which is usually true above the ¾ load point. The loss in motor-field rheostat should also be allowed for.

Another similar method, called "*pumping back*," is to connect the shafts of the two machines as before, by clutch or belt; arrange the electrical connections and instruments as in the following diagram.

D is the dynamo under test; M is the similar machine used as a motor; and G is the generator for supplying current for the losses and differences between M and D. The speed of the combination, as well as the load on D, can be adjusted by varying the field of M.

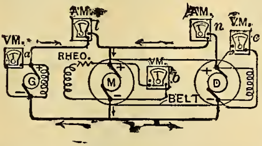

FIG. 7. Efficiency test of two similar dynamos.

The motor, M, drives D by means of the shaft or belt connection. M gets its current for power from two sources, viz., G and D. In order to determine the amount of mechanical power developed by M, and also to be able to separate the magnetic and frictional losses in the two machines, a *core-loss* test should have been made on the machine M at the same speed, current, and E.M.F. as it is to have in the efficiency test. The loss in the cable connections between M and D must also be taken into account, and is equal to the difference in volts between voltmeters *c*, and *b*, × the current flowing in ammeter *n*.

Let V = E.M.F. of D, shown on *c*,
$V_{,}$ = E.M.F. of M by vm. *b*,
$V_{,,}$ = E.M.F. of G by vm. *a*,
I = amperes current from D by am. *n*,
$I_{,}$ = amperes current from G by am. *l*,
$I_{,,}$ = amperes current in M $= I + I_{,}$,
e = drop in connections between D and M $= V - V_{,,}$,
L = loss in connections between D and M $= e \times I$,
r = D's internal resistance,
r_1 = M's internal resistance,
w = core loss + armature loss + field loss + friction of M in watts + L (loss in connections).

Then

$$W = \text{the useful output of D} = V \times I,$$

$$W_{,} = \text{energy supplied by G} = V_{,,} \times I_{,},$$

$$W + W_{,} = \text{total energy supplied to M},$$

$$W + W_{,} - w = \text{energy required to drive D},$$

$$\%\ \text{commercial efficiency of D} = \frac{W}{W + W_{,} - w} \times 100.$$

$$I^2r = \text{electrical loss in D},$$

$$\%\ \text{electrical efficiency} = \frac{W}{W + I^2r} \times 100.$$

The other way of calculating the efficiency with this arrangement is to measure the output $= W_1$ from G, with full load on D. W_1 then is the losses of both machines under load; and knowing the I^2R loss in the armature and field of each, the efficiency is quickly and accurately calculated. This method is best, as no core loss is required, and includes the "load losses."

ELECTRICAL METHOD OF SUPPLYING THE LOSSES AT CONSTANT POTENTIAL.

Modification of "Kapp Method," by Prof. Wm. L. Puffer, from notes privately printed for the students of the Massachusetts Institute of Technology.

Specification.

Two similar shunt dynamos under full load, one as a motor driving the other as a loaded dynamo through a mechanical coupling. Mains at same voltage as dynamos, and only large enough to supply the full-load losses of both dynamos.

Line up the two dynamos carefully, and mechanically connect them by a good form of mechanical coupling, strong enough to transmit the full load to the dynamo.

Connect the field magnet windings of each machine to the supply mains, putting a suitable field rheostat in each. If desirable for any reason, the field of the dynamo may be left connected as designed; but the field of the motor, which does not in any way enter as a quantity to be measured during the test, should be connected to the supply mains.

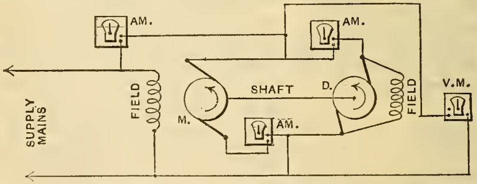

FIG. 8. Diagram of Connections for Professor Puffer's Modification of Kapp's Dynamo Test.

Method of Starting.

Close the field circuit of the motor, and by the motor starting rheostat gradually bring the motor up to full speed. The dynamo armature will be also at proper speed and on open circuit. Now close the dynamo field and adjust the field rheostat until the dynamo is at about normal voltage. Adjust the speed roughly at first by the use of the field rheostat of the motor, remembering that an added resistance will cause the speed to rise. Next see that the voltage of the dynamo is equal to that of the motor, or, in other words, that there is no difference of potential between opposite sides of the main switch on the dynamo. Close this switch and there may, or may not, be a small current in the dynamo armature. Now carefully increase the armature voltage of the dynamo, watching the ammeter, and weaken that of the motor; a current will flow from the dynamo to the motor, and the motor will transmit power mechanically to the dynamo.

The current which was first taken from the supply wires to run the motor and dynamo armatures will increase somewhat. By a careful adjustment of the two rheostats and the lead on each machine, the conditions of full load of the dynamo may be produced. The motor is overloaded and its armature will carry the sum of the dynamo and supply currents. Great care must be taken in adjusting the brushes of the machines, because of great changes in the armature reactions which take place as the brushes are moved. It is well to remember that a backward lead to the motor brushes will increase the speed, as the armature reactions will considerably weaken the effective field strength.

Cautions.

The increase of speed will raise the dynamo voltage, and cause the current flowing in the armatures to greatly increase. A forward movement of the motor brushes will reduce both speed and current. A forward movement of the dynamo brushes will increase the armature reaction, and cut down the current through the armatures, while a backward movement will cause it greatly to increase. Very great care must be taken in adjusting the brush lead, as a movement of the brushes of either machine, which would be of little importance usually, will produce sometimes a change in current value equal to the full-load current. It is quite possible but poor practice to produce the load adjustment by use of the brushes alone.

It is best to have ammeters of proper size in all circuits, but those actually required are in the dynamo leads and in the supply mains. A single voltmeter is all that is required.

The field magnet circuits ought to be connected as shown, and the ammeters placed so that the energy in the fields does not come into the test of the losses in the armatures. The magnet of the machine under test, a dynamo in this case, should be under the proper electrical conditions for the load, yet not in the armature test, because the object of the test can best be made the determination of the stray power loss under the conditions of full load; then having found this, assume the exact values of E, I, and speed, and so build up the data for the required efficiency under a desired set of conditions which might not have been exactly produced during the test.

Immediately after the run, all hot resistances should be measured as rapidly and carefully as possible, to avoid any error due to a change in temperature.

The energy given to the two armatures less the I^2R in each armature, will be the sum of all the armature losses of the two dynamos under the conditions of the test, so that we measure directly the armature losses of the dynamos while fully loaded.

It is evident that the two armatures are not under *exactly* the same conditions, except as to speed, for the dynamo armature will have an intensity of magnetic field that will give an armature voltage of $V_t + I_A R_A$, while the motor will be weaker as V_t is the same for both armatures, and the motor armature voltage will be $V_t - I_A R_A$. All the iron core losses will be made much greater in the dynamo than in the motor. The motor armature must carry a current equal to the sum of the dynamo and supply currents, and will get much hotter; its reaction will also be greater, and there will be a tendency for greater sparking at the brushes.

The total stray power thus obtained may be divided between the two armatures equally, but preferably in proportion to the armature voltages, unless the true law for the armatures is known. All resistances of wires, etc., must be noted and corrections applied, unless entirely negligible.

Two 15-H.P. dynamos were tested by the class of '93, using this method. One of the full-load tests is here given as a sample of calculation. The exact rating of the dynamos is not known, but is nearly 45 amperes at 220 volts, with the dynamo at a speed of 1600 r.p.m.

The averages of the observed readings taken during the test, and after a run of about five hours to become heated, was as below.

Example of Calculation.

(Connections as shown in Fig. 8.)

Volts at supply point	220.3
Amperes of	15.71
Output of dynamo, amperes	45.80
Dynamo field current	1.945
Speed	1594.

To Measure Armature Resistance.

Motor $V = 1.952$ $I = 10.18$
Dynamo $V = 2.406$ $I = 10.08$

The motor field is out of the test while the dynamo field is in the test.

Calculation.

Watts supplied 220.3 × 15.71 = 3461.

$$\begin{array}{l} .3430 = V \\ .1962 = I \\ \hline .5392 = 3461 \end{array}$$

Dynamo armatures R. =

$$\frac{2.406}{10.08} \quad \begin{array}{l} .3813 \\ .0035 \\ \hline .3778 = 0.2387 \end{array} \quad R_{ad}$$

Motor armature R. =

$$\frac{1.952}{10.18} \quad \begin{array}{l} .2905 \\ .0077 \\ \hline .2828 \end{array} = \quad R_{am} \; 0.1918$$

$I^2_{ad} \; R_{ad}$

$I_a = 45.80 + 1.94 = 47.74$

$$47.74^2 = \begin{cases} .6789 \\ .6789 \end{cases}$$

$$R_a \quad .2387 = \begin{array}{l} .3778 \\ \hline .7356 = 554.0 \end{array} \quad I^2_a \; R_a \; D$$

$I^2_{am} \; R_{am}$

$I_a = 45.80 + 15.71 = 6151$

$$I \quad 61.51^2 = \begin{cases} .7889 \\ .7889 \end{cases}$$

$$R .1918 \quad \begin{array}{l} .2828 \\ \hline .8606 = 725.4 \end{array} \quad I^2_a \; R_a \; M$$

Dynamo Field

$$\begin{array}{ll} I = 1.945 & .2889 \\ V = 220.3 & .3430 \quad \text{Field } D \\ & \overline{.6319} = 428.4 \end{array}$$

Watts supplied	=		3461
Dynamo field	=	428.4	
$I^2 R$ M	=	725.4	
$I^2 R$ D	=	554.0	
Total heat lost	=	1697.8	1698
Total stray power	=		1763 M and D.

V_{ad}

$V_t + I_a R_a$

47.74 × .2387 .6789
.3778

$IR = 11.4 = .0567$

$V_t = 220.3$

$231.7 = V_{ad}$

V_{am}

$V_t - I_a R_a$

61.51 × .1918 .7889
.2828

$IR = 11.8 = .0717$

$V_t = 220.3$

$208.5 = V_{am}$

Divide the total stray power between the two armatures as their armature voltages.

Stray power dynamo.

$$\frac{231.7}{231.7 + 208.5} \times 1763.$$

.2462
.6436
.6026
.3649

Stray power dynamo = 928.0 = .9675
Stray power motor = 1763 — 928.0 = 835.0

The quantity 928.0 is the object of our test, i.e., the stray power when as nearly as may be under actual running conditions.

Calculation of Efficiencies.

As run.

Output of dynamo = 220.3 × 45.80

.3430
.6609
.0039 = 10090 Watts output

10090	554	$I^2 R_{ad}$
544	428	Field
428	928	Stray power
11062 = Work done by current.	11990	Watts input to the dynamo.

Eff. of Conv.

$\frac{11062}{11990}$ .0437
.0789
.9648 = 92.2 per cent.

Comm. Eff.

$\frac{10090}{11990}$ .0039
.0789
.9250 = 84.1 per cent.

Power required to run Dynamo.

$\frac{11990}{746}$ .0789
.8727
.2062 = 16.1 H. P.

In this test, carbon brushes were used, and the lead adjusted as carefully as possible. If the exact rating of this dynamo had been 45 amperes and 220 volts at a speed of 1600, and we wished to find the efficiencies corresponding, we should proceed in this way.

The test was made under conditions as nearly as possible to the rating, and the stray power as found will not be perceptibly different from what it would be under the exact conditions.

When the load has been as carefully adjusted as in this test, it is seldom worth while to make these corrections, as they are smaller than changes produced by accidental changes of oiling, temperature, brush pressure, etc., of two separate tests.

Advantages of the Method.

Small amount of energy used in making the test, namely, only the losses. No wire or water rheostat required. Test made under full load, and yet the losses are directly measured. All quantities are expressed in terms depending on the same standards, and therefore the efficiency will be but little affected by any error in the standards. No mechanical power measurements are made, and all measurements are electrical.

Disadvantages.

Requires two similar machines. Armature reactions are not alike in both machines. Leads are not alike. The iron losses are not the same. No belt pull on bearings. Must line up machines and use a good form of mechanical coupling. Sometimes difficult to set the brushes on the motor. The motor armature is much overloaded.

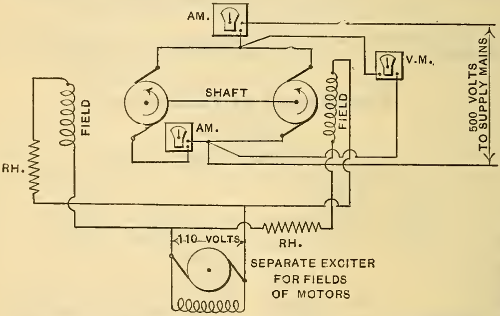

FIG. 9. Diagram of Connections for Test of Street Car Motors, Prof. Puffer.

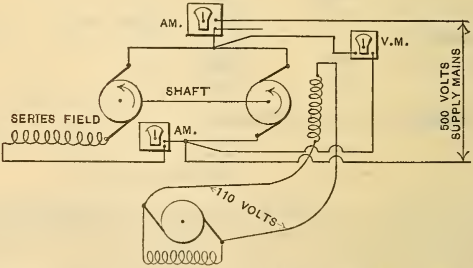

FIG. 10. Diagram of Connections of Modification of the Previous Diagram, by Prof. Puffer.

This method is of advantage in the test of railway series motors, if slightly modified by the separate excitation of the motor fields. If the series field windings be not separately excited there will be a great deal of unnecessary difficulty from great changes of speed as the load is varied. However, one field may be kept in circuit on the machine used as a motor, as the test can then be made with the motor under its exact conditions. There will be a very great change of speed during adjustment of load, but there will be no danger of injuring anything, as the separate excitation of the dynamo field is an aid to steadiness. Railway motors, as generally made, will not stand their full rated load continuously, and the motor is likely to get too hot if not watched; the machine used as a dynamo will run cold, as it will not have a large current in it. The friction of brushes is very large in these motors, and in general there is a want of accuracy in the division of the total stray power between the two armatures. It can only be very approximately done by the aid of curves showing the relation between speed and stray power, and armature voltage and stray power.

Hopkinson's Test of two Similar Dynamos.

In the original Hopkinson method, the two dynamos to be tested were placed on a common foundation with their shafts in line, and coupled together. The combination was then driven by a belt from an engine, or other source of power, to a pulley on the dynamo shafts. The leads of both machines were then joined in series, and the fields adjusted so that one acted as a motor driven by current from the other. The outside power in that case supplied, and was a measure of the total losses in the combination, the efficiency of either machine being taken as the square root of the efficiency of the combination.

Many modifications of this test have been used, especially in the substitution of some method of electrically driving the combination, as the driving-power is so much easier measured if electrical.

This test is somewhat like that last given, but the two machines are connected in *series* through the source of supply for the *difference* in power, such as a storage battery or generator. The following diagram shows the connections for the Hopkinson test, with a generator for supplying the difference in power.

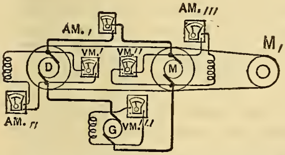

FIG. 11. Diagram of connections for Hopkinson's test of two similar dynamos.

In this test the output of G plus energy taken by M_1 (motor driving the system), gives losses of motor and dynamo (the losses of M_1 being taken out. These losses being known, the efficiency can be calculated.

If the two machines D and M are alike, G supplies the I^2R losses of armatures, and M the friction, core losses, and I^2R of fields.

Another method useful where load and current are both available, is to drive one of two similar dynamos as a motor, and belt the second dynamo to it. Put the proper load on the dynamo, and the efficiency of the combination is the ratio of the watts taken out of the dynamo to the watts supplied to the motor. The efficiency of either machine, neglecting small differences, is then the square root of the efficiency of both.

If $W =$ watts put into the motor,
$W_{,} =$ watts taken from the dynamo,
$x =$ efficiency per cent of the combination,
$y =$ efficiency of either machine.

$$x = \frac{W_{,} \times 100}{W}$$

$$y = \sqrt{x}.$$

The above test is especially applicable to rotary converters, the belt being discarded, and the *a c* sides being connected by wires; thus the first machine supplies alternating current to the second, which acts as a motor generator with an output of direct current. The only error (usually small) is due to the fact that both machines are not running same load, since that one supplies the losses of both.

Fleming's Modification of Hopkinson Test. — In this case the two dynamos under test are connected together by belt or shafts, and are driven electrically by an external source of current, say a storage battery or another dynamo, which is connected in series with the circuit of the two machines. Figure 12 shows the connections for this test, which will be found carried out in full in Fleming's "Electrical Laboratory Notes and Forms."

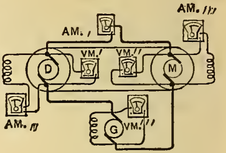

FIG. 12.

MOTOR TESTS.

Probably the most common method of testing the efficiency and capacity of motors is with the prony brake, although in factories where spare dynamos are to be had, with load available for them, there can be no question that belting the motor to the dynamo with an electrical load is by far the most accurate, and the easiest to carry out.

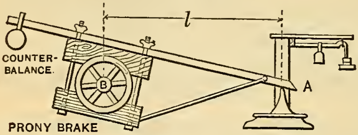

FIG. 13.

Prony brake test. — In this test a pulley of suitable dimensions is applied to the motor-shaft, and some form of friction brake is applied to the pulley to absorb the power. The following diagram shows one of the simplest forms of prony brake; but ropes, straps, and other appliances are also often used in place of the wooden brake shoes as shown.

NOTE. — See Flather, "*Dynamometers and the Measurement of power.*"

As the friction of the brake creates a great amount of heat, some method of keeping the pulley cool is necessary if the test is to continue any length of time. A pulley with deep inside flanges is often used; water is poured into the pulley after it has reached its full speed, and will stay there by reason of the centrifugal force until it is evaporated by the heat, or the speed is lowered enough to let it drop out. Rope brakes with spring balances are quite handy forms.

The work done on the brake per minute is the product of the following items:

$l =$ the distance from the centre of the brake pulley to the point of bearing on the scales, in feet,
$n =$ number of revolutions of the pulley per second,
$w =$ weight in lbs. of brake bearing on scales.

Power $= 2\pi l n w =$ foot-pounds per second, and

$$\text{H.P.} = \frac{2\pi l n w}{550}$$

The input to the motor is measured in watts, and can be reduced to horsepower by dividing the watts by 746; or the power absorbed by the brake can be reduced to watts as follows: —

If the length, l, be given in centimeters, and the weight, w, be taken in grams, the power absorbed by the brake is measured directly in ergs, and as one watt $= 10^7$ ergs, the

$$\text{Watts output at the brake} = \frac{2\pi l n w}{10^7} = W.$$

The watts input $= W_{\prime}$, and efficiency $\% = \frac{W}{W_{\prime}} \times 100.$

If the output is measured in $l =$ feet and $w =$ lbs., then

$$W = 2.72\,\pi\, l\, w.$$

$$\text{Input in h.p.} = \frac{W_{\prime}}{746} = \text{h.p.}$$

$$\text{Output H.P.} = \frac{2\pi l n w}{550} \text{ and}$$

$$\text{efficiency}\% = 100\,\frac{\text{H.P.}}{\text{h.p.}}$$

If it is desired to know the friction and other losses in the motor, after the brake test has been made, the brake can be removed, and the watts necessary to drive the motor at the same speed as when loaded, can be ascertained.

Electrical load test *(including loss in belting, and extra loss in bearings due to pull of belt).* — This test consists in belting a generator to the motor and measuring the electrical output of the generator, which added to the friction and other losses in the generator, makes up the load on the motor. The efficiency is then measured as before, by the ratio of output to input. The great advantage of this form of test is, that it can be carried on for any length of time without trouble from heat, and the extra loss in bearings due to pull of belt is included, which is therefore an actual commercial condition.

In this form of test the losses in the generator are termed *counter torque*, and the method of determining them is given following this.

Counter torque. — In tests of some motors, especially induction motors, the load is supplied by belting the motor under test to a direct current generator having a capacity of output sufficient to supply all load, including overload.

In determining the load applied to the motor and the *counter torque*, it is necessary to know, besides the *I. E.* or watts output of the generator, the following : —

I^2R of generator armature,
Core loss of generator armature,
Bearing and brush friction and windage of generator,
Extra bearing friction due to belt tension.

It is necessary to know the above items for all speeds at which the combination may have been run during the testing. This is especially useful in determining the breakdown point on induction and synchronous motors, both of which can be loaded to such a point that they "fall out of step."

While the motor is under test especial note should be made of the speeds at which the motor armature and generator armature rotate, and of the watts necessary to drive the motor at the various speeds without load.

The *counter torque* will then be the sum of the following three items : —

$W = I^2R$ of generator armature,
$W_c =$ core loss of generator armature,
$F =$ bearing and brush friction and windage of the generator armature.

The field of the D. C. machine must be separately excited and kept at the same value during the load tests and the tests for "*stray power*," and does not enter into any of these calculations.

Belt-on test. — After disconnecting current from the motor under test, and with the belt or other connection still in place, supply sufficient voltage to the D. C. machine armature to drive it as a motor at the speeds run during the motor test, holding the field excitation to the same value as before, but adjusting the voltage supplied to the armature for changing the speed.

Take readings of

Speed, i.e., number of revolutions of D. C. armature,
Volts at D. C. armature,
Amperes at D. C. armature.

Construct a curve of the power required to drive the combination at the various speeds shown during the motor test.

Belt-off test. — Throw the belt or other connection off, and take readings similar to those mentioned above, which will show the power necessary to drive the D. C. machine without belt.

Then for any speed of the combination the "*stray power*" will be found as follows : —

$W_{\prime} =$ watts from *belt-off* curve, required fo drive the D. C. machine as a motor.
$W_{\prime\prime} =$ watts from *belt-on* curve, required to drive the combination.
$W_c =$ core loss in D. C. armature.
$F =$ friction of D. C. machine, *belt off*.
$F_{\prime} =$ friction of motor under test, running light and without belt.
$f =$ increase in bearing friction of D. C. machine, due to belt tension.
$f_{\prime} =$ increase in bearing friction of motor, due to belt tension.

From the *belt-off* curve,

$$W_{\prime} = w_c + F. \qquad (1)$$

From the *belt-on* curve,

$$W_{\prime\prime} = w_c + F + F_{\prime} + f + f_{\prime}. \qquad (2)$$

Subtract (1) from (2)

$$W_{\prime\prime} - W_{\prime} = F_{\prime} + f + f_{\prime}$$
$$W_{\prime\prime} - W_{\prime} - F_{\prime} = f + f_{\prime}. \qquad (3)$$

The values of f and $f_{\prime}$ cannot be determined accurately; but if the machines are of about the same size as to bearings and weights of moving parts, it is very close to call them of equal value, when,

$$f \text{ or } f_{\prime} = \frac{(W_{\prime\prime} - W_{\prime} - F_{\prime})}{2} \qquad (4)$$

The friction $F_{\prime}$ of the motor under test has been previously found by noting the watts necessary to drive it at the various speeds. If it is an *induction* motor, the impressed voltage is reduced very low in determining the friction in order that the core loss may be approximately zero.

As all the values of the quantities on the right-hand side of the equation (4) are now known, f is determined, and may be added to $W_{\prime}$ to give the total "*stray power*." A curve is then plotted from the values of "*stray power*" at different speeds.

Counter torque $= W_{\prime} + f +$,
Total load $= I\,E + I^2R + (W_{\prime} + f)$,
Where $I\,E =$ watts load on the D. C. machine when it is being driven by the motor,
If $S = W_{\prime} + f =$ "*stray power*," then
Total load $= I.\ E. + I^2R + S$.

The value of f is so small when compared with the total load, that any ordinary error in its determination will cut no figure.

Test of Street-Railway Motors.

The "*pumping-back*" test, as described before, with some little modification serves for testing street-railway motors. The following diagram shows the arrangement and electrical connections.

The motors are driven mechanically by another motor, the input to which is a measure of the losses, frictional, core losses, gears, bearings, etc., in the two motors; the two motors are connected in series, through a booster, B, care being taken to make the connections in such a manner as to have the direction of rotation the same; and their voltages opposing.

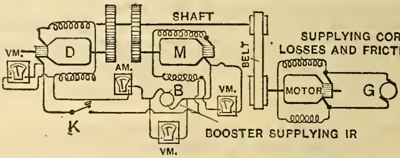

FIG. 14. Diagram of connections and arrangement of street-railway motors.

Readings are taken and the efficiencies are calculated as in the "pumping-back" test.

In eliminating the friction of bearings, etc., and of the driving-motor, it is run first without belts, the input being recorded as taken, at the speed necessary. The belt is then put on and a reading taken at proper speed, with both the motors under load.

The load being adjusted by varying the field of booster B, the total losses of the system are then $I\,E$ from booster plus the difference between belt-on reading with full load through the motors, and belt-off reading as noted (allowance being made for change of I^2R of driving-motor). If the two motors are similar, half this value is the loss in one motor, from which the efficiency can be calculated as previously shown.

Induction motors.—In addition to the tests to which the D. C. motor is ordinarily submitted, there are several others usually applied to the induction motor, as follows: —

Excitation; Stationary impedance; Maximum output; and some variations on the usual heat and efficiency tests.

Excitation: This is also the test for core loss + friction, allowance being made for I^2R of field; with no belt on the pulley the motor is run at full impressed voltage. Read the amperes of current in each leg, and total watts input. The amperes give the excitation or "running-light" current, and the watts give core loss + friction + I^2R of excitation current.

Stationary impedance: Block the *rotor* so it cannot move, and read volts and amperes in each leg, and total watts input. This is usually done at half voltage or less, and the current at full voltage is then computed by proportion. This then gives the current at instant of starting, and a measure of impedance from which, knowing the resistance and core loss, other data can be calculated, such as maximum output, efficiency, etc.

Maximum output: This might be called a *break-down* test; as it merely consists in loading the motor to a point where the maximum torque point is passed and thus the motor comes to rest.

Keep the impressed voltage constant and apply load, reading volts, amperes in each leg, the total watts input, and revolutions; also record the load applied at the time of taking the input. Then take counter torque as explained before, from which the efficiency, the apparent efficiency, the power factor, and maximum output are immediately calculated.

Heat test. — Run motor at full load for a sufficient length of time to develop full temperature, then take temperatures by thermometer at the following points: —

1. Room, not nearer to the motor than three feet and on each side of motor.
2. Surface of field laminations.
3. Ducts (field).
4. Field or stator conductors, through hole in shield.
5. Surface of rotor.
6. Rotor spider and laminations.
7. Bearings, in oil.

During heat run, read amperes and volts in each line.

Efficiency test. — Apply load to the motor, starting with nothing but friction; make readings at twelve or more intervals, from no load to breakdown point. Keep the speed of A. C. generator constant, also the impressed voltage at the motor.

Read, Speed of motor.
Speed of A. C. dynamo.
Amperes input to motor, in each leg.
Volts impressed at motor terminals.
Watts input to motor, by wattmeter.
Current and volts output from D. C. machine belted to motor,
Counter torque as explained above, and excitation reading watts.

From the above the efficiency, apparent efficiency, power factor $\left(=\frac{\text{apparent efficiency}}{\text{real efficiency}}\right)$, and maximum output can be calculated.

In reading watts in three-phase motors, it is best to use two wattmeters, connected as shown in following sketch: —

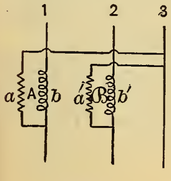

FIG. 15.

1, 2, 3, are the three-phase lines leading to the motor.

A and B are two wattmeters.

b is the current coil of A, and b^1 of B.

a is voltage coil of A, and a^1 of B.

The sum of the deflections of A and B give total watts input. At light loads one wattmeter usually reads negative, and the difference is the total watts.

Results. — At the end of the preceding tests the following results should be computed, and curves plotted from them.

$$\% \text{ synchronism} = \frac{\text{Speed of motor} \times 100.}{\text{Synchronous speed.}}$$

$$\%\text{ real efficiency} = \frac{\text{Output of motor} \times 100}{\text{Input by wattmeter}}.$$

$$\%\text{ apparent efficiency} = \frac{\text{Output of motor} \times 100}{\text{volt} \times \text{amperes}}.$$

$$\text{Power factor} = \frac{\text{Watts}}{\text{Volt} \times \text{amperes}} = \frac{\text{apparent efficiency}}{\text{real efficiency}}.$$

$$\text{Torque-pounds pull at 1 ft. radius} = \frac{5{,}250\text{ H.P.}}{\text{revolutions per minute}}.$$

The above results should be plotted on a sheet in curves similar to the following, taken from Steinmetz's article on "Induction Motors."

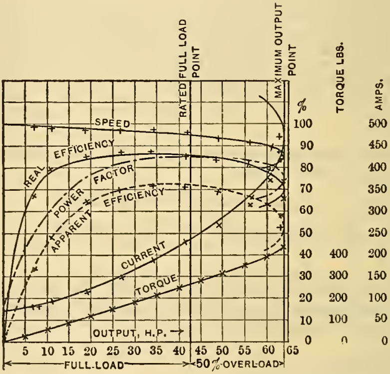

FIG. 16. Curves of results of tests of induction motor.

Synchronous motor. — Synchronous motors are separately excited, and the D. C. exciter should have its qualities tested as a dynamo. Synchronous motors are tested for *Break-down point*; *Starting current* at different points of location of the rotor; *Least exciting current* for various loads. All these in addition to the regular efficiency and other tests. Core losses, friction, I^2R losses, etc., can be found by any of the usual methods previously described.

Break-down point. Synchronous motors have but little starting-torque; and it is necessary to start them without load, throwing it on gradually after the motor has settled steadily and without "hunting" on its synchronous speed. The break-down point is found by applying load to the point where the motor falls out of step, which will be indicated by a violent rush of current in the ammeter simultaneous with the slowing down.

This test is usually carried out at about half voltage, the ratio of the load on the motor at the moment of dropping out of step will be to the full load of break-down as the square of the voltages, the load being adjusted at minimum input in each case. For example, say a certain motor, built to run at 2,000 volts, breaks down at 150 K.W., with an impressed voltage of 1,000. Then the true full break-down load will be

$$\frac{2{,}000^2}{1{,}000^2} \times 150 = 600\text{ K.W.}$$

Starting current. Owing to consequent disturbance to the line, it is desirable that the starting current of a synchronous motor be cut down to the lowest point; but it is difficult to reduce this starting current lower than 200% of full-load current. A synchronous motor also starts easier at certain positions of its *rotor* as related to poles. With the *rotor* at rest, and the location of the centre of its pole-pieces chalked on the opposite member, the circuit is closed, the impressed voltage is kept constant, and the current flowing in each leg of the circuit is read, and the time to reach synchronism. Care should be taken to note the amount of the *first rush* of current, and then the settling current at speed.

Least exciting current. The *power factor* of a synchronous motor will be 100 only when, with a given load on the motor, the exciting current is adjusted so that there is neither a *leading* nor *lagging* current in the armature. Sometimes it is desirable to produce a *leading* current in order to balance the effect of induction motors on the line, or inductance of the line itself. This is done by *over-exciting* the fields.

With a given load on the motor, the 100 power-factor is found by comparing the amperes in the motor armature with the exciting current in the field. Starting with the excitation rather low, the armature current will be high and *lagging;* as the excitation is increased, the armature current will drop, until it reaches a point where, as the excitation is still increased, the armature current begins to rise, and keeps on rising as the exciting current is increased, and on this side of the low point the armature current is *leading.*

With no reason for making a leading current, the best point to run the motor at is, of course, that at which the armature current is the lowest; and at that point the power-factor is 100.

Synchronous Impedance.—The E.M.F. of an alternating dynamo is the resultant of two factors, i.e., the *energy E.M.F.* and *inductive E.M.F.*

The *energy E.M.F.* may be determined from the saturation curve by running the machine without load, and learning the field strength necessary to produce full voltage.

The *inductive E.M.F.* is at right angles to the *energy E.M.F.*, and is determined by driving the machine at speed, short-circuiting the armature through an ammeter, and exciting the field just enough to produce full-load current in the armature. The amount of field current necessary to produce full load is a measure of the *inductive* E.M.F., which can be determined from the saturation curve as before, and the *resultant E.M.F.* will be

$$\text{Resultant E.M.F.} = \sqrt{\text{energy E.M.F.}^2 + \text{inductive E.M.F.}^2}.$$

Saturation test.—This test shows the quality of the magnetic circuit of a dynamo, and especially the amount of current necessary to saturate the field cores and yokes to a proper intensity. In this test it is important that the brushes and commutator be in good condition, and that all contacts and joints be mechanically and electrically tight.

The dynamo armature must be driven at a constant speed, and the leads from the voltmeter placed to get readings from the brushes of the dynamo must have the best of contacts.

The fields of the dynamo must be separately excited, and must have in the circuit with them an ammeter and rheostat capable of adjusting the field current for rather small changes of charge.

The armature must be without load, and a voltmeter must be connected across its terminals.

Should there be residual magnetism enough in the iron to produce any pressure without supplying any exciting current, such pressure should be recorded; or perhaps a better way is to start at zero voltage by entirely demagnetizing the fields by momentary reversal of the exciting current.

To start the test, read the pressure, due to residual magnetism if not demagnetized, or if demagnetized, start at zero. Give the fields a small exciting current, and read the voltage at the armature terminals; at the same time read the current in the fields, and the revolutions of the armature. Increase the excitation in small steps until the figures show that the knee of the iron curve has been passed by several points; then reverse the operation, decreasing the excitation by like amounts of current, until zero potential is reached.

This is usually as far as it is necessary to go in practice; but occasionally it is well to complete the entire magnetic cycle by reversing the exciting current, and repeating the steps and readings as above described.

The readings should be plotted in a curve with the amperes of exciting current as abscissae, and volts pressure as ordinates.

The E.M.F. will be found to increase rapidly at first; and this increase will be nearly proportional to the exciting current until the "*knee*" in the curve is reached, when the E.M.F. increase will not be proportional to the excitation until after the "*knee*" is passed, when the increase in E.M.F. will again become nearly proportional to the excitation, but the increase will be at such a low rate as to show that the magnetic circuit is practically saturated; and it is not economical to work the iron of a magnetic circuit too far above the knee, nor is it expedient to work it at a point much below the "*knee*," except for boosters.

The exciting current must not be broken during this test, except possibly at zero; nor must its value be reduced or receded from in case a step should be made longer than intended. Inequalities of interval in steps of exciting current will make little difference when all are plotted on a curve. For the same value of exciting current the down readings of E.M.F. will always be higher than those on the up curve.

Resistance of field coils. — The resistance of the shunt fields of a dynamo or motor can be taken in any of the usual ways: by Wheatstone bridge; by the current flowing and drop of potential across the field terminals; and it is usual, in addition, to take the drop across the rheostat at the same time. The resistance of each field coil should be taken to insure that all are alike.

Resistance of series fields, and shunts to the same, must be taken by a different method, as the resistance is so low that the condition of contacts may vary the results more than the entire resistance required. The test for resistance of armatures following this is quite applicable. Of course any test for low resistances is applicable; but the one described is as simple as any, and quite accurate enough for the purpose.

Resistance of armature. — In order to determine the I^2R loss in a generator or motor armature, its resistance must be measured with considerable care; and the ordinary Wheatstone bridge method is of no use, for the reason that the variable resistance of the contacts is often more than that of the armature itself. The drop method, so useful with higher resistance devices, is not accurate enough for the work; and the most accurate method is probably the direct comparison with a standard resistance by means of a good galvanometer and a storage battery.

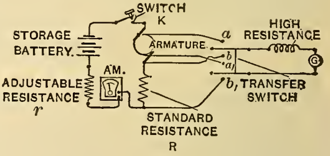

FIG. 17. Diagram of arrangement for measuring resistance of armatures.

Clean the brushes, commutator surface, or surface of the collector-rings, and in the case of a D. C. machine, see that opposite brushes bear on opposite segments.

Connect the galvanometer and its leads, the storage battery and resistances, as in the following diagram. The standard resistance, R, will ordinarily be about .01 ohm, but may be made of any size to suit the circumstances. The storage battery must be large enough to furnish practically constant current during the time of testing. The galvanometer must be able to stand the potentials from the battery; and it is usually better to connect in series with it a high resistance, so that its deflections may not be too high. The deflection of the galvanometer should be as large as possible, and proportional to the current flowing. The leads a, a_1, and b and b_1, are so arranged with the transfer switch that one pair after the other can be thrown in circuit with the galvanometer; and it is always well to take a deflection first with R, then again after taking a deflection from the armature.

The leads a and a_1 must be pressed on the commutator directly at the brush contacts, and may often be kept in place by one of a set of brushes at either side.

Test. — Close the switch, k, and adjust the resistance, r, until the ammeter shows the amount of current desired, and watch it long enough to be sure it is constant. Close the transfer switch on b and b_1, and read the galvanometer deflection, calling it d. Throw the transfer switch to the contacts a, and a_1, read the galvanometer deflection, and call it d_1. Transfer the contacts back to b, and b_1 and take another reading; and if it differs from d_1, take the mean of the two.

Let $x =$ resistance of the armature, then

$$x = \mathrm{R}\,\frac{d_1}{d}.$$

NOTE.—See Flemming's "Electrical Laboratory Notes and Forms."

Tests for Faults in Armatures.

The arrangement of galvanometer for testing the resistance of an armature is the very best for searching for faults in the same, although it is not often necessary to measure resistance.

Test for open circuit.—Clean the brushes and commutator, then apply current from some outside source, say a few cells of storage battery or low pressure dynamo, through an ammeter as in the following diagrams. Note the current indicated in the ammeter; rotate the armature slowly by hand, and if the break is in a lead, the flow of current will stop when one brush bears on the segment in fault. Note that the brushes must not cover more than a single segment.

If on rotating the armature completely around the deflection of the ammeter does not indicate a broken lead, then touch the terminals of the galvanometer to two adjacent bars, working from bar to bar. The deflection between any two commutator bars should be substantially the same in a perfect armature; if the deflection suddenly rises between two bars it is indicative of a high resistance in the coil or a break (open circuit).

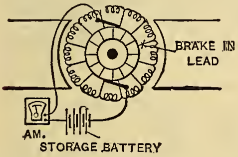

FIG. 18. Test for break in armature lead.

The following diagram shows the connections.

A telephone receiver may be used in place of the galvanometer, and the presence of current will be indicated by a "tick" in the instrument as circuit is made or broken.

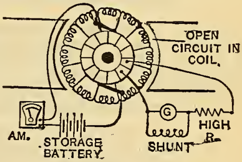

FIG. 19. Bar to bar test for open circuit in coil.

Test for short circuit.—Where two adjacent commutator bars are in contact, or a coil between two segments becomes short-circuited, the bar to bar test with galvanometer will detect the fault by showing no deflection. If a telephone is used, it will be silent when its terminal leads are connected with the two segments in contact. See diagram below for connections. If there be a short circuit between two coils the galvanometer terminals should include or straddle three commutator bars. The normal deflection will then be twice that indicated between two segments until the coils in fault are reached, when the deflection will drop. When this happens, test each coil for trouble; and if individually they are all right, the trouble is between the two. The following diagram shows the connections.

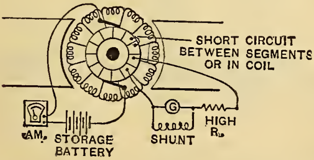

FIG. 20. Bar to bar test for short circuit in one coil or between commutator segments.

Test for grounded armature.—Place one terminal of the galvanometer on the shaft or frame of the machine, and the other terminal on the commutator. (The storage battery, ammeter, and leads must be thoroughly insulated from ground.) If, under these circumstances, there is any deflection of the galvanometer, it indicates the presence of a *ground*, or contact between the armature conductors and the frame of the machine. Move the terminal about the commutator until the least deflection is shown, and at or near that point will be found the contact in the particular coil connected between two segments showing equal deflection, unless the contact happens to be close to one segment, in which case there will be zero deflection. Contacts in field coils can be located by the same method. The following diagram shows the connections.

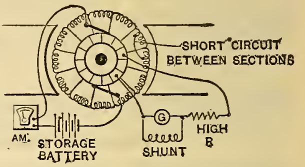

FIG. 21. Alternate bar test for short circuit between sections.

To determine if armature of multipolar dynamo is electrically centred, put down brushes 1 and 2, and take voltage of machine; put down brush 3, and lift 1, take voltage again; put down brush 4 and lift 2, again taking voltage; repeat the operation with all the brushes, and the voltage with any pair should be the same as that of any other pair if the armature is electrically central.

The same thing can also be determined by taking the pressure curves all around the commutator as shown in the notes on *characteristics on dynamos.*

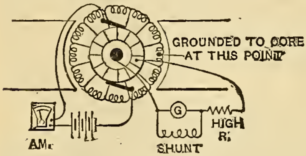

FIG. 22. Test for ground in armature coils.

In the above the brushes should be exactly at the neutral point.

Test for E.M.F. of Dynamo without Running it.

Prof. F. B. Crocker gives the following method (page 247 Trans. A. I. E. E., 1897), for determining the E.M.F. of a dynamo without driving it by outside power, provided a current of the proper voltage is at hand sufficient to give it full torque as a motor.

Clamp a lever to the pulley, and weigh the torque, as a motor, at radius r, with a spring balance or a platform scale.

r = radius of torque lever.
s = speed of revolutions per minute, as a dynamo.
p = pounds pull at radius r.
I = current.
E = E.M.F.

$$\frac{E\,I}{746} = \frac{2\pi\, r\, s\, p}{33{,}000}.$$

$$E = \frac{r\, s\, p}{7.04\, I}.$$

Field strength is the same as if running as a dynamo; and by tapping the shaft when test is made, friction losses are partially eliminated, and the method is sufficiently correct for all efficiencies.

THE STATIC TRANSFORMER.

THE static transformer is a device used for changing the voltage and current of an alternating circuit in pressure and amount. It consists, essentially, of a pair of mutually inductive circuits, called the primary and secondary coils, and a magnetic circuit interlinked with both the primary and secondary coils. This magnetic circuit is called the core of the transformer.

The primary and secondary coils are so placed that the mutual induction between them is very great. Upon applying an alternating voltage to the primary coil an alternating flux is set up in the iron core, and this alternating flux induces an E.M.F. in the secondary coil in direct proportion to the ratio of the number of turns of the primary and secondary.

Technically, the primary is the coil upon which the E.M.F. from the line or source of supply is impressed, and the secondary is the coil within which an induced E.M.F. is generated.

The magnetic circuit or core in transformers is composed of laminated sheet iron or steel. The following cuts represent sections of several different types.

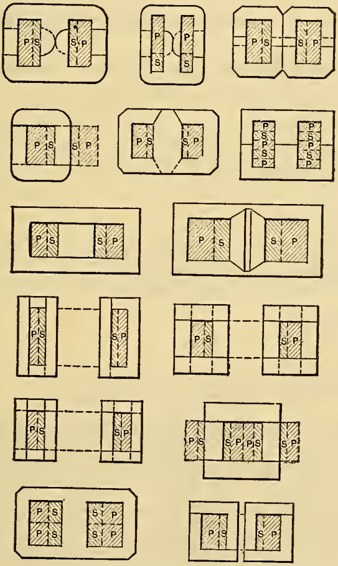

FIG. 1. Cores of some American Transformers.

p = primary winding ; s = secondary winding.

In those showing a double magnetic circuit the iron is built up through and around the coils, and they are usually called the " Shell " type of transformer.

Those having a single magnetic circuit, and having the coils built around the long portions or legs of the core, the short portions or yoke connecting these legs at each end, are called "core" type of transformer.

The duties of a perfect transformer are:

(1) To absorb a certain amount of electrical energy at a given voltage and frequency, and to give out the same amount of energy at the same frequency and any desired voltage.

(2) To keep the primary and secondary coils completely isolated from one another electrically.

(3) To maintain the same ratio between impressed and delivered voltage at all loads.

The commercial transformer, however, is not a perfect converter of energy, although it probably approaches nearer perfection than any form of apparatus used to transform energy. The difference between the energy taken into the transformer and that given out is the sum of its losses. These losses are made up of the copper loss and the core loss.

The core loss is that energy which is absorbed by the transformer when the secondary circuit is open, and is the sum of the hysteresis and eddy current loss in the core, and a slight copper loss in the primary coil, which is generally neglected in the measurements.

The hysteresis loss is caused by the reversals of the magnetism in the iron core, and differs with different qualities of iron With a given quality of iron, this loss varies as the 1.6 power of the voltage with constant frequency.

Steinmetz gives a law or equation for hysteresis as follows:

$$W_H = \eta \mathfrak{B}^{1.6}.$$

W_H = Hysteresis loss per cubic centimeter per cycle, in ergs ($= 10^{-7}$ joules).

η = constant dependent on the quality of iron.

If N = the frequency,

V = the volume of the iron in the core in cubic centimeters,

P = the power in watts consumed in the whole core,

then $P = \eta N V \mathfrak{B}^{1.6} 10^{-7}$,

and $$\eta = \frac{P}{N V \mathfrak{B}^{1.6} 10^{-7}}.$$

In Table A, on page 333, this hysteresis constant η is given for several different transformers.

In the construction, the core loss depends on the following factors:

(1) Magnetic density,
(2) Weight of iron core,
(3) Frequency,
(4) Quality of iron,
(5) Thickness of iron,
(6) Insulation between the sheets or laminations.

The density and frequency being predetermined the weight or amount of iron is a matter of design. The quality of the iron is very variable, and up to the present time no method has been found to manufacture iron for transformers which gives as great a uniformity of results as to the magnetic losses as could be desired.

On the thickness of the laminations and the insulation between them depend the eddy current losses in the iron. Theoretically[1] the best thickness of iron for minimum combined eddy and hysteresis loss at commercial frequencies is from .010″ to .015″, and common practice is to use iron about .014″ thick.

The copper losses in a transformer are the sum of the I^2R losses of both the primary and secondary coils, and the eddy current loss in the conductors. In any well-designed transformer, however, the eddy current loss in the conductors is negligible, so that the sum of the I^2R losses of primary and secondary can be taken as the actual copper loss in the transformer.

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[1] Bedell, Klein, Thomson, Elec. W., Dec. 31. 1898.

TABLE A.

(Ford.)

No.	Loss, Watts.						$\mathcal{B}$		Hysteresis Constant η.	
	Per Pound.		Per Cu. In.		Per Cu. Cm.					
	$N = 125.$	$N = 60.$	$N = 125.$	$N = 60$	$N = 125.$	$N = 60$	$N = 125.$	$N = 60.$	$N = 125.$	$N = 60.$
1	.96	1.61	.27	.45	.017	.027	3770	7870	2.59×10^{-10}	2.66×10^{-10}
2	.62	.86	.18	.24	.011	.015				
3	.46	.64	.13	.18	.008	.011	2050	4280	3.20 "	2.90 "
4	.75	1.00	.21	.27	.013	.017	2600	5400	3.52 "	3.04 "
5	.85	1.25	.24	.32	.015	.020	3640	7500	2.39 "	2.10 "
6	2.14	3.93	.68	1.10	.041	.067	3750	7720	6.26 "	6.57 "
7	.85	1.25	.24	.35	.014	.021	3630	7560	2.24 "	2.12 "
8	.32	.42	.09	.12	.005	.007	1960	4080	2.38 "	2.22 "
9	1.42	1.82	.40	.52	.024	.031				
10	.48	.67	.13	.19	.008	.011	2380	4960	2.54 "	2.24 "
11	1.07	1.39	.30	.40	.018	.021	4670	8460	2.42 "	2.06 "
12	.82	1.06	.23	.30	.014	.018	3210	6650	2.75 "	2.28 "
13	.84	1.21	.24	.34	.014	.021				
14	.75	1.50	.20	.40	.013	.024	5250	10950	1.94 "	2.45 "
15	.93	1.21	.26	.34	.017	.021	3540	7470	2.88 "	2.26 "
16	1.43	2.74	.40	.77	.024	.047	3120	6400	4.73 "	6.33 "

TRANSFORMER EQUATIONS.

Practically all successful designs of transformers are determined to greater or less extent by the method of cut and try. Empirical methods are of little value if the designer can obtain data on other successful transformers for the same kind of work, and base the calculations for the new apparatus on the behavior of the old while under test.

For any transformer or reactive coil:

Let $E = \sqrt{\text{mean}^2}$ of the induced E.M.F.
$\Phi =$ total flux.
$\mathfrak{B}'' =$ lines of force per square inch.
$A =$ section of magnetic circuit in square inches.
$N =$ frequency in cycles per second.
$T =$ total turns of wire in series.

$$4.44 = \frac{2\pi}{\sqrt{2}} = \sqrt{2} \times \pi$$

$$\text{Then } E = \frac{4.44\, N \Phi T}{10^8} \qquad (1)$$

This equation is based on the assumption of a sine wave of electromotive force, and is the most important of the formulae used in the design of an alternating current transformer.

By substituting and transposing we can derive an equation for any unknown quantity.

Thus if the volts, frequency, and turns are known, then—

$$\Phi = \frac{E \times 10^8}{4.44 \times N \times T} \qquad (2)$$

$$\text{But } \Phi = \mathfrak{B}'' A \qquad (3)$$

$$\text{Therefore } A = \frac{E \times 10^8}{4.44 \times N \times T \times \mathfrak{B}''} \qquad (4)$$

which equation gives at once the cross section of iron necessary for the magnetic circuit after we have decided on the total primary turns, and the density at which it is desired to work the iron.

Again, if the volts, frequency, cross section of core, and density are known, we have, transposing equation (4),

$$T = \frac{E \times 10^8}{4.44 \times N \times \mathfrak{B}'' \times A}$$

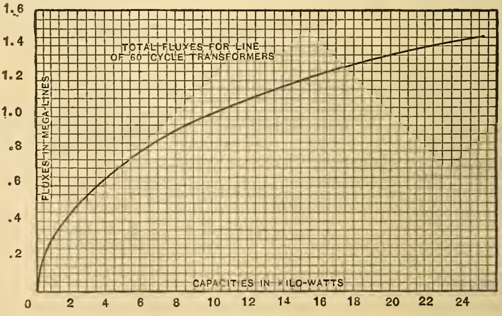


FIG. 2.

Fig. 2 is a curve giving the total fluxes as ordinates and capacities in k.w. as abscissae. This curve represents approximately common practice for a line of lighting transformers, to be operated at 60 cycles.

For any other frequency or for power work, a curve of total fluxes can be drawn after three or more transformers have been calculated with quite widely differing capacities.

Magnetic densities in the cores of transformers vary considerably with the different frequencies and different designs of various makers. The practical limits of these densities are as follows:

For 25 cycle transformer from 60,000 to 90,000 C.G.S. lines per square inch.

For 60 cycle transformers from 40,000 to 60,000 lines per square inch.

For 125 cycles from 30,000 to 50,000 lines per square inch.

Densities for other frequencies are taken in proportion.

Current densities in transformer windings vary between 1000 and 2000 circular mills per ampere. Some makers design for greater current density in the secondary than in the primary. The circular mils per ampere in transformers of the best design are often 1000 or 1500 in the primary coil, and 1200 or 2000 for the secondary coil.

The proper adjustment of the current density should be such as to give equal heat distribution throughout the coils, and the relative densities in the two coils should be based on their relative radiating surfaces.

FEATURES OF DESIGN.

In the design of a successful transformer, the features to be given particular attention are:

1. Insulation between primary and secondary,
2. Heating,
3. Efficiencies,
4. Regulation,
5. Cost,
6. Power factor and exciting current.

Insulation.

The insulation of a transformer is really a measure of its *durability*, and it must be obvious that if it is not well designed and properly constructed to prevent the breakdown of its insulation, it is not a good investment; and the same reasoning holds good if the insulation deteriorates rapidly. Simplicity of form and constructive details is a good point, and as transformers are liable to be exposed to all sorts of weather and other conditions, they should always be designed to withstand all of them.

Insulation between coils *must* be of the best possible kind, as electrical connection here is a menace to life and property, and destruction of the transformer also means costly repairs, loss of income while current is off, and what is of more importance, great annoyance to customers.

A liberal margin of overload is necessary, and if specifications call for a rise of temperature not exceeding 40° C., at full load, any ordinary overload will do no harm, provided the insulation is safe. The rules of the *Committee on Standardization* of the A. I. E. E. state the proper voltages to be used in testing transformers for insulation, and the values so stated will be found in the part of this chapter devoted to *tests of transformers.* The writer has never been thoroughly satisfied with the methods in common use for determining the rise of temperature in transformers or dynamos or similar appliances. The thermometer test is too superficial, and the resistance test is the average only, while what is wanted is the *hottest* temperature at any point, for that is the danger point. It is probable that the ordinary small commercial sizes of transformers do not need such refinements, but the larger sizes would be much better tested with a special copper test coil placed at the danger point during construction, with leads brought outside for testing. This might not be necessary in more than one or two of the same type and size, but would never be out of place in every one of the larger sizes now coming so commonly into use in the modern power transmission plant. Insulation materials for transformers are of numerous kinds, and no two makers use identical combinations, although most use the same or similar materials; following is a list of those in common use;

and the reader is referred to the list of specific resistances (see index) for the breakdown point of most of them.

Oiled linen,
Oiled silk,
Mica,
Micanite, flakes of mica pasted together in different forms,
Fiber, and all the other forms of artificial board.

Wires are nearly always double cotton covered.

As for oils for the oil-insulated transformers, the Westinghouse Company uses a clear thin oil much like signal-oil, and called *Red Seal*, while the General Electric Company uses a special transformer oil, which is heavy, but is simply a good machine-oil freed from water.

An order to the Standard Oil Company for transformer oil will bring an oil that will serve every ordinary purpose, and many times it will be found that unless some particular oil is specified they will seldom send the same twice. The laboratory of the *National Board of Fire Underwriters* has used a number of different kinds in its high-testing transformers (40,000 volts), and has never found any difference in results although ordered as stated above.

Heating and Ventilation.

One of the necessary requirements of any piece of machinery is that it must be able to operate for certain periods of time at its full load, and in some cases over-load, without undue heating.

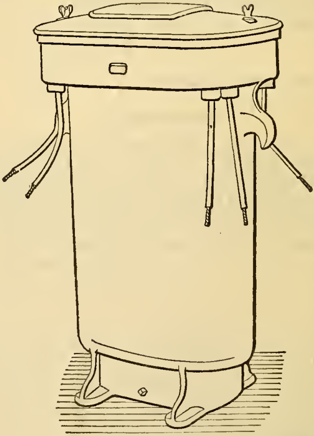


FIG. 3. G. E. Co. Type H Transformer — 20000 watts, oil-cooled.

In a transformer, the capacity for work increases directly as the volume of material, densities and proportions remaining constant. The volume, however, increases as the cube of the dimensions, and the radiating surface as the square of the dimensions; therefore, it is evident that the capacity for work increases faster than the radiating surface. Since the losses are also in proportion to the volume, the designer soon reaches a point where it is necessary to provide additional means for ventilation or radiation of heat, in order that the transformer may run under load without undue temperature rise.

Self-cooled transformers are those which require no artificial means for dissipating the heat energy lost in the apparatus during operation. These can be divided into two classes, the Ventilated or Natural Draft, and the oil-cooled.

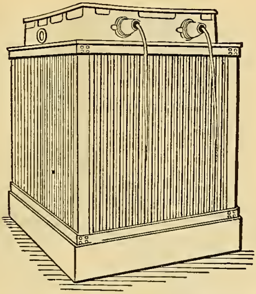


FIG. 4.—500-k.w. Self-Cooling Transformer. W. E. & M. Co. Type, Oil-cooled.

The **Ventilated** or **Natural Draft transformer** is one in which air is the direct means of absorbing the heat, it being designed so that currents of air readily pass through the transformer. Such transformers are not well adapted for out-door installations, as they require a separate housing; otherwise there is a liability of water or moisture getting inside of the case.

Oil-cooled transformers are those in which the coils and core are immersed in oil, the oil acting as a medium to conduct the heat from the coils to the surrounding tank. In addition to acting as a heat-conducting medium, the oil also serves to preserve the insulation from oxidation, increases the breakdown resistance of the insulation, and re-insulates the insulation in case of a puncture.

The use of oil in a transformer results in a more rapid conduction between the transformer proper and its case or tank, and the lowering of the temperature increases the life of the transformer. Again, instances are known of the discharge of " atmospheric electricity," or a discharge of lightning at a distance that has punctured the insulation of a transformer, and when filled with oil, the oil flows in and repairs the rupture, which may be too small to cause immediate damage. If a sufficient space is left inside the case, the oil will get up a circulation by its own convection currents, the cooler oil rising inside as it becomes more and more heated, the hot oil on the top falling as it is cooled by contact with the inside surface of the tank.

This cooling may be further increased by making the containing case with deep vertical corrugations, thus largely increasing its radiating surface.

The curves on page 338 serve to show the effect on the temperature of the use of oil. Curve 1 represents the temperature rise (by resistance method) of a transformer without oil; curve 2, the temperature rise of the same transformer with oil; curve 3, the temperature rise of the oil; curve 4, the temperature rise of another transformer run without oil; and curve 5, the highest temperature rise accessible to thermometer, whose actual temperature (by resistance) is shown in curve 4.

When the transformers are of such a size that sufficient radiating surface cannot be had in the tank to dissipate the heat, it becomes necessary to provide artificial means for cooling the same. Some of the means adopted are, water circulation, forced oil or air circulation. For both the water and oil circulation the coils and core are immersed in oil.

The **water-cooled transformer** has its heated oil cooled by means of water circulating pipes placed in the oil. The transformer thus has the advantage of oil insulation, and the circulation of the cold water through the pipes requires much less power than the pumping of the oil, and in addition does not require external cooling apparatus. This method is subject to a slight danger, due to possible leak of water pipes.

Transformers have been constructed in sizes up to about 2000 k.w., using water circulation for cooling.

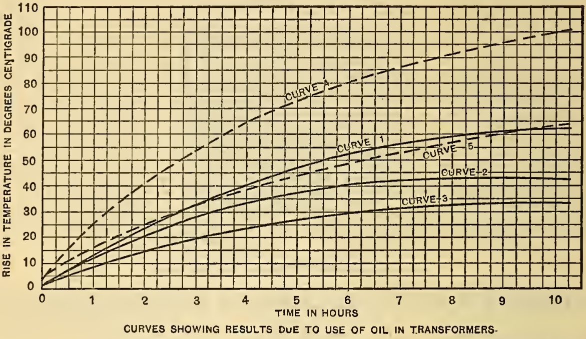
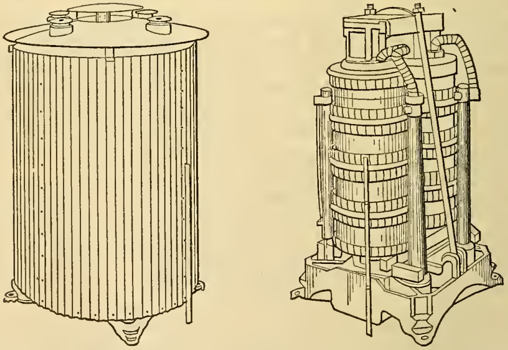


FIG. 5.

An Air-Blast Transformer—or one in which ventilation and radiation of heat is, by means of a blast or current of air, forced through the transformer coils and core is shown in Fig. 8. In this transformer, the coils are built up high and thin, and assembled with spaces between them, the air being forced through these spaces. The iron core is also built up of numerous openings through which the air is forced for cooling purposes. This style of transformer has been constructed in sizes up to about 1000 k.w.



FIGS. 6 and 7. Natural Draft Transformer — Showing Case Removed.

The following tables show results of tests on a number of commercial transformers by Mr. A. H. Ford.

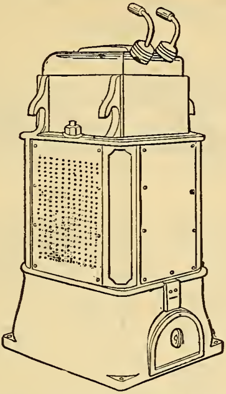


FIG. 8. Air-Blast Transformer.

B Heating Tests.

Transformers in their cases. (Ford.)

No.	Rise in Temperature °C.	Watts radiated per sq. in. of Case. W_1.	Watts radiated per sq. in. of Core and Coils. W_2.	No.	Rise in Temperature °C.	Watts radiated per sq. in. of Case. W_1.	Watts radiated per sq. in. of Core and Coils. W_2.
1	31.4	.143	.175	9	31.0	.172	.300
	24.3	.091	.107		39.4	.134	.234
	57.4	.168	.198				
2	20.1	.052	.110	12	31.6	.086	.145
	15.2	.047	.098		20.5	.067	.113
	47.8	.102	.214		51.8	.125	.211
	30.8	.085	.190		21.5	.122	.206
3	20.8	.105	.121	13	60.0	.113	.131
	17.5	.080	.093		49.4	.079	.104
	50.2	.168	.195				
	38.4	.134	.155				
5	21.8	.118	.166	14	43.4	.168	.266
	19.1	.090	.127		32.1	.079	.130
	40.8	.172	.242		101.8	.250	.396
	40.6	.144	.203		76.9	.150	.234
6	62.4	.388	.542	15	25.4	.099	.150
	52.3	.246	.346		21.2	.074	.112
	86.8	.412	.580		67.5	.168	.255
	72.2	.455	.640		51.6	.149	.225
7	20.0	.082	. . .	16	73.4	.225	.396
	17.8	.058	. . .		66.1	.175	.242
	56.3	.144	. . .		100.0	.340	.466
	36.0	.100	. . .		70.0	.242	.334

C Heating Tests.

Transformers out of their cases.

(Ford.)

No.	Rise in Temperature °C.	Watts radiated per sq. in. of Exposed Surface. W.	No.	Rise in Temperature °C.	Watts radiated per sq. in. of Exposed Surface. W.
1	27.9	.175	11	27.0	.274
	21.2	.107		18.9	.208
	51.0	.222		52.2	.372
				50.4	.320
2	14.6	.110			
	13.6	.098			
	41.4	.240	12	19.7	.145
	42.4	.220		12.3	.113
				55.9	.229
3	20.3	.122		53.8	.195
	12.4	.093			
	33.2	.167			
	30.8	.136	14	29.1	.266
				24.0	.125
4	16.2	.160		96.7	.382
	13.4	.110		77.0	.286
	59.4	.240			
	51.4	.200			
			15	25.1	.150
6	50.0	.547		14.3	.112
	24.4	.346		61.3	.270
	72.0	.595		59.4	.250
	58.9	.655			
7	14.0	.082	16	44.3	.396
	6.4	.058		31.4	.243
	75.0	.185		64.3	.438
	19.0	.121		42.9	.304

Efficiencies.

The efficiency of a transformer is the ratio of the output watts to the input watts. Thus

$$\text{Efficiency} = \frac{\text{Output watts}}{\text{Input watts}} = \frac{\text{Output}}{\text{output} + \text{core loss} + \text{copper loss}}$$

The core loss, which is made up of the hysteresis loss and eddy current loss, remains constant in a constant potential transformer at all loads, while the copper loss, or I^2R loss, varies as the square of the current in the primary and secondary. Methods for determining all the losses are fully described in the chapter on transformer testing.

In a service where a transformer is generally worked at full load, while connected to the circuit, as in power work, the average or "all-day" efficiency will be about the same as its full-load efficiency. By "all-day" efficiency is meant the percentage which the energy used by the customer is of the total energy sent into the transformer during twenty-four hours.

In lighting work the transformers are usually connected to the mains or are excited the full twenty-four hours per day, while the customer draws current from them during from three to five hours in the twenty-four. Assuming on an average five hours full load, the losses will be 5 hours I^2R and

24 hours core loss. The calculation of the "all-day" efficiency can, therefore, be made by the following formula:

$$\text{All-day efficiency} = \frac{\text{Full load} \times 5}{\text{Core loss} \times 24 + I^2R \times 5 + \text{Full load} \times 5}$$

From this it is evident that while for power work or continuous full load, the relative amount of the core and copper losses will not affect the "all-day" efficiency seriously, yet in the design of transformers which are worked at full load only a short time, but are always kept excited, a large core loss means a very low "all-day" efficiency.

The two tables on pages 342 and 343 show various efficiencies of a number of transformers, giving maximum efficiencies and "all-day" efficiencies. They also show the core loss of various commercial transformers as found by Mr. Ford.

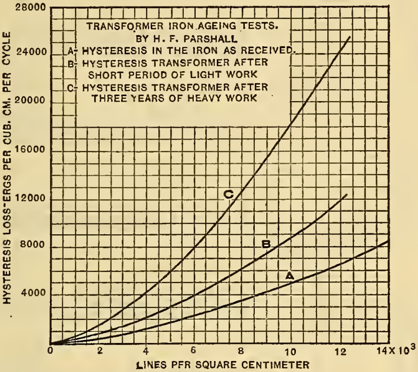


FIG. 9.

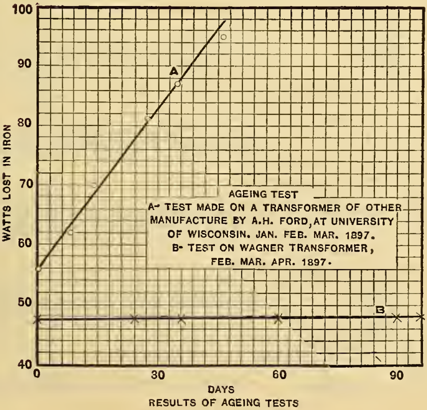


FIG. 10.

IRON CORE LOSS OF TRANSFORMERS.

Tests by Arthur Hillyer Ford, B. S., under the direction of Prof. D. C. Jackson.

Number.	Output Watts.	Iron Loss.		Copper Loss Max.	Efficiency Maximum.		All-Day Efficiency.		Open Circuit Current.		Power Factor at No Load.	
		$N = 125$.	$N = 60$.		$N = 125$.	$N = 60$.	$N = 125$.	$N = 60$.	$N = 125$.	$N = 60$.	$N = 125$.	$N = 60$.
1	450	23.4	38.6	12.2	92.5	90.0	78.4	69.6	.033	.061	.710	.634
2	1,000	24.4	27.6	32.8	94.9	94.4	87.2	85.8	.028	.064	.752	.520
3	1,250	37.0	48.5	29.7	95.0	94.0	85.1	83.0	.043	.066	.840	.730
4	1,500	50.5	70.6	45.2	94.6	94.0	84.8	80.6	.076	.124	.640	.565
5	1,500	45.7	60.1	36.2	94.8	94.0	85.5	83.4	.054	.099	.817	.615
6	1,500	126.0	206.0	14.8	91.5	87.4	70.8	60.0	.173	.475	.650	.400
7	1,500	32.2	46.5	38.1	95.7	94.5	89.4	85.0	.052	.100	.620	.465
8	1,500	33.7	44.6	57.5	94.7	94.2	86.0	85.3	.054	.068	.628	.656
9	1,500	97.5	125.0	38.5	91.7	90.1	76.5	70.2	.124	.190	.786	.657
10	1,500	31.5	44.5	44.0	95.6	94.7	89.0	85.8	.050	.076	.615	.590
11	1,500	57.5	76.0	30.9	94.5	93.4	83.0	79.2	.073	.113	.796	.672
12	1,500	43.2	55.5	28.5	95.3	94.6	86.5	83.7	.077	.144	.556	.384
13	1,500	57.0	82.0	35.3	93.7	92.0	83.0	77.8	.085	.125	.670	.656
14	1,800	53.5	108.7	66.6	94.0	91.7	84.7	75.5	.076	.600	.710	.182
15	2,009	42.4	56.3	54.8	95.2	94.5	88.6	86.5	.055	.091	.785	.630
16	2,500	135.0	230.0	44.4	92.5	89.0	77.0	68.0	.230	.540	.585	.430
17	7,500	74.0	100.0	240.0	96.7	96.4	93.1	91.2	.116	.168	.638	.595
18	7,500	90.0	122.0	160.0	97.0	96.6	92.8	91.0	.160	.209	.566	.585
19	1,000	19.0	29.0	28.0	95.6	94.5	89.5	85.8	.028	.047	.680	.620
20	4,500	49.5	70.0	100.0	97.1	96.5	93.0	91.1	.080	.100	.620	.700
21	10,000	103.0	144.0	160.0	97.5	97.2	93.8	92.0	.160	.230	.610	.640

GENERAL ELECTRIC TYPE H 60 CYCLE TRANSFORMERS.

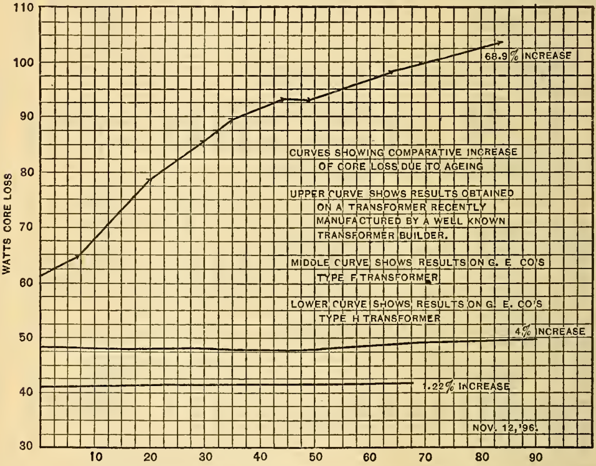
Adapted for Use on Circuits Having a Frequency of from 50 to 150 Cycles. Data Based on 1040 Volts Primary Current.

After a run of eight hours, at full load, the rise in temperature of the oil will not exceed 45 degrees Centigrade.

Watts Capacity.	Iron Core Loss 60 Cycles.	Iron Core Loss 125 Cycles.	Regulation 60 Cycles Per Cent Drop.	Regulation 125 Cycles Per Cent Drop.	Efficiency Full Load 60 Cycles.	Efficiency Full Load 125 cycles.	Net Weight. Pounds.
600	23	18	2.8	2.9	93.6	94.1	80
1000	30	23	2.59	2.7	94.6	95.2	100
1500	35	27	2.45	2.62	95.3	95.9	135
2000	45	34	2.3	2.5	95.7	96.2	170
2500	48	37	2.1	2.45	96.1	96.6	205
3000	60	46	2.1	2.45	96.3	96.6	225
4000	68	52	2.	2.35	96.5	96.8	280
5000	76	58	2.	2.44	96.5	96.9	330
6000	93	71	1.8	2.	96.6	96.9	445
7500	116	88	1.7	1.9	96.7	97.1	565
10000	155	117	1.44	1.61	97.1	97.5	695
15000	192	145	1.35	1.40	97.5	97.7	1,025
20000	254	192	1.32	1.35	97.6	97.9	1,250
25000	310	238	1.3	1.3	97.7	98.	1,525
30000	360	272	1.3	1.3	97.8	98.1	1,825

Magnetic fatigue or aging of iron subjected to magnetic reversals is now well recognized, and precautions are taken to prevent it by all the better class of transformer manufacturers. Unless great care is taken in this respect the core loss is liable to increase very considerably after time has elapsed, this loss increasing from 25 % to often more than 100 % of the original core loss. The following curves show the difference between carefully selected and prepared iron, and ordinary commercial iron. The upper curve shows a very great increase in iron loss after 80 days' run, while the two lower curves show but little increase after the same length of time.

Curves 9 and 10 also show results of aging tests by Mr. W. F. Parshall and Mr. A. H. Ford.



CURVES SHOWING INCREASE OF TRANSFORMER CORE LOSS DUE TO AGEING

FIG. 11.

Regulation.

The most important factor in the life of incandescent lamps is a steady voltage, and a system of distribution in which the regulation of pressure is not maintained to within 2 % is liable to considerable reduction in the life and candle power of its lamps. For this reason it is highly important that the *regulation*, i.e., the change of voltage due wholly to change of load on the secondary of a transformer, be maintained within as close limits as possible.

In the design of a transformer, good regulation and low-core loss are in direct opposition to one another when both are desired in the highest degree. For instance, assuming the densities will not be changed in the iron or in the copper, if we cut the section of the core down one-half, we decrease the core loss one-half. The turns of wire, however, are doubled, and the reactance of the coils quadrupled, because the resistance changes with the square of the turns in series.

A well-designed transformer, however, should give good results, both as regards core loss and regulation, the relative values depending upon the class of work it is to do, and the size of the transformer. The following table shows the results of tests for regulation of a number of commercial transformers obtained in the open market by Mr. Ford.

REGULATION OF TRANSFORMERS.

Tests by Arthur Hillyer Ford, B. S., under the direction of Prof. D. C. Jackson.

No.	Watts Output.	Total Drop.		*IR* Primary.		*IR* Secondary.		Leakage Drop.	
		$N = 125.$	$N = 60.$	$N = 125.$	$N = 60.$	$N = 125.$	$N = 60.$	$N = 125.$	$N = 60.$
1	454	82.0	21.0	24.2	28.0	1.94	2.48	78.0	15.7
2	1000	3.1	3.2	16.6	14.7	1.48	1.43	.1	.3
3	1250	2.3	3.5	10.9	12.4	.80	1.00	.5	1.3
4	1500	3.5	2.8	7.9	7.7	.85	.88	1.9	1.1
5	1500	2.9	2.0	9.3	8.7	1.04	.98	1.0	.1
6	1500	1.8	1.2	3.4	3.9	.41	.42	1.1	.4
7	1500	4.9	3.3	12.6	13.0	1.05	1.10	2.6	.9
8	1500	2.6	2.7	11.5	11.5	2.20	2.20	. . .	. . .
9	1500	4.0	3.1	7.9	7.9	.78	.78	2.4	1.5
10	1500	2.7	1.8	11.9	12.0	.79	.79	.7	. . .
11	1500	2.8	2.2	8.2	7.9	1.04	1.04	1.0	.4
12	1500	3.8	2.0	12.7	12.5	1.36	1.36	1.2	. . .
13	1500	4.6	3.4	8.5	8.5	1.36	1.36	2.4	1.2
14	1800	5.2	4.7	17.0	17.8	1.40	1.40	2.1	1.5
15	2000	5.3	4.2	8.2	8.4	1.71	1.75	2.8	1.7
16	2500	2.1	2.5	5.9	5.9	.80	.80	.7	1.1
17	7500	3.0	2.8	. . .	. . .	2.8 . . .	. . .	.2	.0
18	7500	2.9	2.3	. . .	. . .	2.1 . . .	. . .	.8	.2
19	1000	2.7	2.9	. . .	2.6	and 2.8	. . .	.1	.1
20	4500	3.0	2.5	. . .	2.3	. . .	. . .	.7	.2
21	10000	1.7	1.8	. . .	1.6	. . .	. . .	.1	.2

Comparative Expense of Operating Large and Small Transformers.

It is obvious that the design of the distributing system has quite as much to do with the maintenance of a steady voltage as does the *regulation* of the transformers, and the proper selection of the size of transformers to be used requires skilled judgment.

When transformers were first used it was the custom to supply one for each house, and sometimes two or three where the load was heavy. Experience and tests soon made it evident that the installation of one large transformer in place of several small ones was very much more economical in first cost, running expenses (cost of power to supply loss), and regulation.

Where transformers are supplied one for each house, it is necessary to provide a capacity for 80 % of the lamps wired, and allowing an overload of 25% at times. Where one large transformer is installed for a group of houses, capacity for only 50% of the total wired lamps need be provided. For residence lighting, where the load factor is always very low, it is often best to run a line of secondaries over the region to be served, and connect a few large transformers to them in multiple.

A study of the following curves will show in a measure the results to be expected by careful selection and placing of the transformers. The first curve, Fig. 12, shows the relative cost per lamp or unit of transformers of different capacity, showing how much cheaper large ones are than small ones.

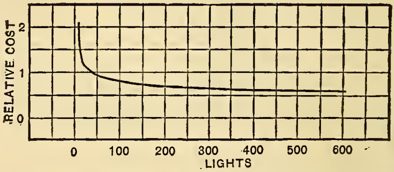


FIG. 12. Relative Cost of Transformers of Different Capacities.

The second set of curves, Fig. 13, shows the power saved at different loads, and using different sizes of transformers.

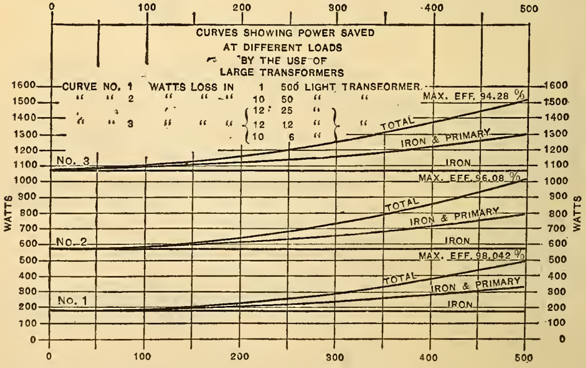


FIG. 13. Relative Efficiency of Large and Small Transformers.

Power Factor is the ratio of the actual watts in a line to the volt amperes or apparent watts in that line. It is also defined as the cosine of the angle of phase displacement of the current from the voltage in the circuit.

The power factor of most commercial transformers is low at no load, varying from 50 % to 70 %, while at high loads the power factor is very nearly 100 per cent. For this reason it is better to distribute the transformers on the line so that they will carry load enough most of the time to keep the power factor reasonably high.

COMMERCIAL TRANSFORMERS.

The following tables show the trade numbers, capacities, and the ordinary characteristics of some of the transformers in more common use at this time, including Stanley Electric Co.; Westinghouse Electric and Manufacturing Co.; "Wood," the Fort Wayne Electric Corporation; Wagner Electric and Manufacturing Co.; General Electric Co., table for which will be found on page 343.

In order to show a comparison of the qualities of transformers as made some time ago and at present, a table of tests by Dr. Fleming, F.R.S., is also included.

STANLEY ELECTRIC MANUFACTURING CO. LIGHTING TRANSFORMERS.

Frequency = 66 P.P.S.

Efficiencies.

Regulation uniformly 2½ % at full load.

Type.	Full Load Output in K.W.	Full Load.	¾ Load.	½ Load.	¼ Load.	⅛ Load.
2 G	½	93.0%	93.1%	92.2%	88.8%	80.7%
3 G	¾	93.0	93.2	93.0	89.5	82.5
4 G	1	95.5	95.7	95.0	92.0	85.0
6 G	1½	95.8	96.0	95.5	92.8	87.6
8 G	2	95.9	95.9	95.5	93.5	88.5
10 G	2½	96.0	96.2	95.8	93.5	90.4
15 G	3¾	96.6	96.7	96.3	94.3	91.3
20 G	5	96.7	96.9	96.6	95.0	91.5
30 G	7½	96.8	97.0	96.7	95.5	92.2
40 G	10	96.8	96.9	96.8	95.7	92.6
60 G	15	97.2	97.2	97.2	96.9	94.8
80 G	20	97.8	97.7	97.5	96.9	95.1
100 G	25	97.6	97.8	97.8	97.2	95.5

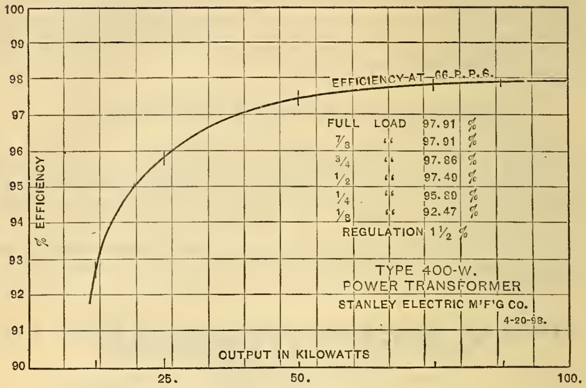

EFFICIENCY AT 66 P. P. S.
FULL LOAD 97.91 %
7/8 " 97.91 %
3/4 " 97.86 %
1/2 " 97.49 %
1/4 " 95.89 %
1/8 " 92.47 %
REGULATION 1 1/2 %
TYPE 400-W.
POWER TRANSFORMER
STANLEY ELECTRIC M'F'G CO.
4-20-98.
% EFFICIENCY
OUTPUT IN KILOWATTS
100
99
98
97
96
95
94
93
92
91
90
25.
50.
100.

FIG. 14.

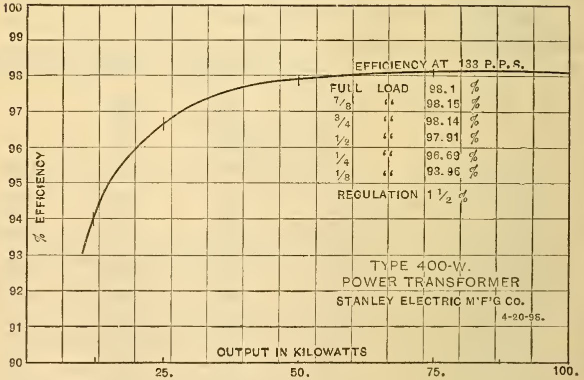

EFFICIENCY AT 133 P. P. S.
FULL LOAD 98.1 %
7/8 " 98.15 %
3/4 " 98.14 %
1/2 " 97.91 %
1/4 " 96.69 %
1/8 " 93.96 %
REGULATION 1 1/2 %
TYPE 400-W.
POWER TRANSFORMER
STANLEY ELECTRIC M'F'G CO.
4-20-96.
% EFFICIENCY
OUTPUT IN KILOWATTS
100
99
98
97
96
95
94
93
92
91
90
25.
50.
75.
100.

FIG. 15.

STANDARD C. S. TRANSFORMERS OF WESTINGHOUSE ELECTRIC AND MANUFACTURING CO.

Iron Losses.

Size.	Watts.	True.		Apparent.	
		$N = 133\frac{1}{3}$	$N = 60$	$N = 133\frac{1}{3}$	$N = 60$
1	250	6.80%	9.40%	8.90%	13.00%
2	500	5.20	6.80	6.60	9.70
4	1000	3.00	4.10	3.70	5.60
6	1500	2.50	3.30	3.20	4.70
8	2000	2.20	2.90	2.80	4.10
12	3000	1.70	2.20	2.20	3.10
16	4000	1.70	2.20	2.20	3.10
20	5000	1.60	2.10	2.10	2.85
25	6250	1.57	2.05	2.02	2.84
30	7500	1.54	2.00	1.90	2.70
40	10000	1.30	1.70	1.71	2.31
50	12500	1.06	1.40	1.40	1.85
60	15000	1.02	1.32	1.35	1.80
75	18750	0.92	1.20	1.17	1.61
100	25000	0.86	1.12	1.12	1.53

STANDARD C. S. TRANSFORMERS OF WESTINGHOUSE ELECTRIC AND MANUFACTURING CO.

Efficiencies.

Size.	Full Load.		$\frac{3}{4}$ Load.		$\frac{1}{2}$ Load.		$\frac{1}{4}$ Load.	
	$N=133\frac{1}{3}$	$N = 60$	$N=133\frac{1}{3}$	$N = 60$	$N=133\frac{1}{3}$	$N = 60$	$N=133\frac{1}{3}$	$N = 60$
1	90.3%	87.7%	88.8%	85.3%	84.7%	79.8%	71.6%	62.0%
2	91.7	90.1	90.7	88.7	88.0	84.9	78.4	72.0
4	94.0	93.0	93.8	92.3	92.5	90.3	97.3	83.0
6	94.5	93.6	94.3	93.3	93.4	91.8	89.2	86.0
8	95.1	94.4	95.0	94.1	94.3	92.8	90.5	88.8
12	95.8	95.2	95.8	95.1	95.4	94.3	92.6	90.5
16	96.34	95.8	96.3	95.5	95.7	94.6	92.8	90.7
20	96.5	96.0	96.34	95.8	95.85	96.8	93.1	91.1
25	97.0	96.54	96.83	96.23	96.15	95.23	93.36	91.52
30	96.96	96.50	96.72	96.21	96.17	95.25	93.47	91.63
40	97.04	96.64	97.02	96.49	96.56	95.76	94.35	92.75
50	97.24	96.90	97.31	96.86	97.03	96.35	95.34	93.98
60	97.38	97.08	97.44	97.04	97.16	96.56	95.52	94.32
75	97.48	97.20	97.58	97.20	97.36	96.80	95.92	94.80
100	97.74	97.48	97.81	97.45	97.58	97.06	96.21	95.17

LIST OF STANDARD SIZE FT. WAYNE "WOOD" TRANSFORMERS.

Capacity in	Watts	300	600	1250	2500	3750	5000	6250	12500	18750	25000	37500
	Lights 16 C. P.	6	12	25	50	75	100	125	250	375	500	750
Per cent Efficiency at	Full load	92.67	94.32	95.08	96.08	96.52	97.01	97.06	97.55	97.89	98.04	98.33
	$\frac{3}{4}$ load	91.70	93.72	94.78	95.78	96.25	96.86	96.96	97.53	97.93	98.19	98.39
	$\frac{1}{2}$ load	89.15	92.05	93.62	94.86	95.30	96.25	96.41	97.31	97.75	97.82	98.33
	$\frac{1}{4}$ load	81.60	86.53	89.45	91.18	92.11	93.76	94.09	95.78	96.41	96.76	97.30
	$\frac{1}{8}$ load		76.76	81.50	84.25	85.81	88.69	89.23	92.10	93.51	94.14	95.09
	$\frac{1}{16}$ load			68.99	72.96	75.31	79.85	80.41	85.75	87.99	89.11	90.82
Volts drop at full load	50 volts Secondary	1	1	1	1	1	1	1	1			
	100 volts Secondary	2	2	2	2	2	2	2	2	2	2.2	2.2
Magnetizing current		.027	.031	.048	.078	.104	.109	.124	.181	.255	.279	.382
Watts loss on open Secondary		16	22	35	57	76	78	92	125	158	189	.244
Weight complete.		31	51	98	153	205	283	355	650	933	1175	1860

WAGNER TRANSFORMERS.

The general results to be expected from the Type G transformers are specified below.

1000 Volt Line — 60 Cycles.

Capacity.		Per Cent of Iron Loss.	Per Cent of Copper Loss.	Per Cent of Regulation.	Per Cent Efficiencies.						
Lights.	Watts.				1¼ Load.	1 Load.	¾ Load.	½ Load.	¼ Load.	$\frac{1}{10}$ Load.	All Day.
10	500	4.39	2.5	2.75	93.77	93.55	92.82	90.89	84.61	69.37	80.92
20	1000	3.15	2.45	2.65	94.71	94.69	94.30	93.06	88.33	75.90	85.09
30	1500	2.57	2.25	2.50	95.36	95.40	95.13	94.10	90.22	79.41	87.27
40	2000	2.32	2.05	2.30	95.74	95.81	95.58	94.64	91.08	81.08	88.35
60	3000	1.875	2.00	2.30	96.15	96.26	96.16	95.46	92.59	84.06	90.03
80	4000	1.61	1.8	2.10	96.56	96.70	96.62	96.04	93.56	85.99	91.28
100	5000	1.465	1.6	1.90	96.92	97.02	96.94	96.34	94.10	87.10	92.05
125	6250	1.3	1.6	1.90	97.05	97.18	96.90	96.71	94.65	88.37	92.72

WAGNER TRANSFORMERS — *Continued.*

Interchangeable 1000 or 2000 Volt Line — 60 Cycles.

Capacity.		Per Cent of Iron Loss.	Per Cent Copper Loss.	Per Cent of Regulation.	Per Cent Efficiencies.						
Lights.	Watts.				$1\frac{1}{4}$ Load.	1 Load.	$\frac{3}{4}$ Load,	$\frac{1}{2}$ Load.	$\frac{1}{4}$ Load.	$\frac{1}{10}$ Load.	All Day.
10	500	4.39	2.9	3.15	93.33	93.20	92.56	90.72	84.54	69.35	80.66
20	1000	3.15	2.75	3.00	94.38	94.42	94.10	92.88	88.27	75.88	84.83
30	1500	2.57	2.60	2.85	94.98	95.08	94.95	93.94	90.15	79.39	87.05
40	2000	2.32	2.35	2.55	95.43	95.53	95.42	94.51	91.04	81.01	88.11
60	3000	1.875	2.25	2.50	95.84	96.03	96.02	95.35	92.55	84.05	89.88
80	4000	1.61	1.95	2.25	96.40	96.56	96.51	95.98	93.54	85.99	91.17
100	5000	1.465	1.8	2.10	96.69	96.83	96.86	96.31	94.09	87.07	91.88
125	6250	1.3	1.8	2.10	96.81	96.99	96.99	96.61	94.66	88.35	92.56
150	7500	1.21	1.65	1.95	97.05	97.21	97.22	96.86	95.02	89.07	93.05
200	10000	1.00	1.6	1.90	97.28	97.46	97.53	97.27	95.78	90.77	93.98
300	15000	.87	1.6	1.90	97.37	97.58	97.69	97.52	96.26	91.86	94.54

WAGNER TRANSFORMERS — *Continued.*

1000 Volt Line — 133 Cycles.

Capacity.		Per Cent Iron Loss.	Per Cent Copper Loss.	Per Cent Regulation.	Per Cent Efficiencies.						
Lights.	Watts.				1¼ Load.	1 Load.	¾ Load.	½ Load.	¼ Load.	1/10 Load.	All Day.
10	500	3.32	2.50	3.00	94.54	94.50	94.07	92.69	87.81	74.96	84.44
20	1000	2.40	2.45	2.95	95.25	95.37	95.21	94.32	90.74	80.51	87.74
30	1500	1.99	2.25	2.75	95.78	95.93	95.84	95.14	92.14	83.26	89.28
40	2000	1.80	2.05	2.55	96.16	96.29	96.20	95.58	92.86	84.60	90.34
60	3000	1.45	2.00	2.50	96.47	96.66	96.67	96.24	94.09	87.18	91.77
80	4000	1.24	1.80	2.40	96.86	97.04	97.11	96.73	94 87	88.88	92.80
100	5000	1.22	1.60	2.20	97.11	97.25	97.25	96.86	94.98	89.04	93.06
125	6250	.99	1.60	2.20	97.29	97.54	97.54	97.29	95.82	90.90	94.02

WAGNER TRANSFORMERS — *Continued.*

Interchangeable 1000 or 2000 Volt Line — 133 Cycles.

Capacity.		Per Cent Iron Loss.	Per Cent Copper Loss.	Per Cent Regulation.	Per Cent Efficiencies.						
Lights.	Watts.				1¼ Load.	1 Load.	¾ Load.	½ Load.	¼ Load.	$\frac{1}{10}$ Load.	All Day.
10	500	3.32	2.90	3.40	94.09	94.14	93.82	92.52	87.07	74.91	84.14
20	1000	2.40	2.75	3.25	94.91	95.10	95.02	94.19	90.67	80.47	87.51
30	1500	1.99	2.60	3.10	95.39	95.61	95.62	94.98	92.08	83.22	89.16
40	2000	1.80	2.35	2.85	95.81	96.01	96.01	95.45	92.76	84.58	90.09
60	3000	1.45	2.25	2.85	96.18	96.43	96.51	96.13	94.02	87.16	91.56
80	4000	1.24	1.95	2.55	96.68	96.90	96.99	96.67	94.84	88.81	92.67
100	5000	1.22	1.80	2.40	96.88	97.06	97.13	96.76	94.94	88.98	92.85
125	6250	.99	1.80	2.40	97.05	97.28	97.42	97.20	95.78	90.84	93.85
150	7500	.91	1.65	2.25	97.29	97.50	97.61	97.42	96.11	91.51	94.32
200	10000	.81	1.60	2.20	97.42	97.64	97.77	97.63	96.45	92.37	94.79
300	15000	.72	1.60	2.20	97.49	97.73	97.88	97.80	96.82	93.14	95.18

TRANSFORMERS TESTED IN 1892 BY DR. J. A. FLEMING, F. R. S. 83 CYCLES.

Transformers.	Maximum output in watts from secondary.	Magnetizing current in amperes.	Primary volts.	Power absorbed in watts at no load.	Apparent watts at no load.	Power factor.	Iron loss in per cent of full load.	Magnetizing current in per cent of full current	Total drop at full load in volts.	Copper drop in volts.	Leakage drop in volts.
Ferranti (1885) type . .	1875	.18	2416	288	432	.66	15.4	23.0	. . .	. . .	. . .
" " . .	3750	.337	2400	540	808	.68	14.6	21.6	1.6	1.9	. . .
" " . .	7500	.25	2435	444	600	.74	5.9	8.1	. . .	. . .	. . .
" " . .	11250	.34	2447	578	816	.70	5.15	7.4	. . .	. . .	. . .
" " . .	15000	.57	2389	1019	1368	.75	6.8	9.0	. . .	. . .	. . .
" (1885 rewound) .	3750	.11	2400	233	264	.88	6.2	7.0	2.4	2.15	.25
" (1892 type) . .	7500	.075	2400	138	180	.77	1.84	2.4	. . .	. . .	. . .
" " . .	11250	.076	2400	148	182	.81	1.31	1.61	3.4	2.75	.65
" " . .	15000	.112	2400	228	269	.85	1.52	1.79	2.1	1.65	.45
" (1892 rewound) .	11250	.103	2400	228	247	.92	2.02	2.2	2.2	1.78	.42
Swinburne Hedgehog . .	3000	.74	2400	112	1775	.063	3.73	59.0	3.2	2.23	.97
" " . .	6000	1.2160	2400	165	2920	.05	2.75	47.5	. . .	. . .	. . .
Westinghouse	6500	.05	2400	95	120	.79	1.46	1.85	2.4	1.38	1.02
Mordey-Brush	6000	.076	2400	140	182	.77	2.33	3.05	1.8	1.75	. . .
" "	750	.0317	2392	61.5	76	.81	8.2	10.2	. . .	. . .	. . .
Thomson-Houston . . .	4500	.083	2400	108	199	.54	2.4	4.42	3.3	2.47	.83
Kapp	4000	.145	2400	152	348	.61	3.8	8.7	1.9	1.83	. . .

SPECIAL TYPES OF TRANSFORMER.

The ordinary static transformer is generally understood to be a constant potential transformer, which is adapted to operate when connected in parallel across a constant potential circuit.

When transformers are designed for special uses, it is customary to designate them by name, indicative of the special work they are intended to perform. A few of these transformers are here described.

Special High Potential Transformer.

In making high potential tests of apparatus, it is very desirable to have a transformer which is adapted to this work.

The General Electric Company is now supplying a transformer designed for the purpose of making high potential tests up to 10000 volts. This transformer is tested up to a pressure of 35000 volts, and is so constructed as to avoid any danger of breaking down as far as possible. Below is a cut, together with a diagram of its connections.

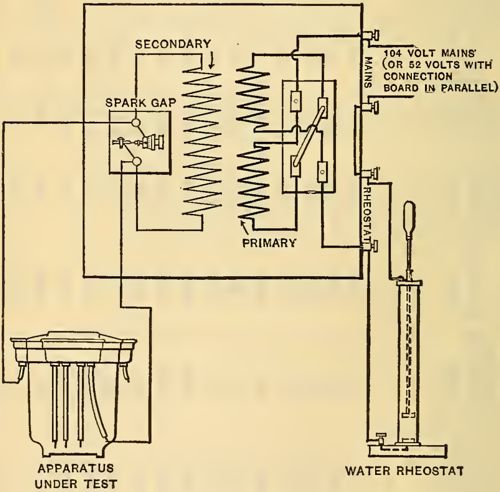


FIG. 16.

The core is rectangular in form, the primary or low-tension side being wound on one leg of the core, while the secondary or high-tension side is divided into four separate coils, and mounted on a sleeve of heavy insulating material, and placed over the opposite leg, the whole being immersed in oil.

A micrometer spark gap is mounted on top of the box or case, and connected in shunt across the high potential terminals. The spark gap is set for the desired voltage by the use of a calibration curve, or by a preliminary calibration by means of a voltmeter connected to the low-tension side, the ratio of transformation being known. The apparatus to be tested is then connected to the high potential terminals, and the potential raised to the desired amount.

This transformer is most invaluable in testing all kinds of apparatus for high-tension work.

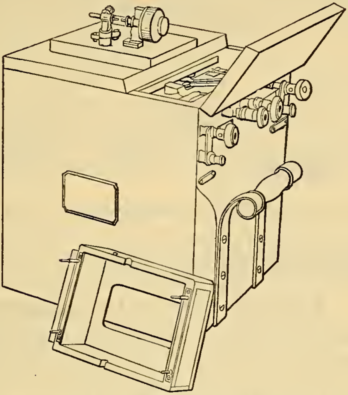


FIG. 17. High Potential Testing Transformer.

Transformers for Constant Secondary Current.

Several methods have been tried with more or less success to obtain constant current at the secondaries of transformers.

The simplest and earliest system for obtaining a constant current in the secondary is by means of transformers whose primaries are connected in series, and a constant current maintained in the primary. This is shown in diagram in Fig. 18. Series transformers for this purpose have never been very successful, due to the trouble caused by the rise of potential in the secondary when opened for any cause. Various devices (Fig. 18), such as short-circuiting points separated by a paraffined paper, or a reactive or choking coil connected across the secondary terminals, have been introduced to prevent any complete opening of the secondary by reason of any defect in the lamp or other device connected in the circuit.

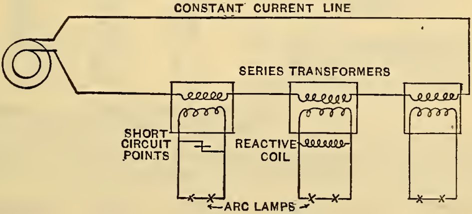


FIG. 18.

Reactive coils used as shunt devices have been used under different names; as compensators, choking coils, and economy coils.

A device of this kind has been introduced by the Westinghouse Electric and Mfg. Company, and others, for use in street-lighting by series incandescent lamps. It is shown diagrammatically in Fig. 19. The lamp is placed in shunt to the coil; when the filament breaks, the total current passes through the coil, maintaining a slightly higher pressure between its terminals than when the lamp is burning. It is thus evident that the regulation of the circuit is limited, due to the excessive reactance of the coils when several lamps are taken out of circuit.

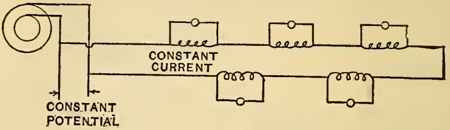


FIG. 19.

Economy Coils or Compensators.

A modification of the above is built by several companies for use on ordinary low potential circuits, where it is desired to run two or three arc lamps. It is a single coil transformer, and is shown in Fig. 20, and diagrammatically in Fig. 21, same page. If any lamp is cut out or open-circuited the current in the main line decreases slightly. As more lamps are cut out the remaining lamps receive less current, and it is necessary to replace the bad lamps in order to obtain normal current through the circuit.

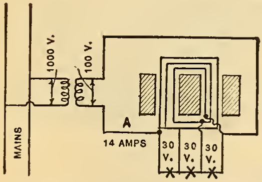


FIG. 20. Westinghouse Economy Coil. For A.C. arc lamps.

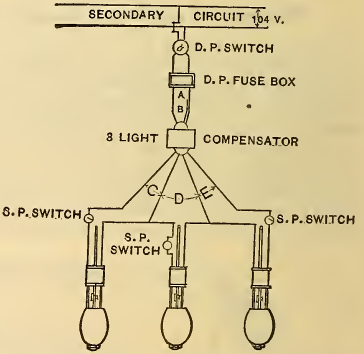


Fig. 21. Arrangement of Apparatus for use of Economy Coil or Compensator.

Transformers for Constant Current from Constant Potential.

The transformers represented in Fig. 22 show a design that will give out an approximately constant current when connected to constant potential circuits. The transformer has its core so designed that there is a leakage path for the flux between the primary and secondary. This is shown in the diagram at *a* and *b*. At open secondary circuit there is little or no tendency for the flux to leak across the gap. When current flows through the secondary, thus creating a counter magneto-motive force, there is then a

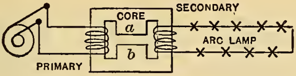


FIG. 22. Constant Current or Series Transformer.

leakage across this path, and if properly proportioned, this leakage will act to regulate the current in the secondary, so that it will be approximately constant.

General Electric Constant Current Transformers.

The transformer just described has the disadvantage that its regulation is fixed for any transformer, and may vary in transformers of the same design, without any ready means of adjustment. The transformer also regulates for constant current over but a limited range in the secondary loads.

The General Electric Company constant current transformer shown in Figs. 23 and 24, is constructed with movable secondary coils, and fixed primary coils.

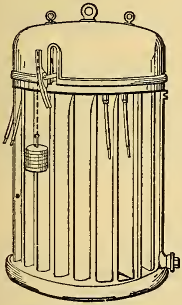


FIG. 23. General Elec. Co. Constant Current Transformers for 50 lights.

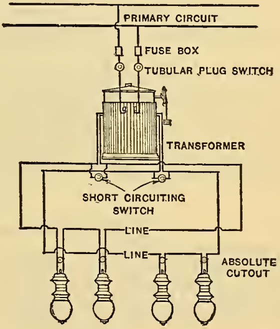


FIG. 24. Connections for Alternating Series Enclosed Arc Lighting System, with 50, 75, or 100 Light Transformer.

The weight of the movable coil is partially counterbalanced, so that at normal full-load current the movable coil or coils lie in contact (See Fig. 25) with the stationary coil, notwithstanding the magnetic repulsion between them. When, however, one or more lamps are out of the circuit, the increasing current increases the repulsion between the coils, and separates them, reducing the current to normal. (See Fig. 26.) At minimum load, the distance between the coils is maximum. The regulation is thus entirely automatic, and is found to maintain practically constant current, or a departure from constant current if desired. The transformer can be adjusted for practically constant current for positive regulation; i.e., increasing current from full load to light loads, or for a negative regulation, i.e., decreasing current, from full load to light loads. This adjustment is obtained by changing the position of a cam from which the counter-weights are suspended. The curves shown in Fig. 28 show the range obtained in a 100-light transformer.

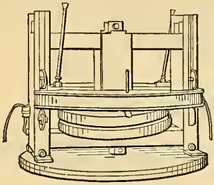


Fig. 25. Full-Load Position of Secondary Coils.

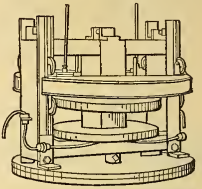


Fig. 26. Half-Load Position of Secondary Coils.

The transformers are enclosed in cast iron or sheet iron tanks filled with transil oil. The oil, in addition to being an insulating and cooling medium, serves to dampen any sudden movement of the secondary coils.

These transformers are connected to the regular constant potential mains, and the larger sizes are arranged for multiple circuits in the secondary. After having been started on a run, the transformers need no attention, as they are entirely automatic in their action.

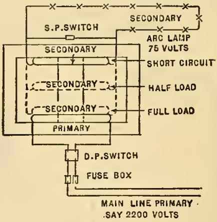


Fig. 27. Diagram of Connections.

The full-load efficiency of this type is practically the same as that of a constant potential transformer of the same capacity. The power factor of the system at full load is about 85 per cent, due to the reactance of alternating arc lamps. At fractional loads, the power factors necessarily are much lower, and it is therefore not desirable to operate such a system at light load.

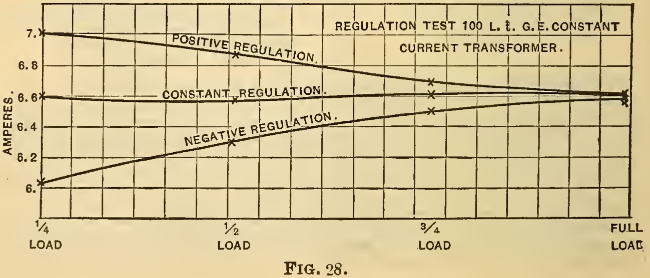


Fig. 28.

REGULATING REACTANCE COIL FOR A.C. ARC CIRCUITS.

Another and very simple device for regulating the current in a series circuit for A.C. arc lamps has been put on the market by the Manhattan General Construction Company. It consists of a single coil of insulated wire arranged to enclose more or less of one leg of a "W"-shaped magnet, as shown in the following cut. The coil is suspended from one end of a lever and counterbalanced by a weight on the other, and so arranged that at all points of its travel it just balances the varying magnetic pull of the coil.

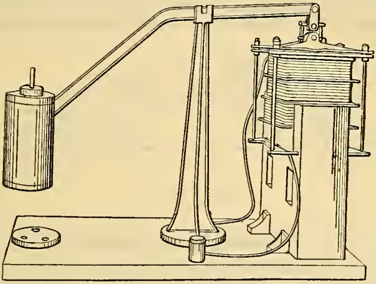


FIG. 29. Regulating Reactance Coil by Manhattan General Construction Co.

The arc circuit is connected in series with this coil with a switch to open the circuit. Without current flowing, the normal position of the coil is at the top or off the leg of the magnet. When the switch is closed, current flows in the circuit (and coil), and draws the coil down on the leg to a point where the reactance of the coil holds the current strength at a predeter-

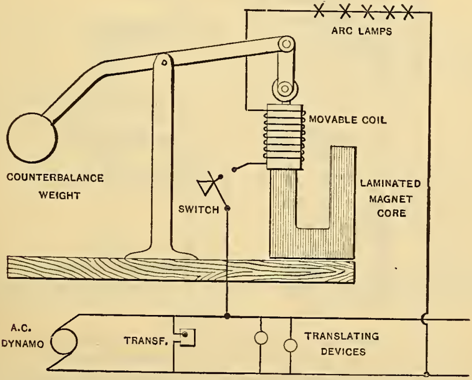


FIG. 30. Diagram of Connections of the Regulating Reactance Coil of the Manhattan General Construction Co.

mined point; as, say, 6.6 amperes. It is said that this device will maintain a current constant within one-tenth of an ampere.

The losses are the iron losses and I^2R losses in the coil, which, with constant current, are the same under all conditions of load.

As it is not always, or even often, that it is necessary to provide for regulation of an arc circuit to the extent of its full load, the makers have adopted the policy of supplying instruments to care for but that part of the load that is expected to vary, in some cases 10 % of the circuit and in others 75 %, thus avoiding the need for larger apparatus, or for insulation for the total voltage of the circuits. They claim another advantage in being able to connect the device in one leg of the series circuit, and allowing the other end of the circuit to be connected to the mains at any such point as may be the nearest at hand. Fig. 30 shows the apparatus diagrammatically.

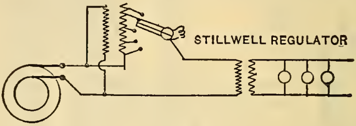


FIG. 31.

Feeder Regulators.

An alternating current feeder regulator is essentially a transformer having its primary connected across the mains, and its secondary in series with the mains. The secondary is arranged so that the voltage at its terminals can be varied over any particular range.

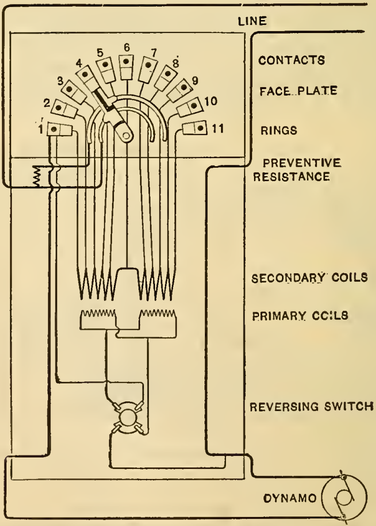


FIG. 32. Internal Connections of a Stillwell Regulator.

The several different styles of feeder regulators have been devised, differing in principle of operation, but all of them have the primary coil connected across the mains, and the secondary coils in series with the mains.

The "Stillwell" regulator, which was designed by Mr. L. B. Stillwell, has the usual primary and secondary coils, and effects the regulation of the circuit by inserting more or less of the secondary coil in series with the line. This secondary coil has several taps brought out to a commutating switch, as shown in Fig. 31. The apparatus is arranged so that the primary can be reversed, and therefore be used to reduce as well as to raise the voltage of the line. It is evident from an observation of the diagram that if two of the segments connected to parts of the coils were to be short-circuited, it would be almost certain to cause a burn-out. To prevent this, the movable arm or switch-blade is split, and the two parts connected by a reactance, this reactance preventing any abnormal local flow of current during the time that the two parts of the switch-blade are connected to adjacent segments. The width of each half of the switch-arm must of necessity be less than that of the space or division between the contacts or segments.

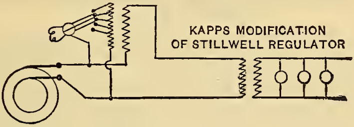


Fig. 33.

As the whole current of the feeder flows through the secondary of the booster, the style of regulator which effects regulation by commutating the secondary cannot well be designed for very heavy currents because of the destructive arcs which will be formed at the switch-blades. To overcome this difficulty, Mr. Kapp has designed the modification which is shown in Fig. 33. In this regulator the primary is so designed that sections of it can be commutated, thus avoiding an excessive current at the switch. This regulator, however, has a limited range, as the secondary always has an E.M.F. induced in it while the primary is excited; and care must be taken to see that there are sufficient turns between the line and the first contact in order to avoid excessive magnetizing current on short circuit.

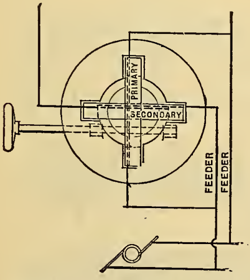


Fig. 34. Connections for M. R. Feeder Regulator of G. E. Co.

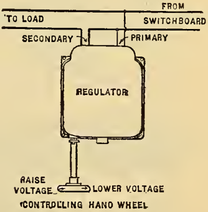


Fig. 35. Diagram of Connections of Feeder Potential Regulator.

The General Electric Company have brought out a feeder regulator, in which there are no moving contacts in either the primary or secondary, and which can be adapted for very heavy currents. This appliance is plainly shown in Figs. 34 and 35. The two coils, primary and secondary, are set at right angles in an annular body of laminated iron, and the central laminated core is arranged so as to be rotated by means of a worm wheel and shaft as shown.

The change in the secondary voltage, while boosting or lowering the line voltage, is continuous, as is also the change from boosting or lowering, or *vice versa.* In this regulator, the change of the secondary voltage is effected by the change in flux through the secondary coil, as the position of the movable core is changed by the turning of the hand wheel and shaft. There are, therefore, no interruptions to the flow of current through either the primary or secondary coils, and the regulator is admirably adapted for incandescent lighting service, where interruptions in the flow of current, however instantaneous, are objectionable.

S. K. C. DEVICES FOR REGULATING A. C. CIRCUITS.

Where polyphase A. C. generators are used for lighting and power it is necessary to provide some method by which the individual phases can be separately and independently regulated.

The method used by this company for accomplishing this result is by changing the effective turns on the armature. At one end of the winding of each phase are several regulating coils from which are brought out to suitable regulator heads taps which are mounted upon a terminal board fastened to the machine; or the regulator heads, if so desired, may be mounted upon the switch-board. The following diagrams illustrate the method of bringing out the regulating taps from the armature coils of a two-phase generator.

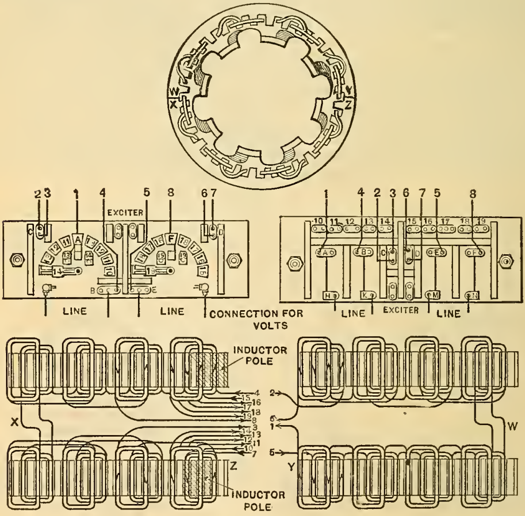


FIG. 36. Two-phase Generator.

The regulator heads are similar to those used in connection with the "Stillwell" regulator, and make use of a modification of the split finger contact arm and choke-coil to prevent short circuit of the regulator coils.

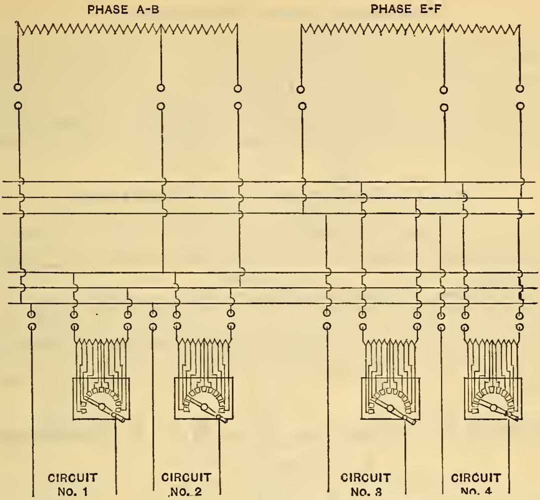


FIG. 37. Diagram of one Two-phase Generator and four Circuits.

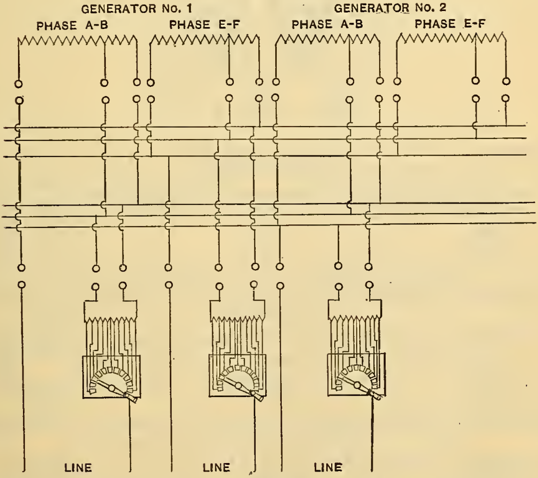


FIG. 38. Diagram of two Two-phase Generators in Parallel and three Circuits.

Separate Circuit Regulations.

Where a number of circuits are run out from the same set of bus bars, regulation of each circuit is provided for in this system by the use of a single coil transformer from various points on the winding of which leads are brought out to a regulator head, from which any part or all of the transformer may be thrown into service to increase the pressure on the line.

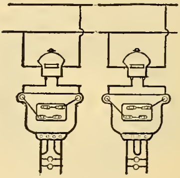
Figures 37 and 38 show in diagram the method of applying this device, which is also provided with the split finger contact and choke-coil to prevent short circuit.

TRANSFORMER CONNECTIONS.

Some of the advantages claimed for alternating current systems of distribution over the direct current systems is the facility with which the potential, current, and phases can be changed by different connections of transformers.

On single-phase circuits, transformers can be connected up to change from any potential and current to any other potential and current; but in a multi-phase system, in addition to the changes of potential and current, the phases can be changed to almost any form that may be desired The following diagrams, taken from General Electric Company publications, represent some of the results obtained by different transformer connections.

Directions for Connecting Type H, G. E. Transformers.



FIGS. 39 and 40.

Transformers Wound for 1040 or 2080 Volts Primary and 52 or 104 Volts Secondary.

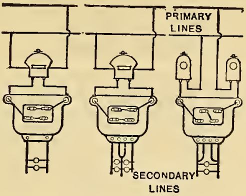
For	1040	volts	primary	and	52	volts	secondary,	See Fig.	39.
"	1040	"	"	"	104	"	"	" "	40.
"	2080	"	"	"	52	"	"	" "	43.
"	2080	"	"	"	104	"	"	" "	44.

Transformers Wound for 1040 or 2080 Volts Primary and 104 or 208 Volts Secondary.

For	1040	volts	primary	and	104	volts	secondary,	See Fig.	39.
"	1040	"	"	"	208	"	"	" "	40.
"	2080	"	"	"	104	"	"	" "	43.
"	2080	"	"	"	208	"	"	" "	44.

Transformers Wound for 1040 or 2080 Volts Primary and 115 or 230 Volts Secondary.

For	1040	volts	primary	and	115	volts	secondary,	see Fig.	39.
"	1040	"	"	"	230	"	"	" "	40.
"	2080	"	"	"	115	"	"	" "	43.
"	2080	"	"	"	230	"	"	" "	44.



FIGS. 41, 42, and 43.

Transformers Wound for 1040 or 2080 Volts Primary and 115 Volts Secondary.

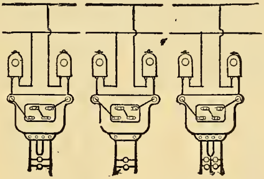
For 1040 volts primary and 115 volts secondary, see Fig. 41.
“ 2080 “ “ “ 115 “ “ “ “ 43.

Transformers Wound for 520 or 1040 Volts Primary and 115 or 230 Volts Secondary.

For 520 volts primary and 115 volts secondary, see Fig. 39.
“ 520 “ “ “ 230 “ “ “ “ 40.
“ 1040 “ “ “ 115 “ “ “ “ 43.
“ 1040 “ “ “ 230 “ “ “ “ 44.

Transformers Wound for 520 or 1040 Volts Primary and 115 Volts Secondary.

For 520 volts primary and 115 volts secondary, see Fig. 39.
“ 1040 “ “ “ 115 “ “ “ “ 43.



FIGS. 44, 45, and 46.

Transformers Wound for 1040 or 2080 Volts Primary and 52 or 104 Volts Secondary, Used on Three-Wire System.

For 1040 volts primary and 52–52 volts secondary, see Fig. 42.
“ 2080 “ “ “ 52–52 “ “ “ “ 46.

Transformers Wound for 1040 or 2080 Volts Primary and 104 or 208 Volts Secondary, Used on Three-Wire System.

For 1040 volts primary and 104–104 volts secondary, see Fig. 42.
“ 2080 “ “ “ 104–104 “ “ “ “ 46.

Transformers Wound for 1040 or 2080 Volts Primary and 115 or 230 Volts Secondary, Used on Three-Wire System.

For 1040 volts primary and 115–115 volts secondary, see Fig. 42.
“ 2080 “ “ “ 115–115 “ “ “ “ 46.

Transformers Wound for 520 or 1040 Volts Primary and 115 or 230 Volts Secondary, Used on Three-Wire System.

For 520 volts primary and 115–115 volts secondary, see Fig. 42.
“ 1040 “ “ “ 115–115 “ “ “ “ 46.

All voltages for which a transformer is wound are stamped on the name plate on the cover of the transformer box. These are the normal voltages for which the transformer is designed, but all transformers can be used satisfactorily for voltages that do not vary more than 10% above or below the designed voltage.

Single-Phase.

The connections of the single-phase step-down and step-up transformers, having parallel connections, need not be explained outside of the preceding diagrams. For residence lighting, the most economical method of supply is through single-phase transformers with three-wire secondaries. A tap is brought out from the middle of the secondary winding, this tap connecting to the middle or neutral of the three-wire system. In this way a few large transformers can be connected by three-wire secondaries in a residence or other district, and will take care of a large number of connected lamps.

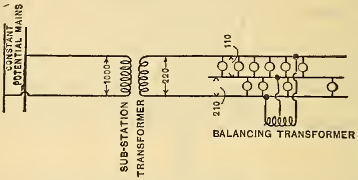


FIG. 47. Arrangement of Balancing Transformer for Three-wire Secondaries.

Kapp shows a modification of the three-wire circuits, in which the outside wires are fed by a single transformer, and the neutral wire is taken care of by a balancing transformer, connected up at or near the center of distribution. The capacity of the balancing transformer need be but half the greatest variation in load between the two sides.

Some makers of transformers have the connection board in their transformers so arranged that the two primary coils may be connected either in series or parallel by mere changes of small copper connecting links, so that the same transformer can be connected up for either 1000- or 2000-volt circuits, and the secondary for either 50 or 100 volts.

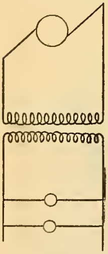


FIG. 48. Single-Phase.

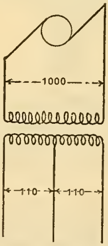


FIG. 49. Single-Phase, with 3-wire Secondary, Useful for Residence Circuits.

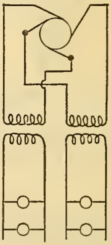


FIG. 50. Two-Phase, 4 Wires.

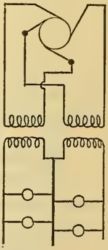


FIG. 51. Three-Wire, Two Phase.

Quarter-Phase.

The plain two-phase or quarter-phase connection, Fig. 50, is simply two single transformers connected to their respective phases, the phases being kept entirely separate. In the three-wire, quarter-phase circuit, one of the leads can be used as a common return, as shown in Fig. 51.

Three-Phase.

The three-phase connections shown in diagram 52 are known as the delta connections, and are of great advantage where continuity of service is very important. The removal of any one transformer does not interrupt the three-phase distribution, and the removal of two transformers still admits of power transmission on a single phase of the circuit.

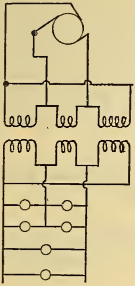


FIG. 52. Three-Phase Delta Connection.

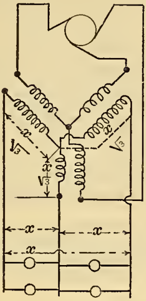


FIG. 53. Three-Phase Star Connection.

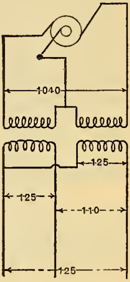


FIG. 54. Monocyclic Connections.

The "Y" or star connection, as shown in diagram 53, has one of the terminals of each primary and secondary brought to a common connection, the remaining three terminals being brought to the main line and the distributing lines. The advantage of the star connection over the delta connection is, that for the same transmission voltage each transformer is wound

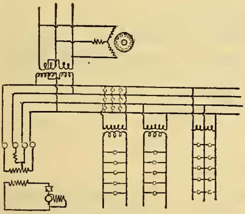


FIG. 55. Connections of Monocyclic System for Light and Power.

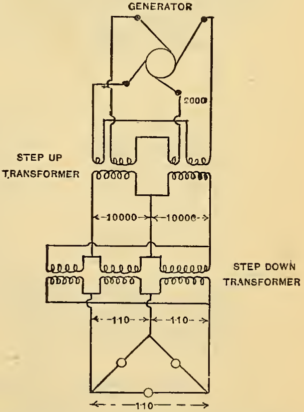


FIG. 56. Changing Quarter-phase to Three-phase, Non-interchangeable Step-up Transformers.

for only 58% of the line voltage. In high-voltage transmission this admits of much smaller transformers being built for high potentials than is possible with the delta connection.

Diagram 55, p. 369, shows a device by Mr. C. P. Steinmetz for enabling the lights and motors to run on the same single-phase circuit. The generator has a supplemental coil called the teazer ; one end of this coil is connected into the middle of the main winding, the other being connected to the power wire or teazer wire of the system. For lighting circuits, connections are made only to the two outside wires, or the main wires of the system, or if it is desired to run three-wire system, the middle connection is made in the middle of the main winding. Where motors are connected up, the third connection is made to the teazer or power wire. This wire supplies current to the motor only during the time of starting, because as soon as the motor is up to synchronism it will then run as a single-phase machine, and no current is taken from the teazer wire.

Arrangement of Transformers for Stepping Up and Down for Long Distance Transmission.

Figures 56, 57, and 58 show diagrammatically the connections for adapting three-phase transmission to quarter-phase generators, with interchangeable and non-interchangeable transformers. The diagrams are probably sufficiently clear for the purposes of this article.

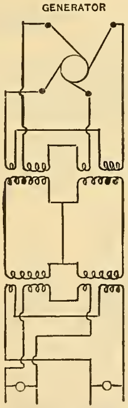


Fig. 57. Changing Quarter-phase to Three-phase, and back to Quarter-phase. All Transformers Interchangeable.

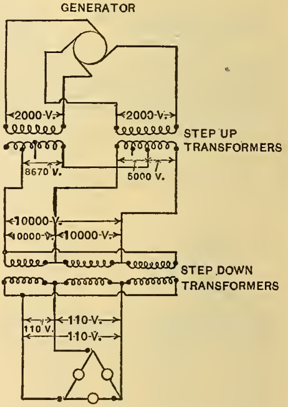


Fig. 58. Changing Quarter-phase to Three-phase. All Step-up Transformers Interchangeable.

Three-Phase to Six-Phase Connections.

A rotary converter wound for six-phase has a greater capacity for work than the same machine wound for three phases. Three-phase transmission, however, is very economical, and in Fig. 59 is shown a diagram by which six phases can be obtained from three phases by the use of only three transformers.

Each transformer has two secondary coils. One secondary of each transformer is first connected into a delta, then the remaining secondary coils are connected up into a delta, but in the reverse order of the first delta. This is an equivalent of two deltas, one of which is turned 180° from the other. In the diagram ABC represents one delta, and DEF the other.

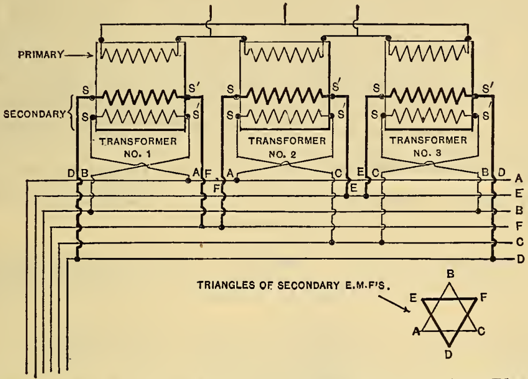


FIG. 59. Diagrams of Connections for Changing from Three-Phase to Six-Phase.

In the same way the two secondaries can be connected up "Y," and one "Y" turned 180° to obtain six phases. The disadvantage of "Y" connection, however, is that in case one transformer is burned out, it is not possible to continue running, as can be done with delta connections.

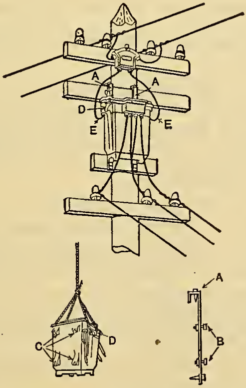


FIG. 60. Method of Handling and Installing Transformers.

From pamphlet of General Electric Company.

TRANSFORMER TESTING.

Although the standard types of transformers of to-day are made on lines found by long experience to be the best for all purposes, and are subject to careful inspection and test at the factory in most cases, yet the various makers have such different ideas as to the value of the different points, that in order to obtain fair bids on such appliances when purchased, it is always best to prepare specifications, and the buyer should be prepared to conduct or check tests to determine whether the specifications have been fulfilled. Large stations should have a full outfit of apparatus for conducting such tests; but smaller purchasers can do quite well by having a competent superintendent, or by hiring an outside engineer to witness the tests at the factory. It is not always necessary to put each individual transformer through all the tests, but the break-down test for insulation should be applied to all.

Prof. Jackson gives the following requirements for guaranties of transformers.

Iron loss for 1000-volt transformers and for frequencies over 100 as follows:

Capacity.	Iron Loss.	Exciting Current.
1000 watts	30 watts	.055 amperes.
1500 watts	40 watts	
2000 watts	50 watts	.080 amperes.
2500 watts	60 watts	
4000 watts	80 watts	
6500 watts	100 watts	.150 amperes.
17500 watts	150 watts	.200 amperes.

For frequencies less than 100 it may be advisable to allow 10 % higher loss to avoid excessive cost.

NOTE. — Guaranties for iron loss should cover ageing for at least one year.

Drop in secondary pressure not to exceed 3 % between no load and full load.

Rise of temperature after 10 hours' run under full load, 70° F. (about 40° C.).

NOTE. — This measurement was probably meant by Professor Jackson to be made by thermometer. It is better to take the rise by resistance measurement, in which case the allowable temperature is 50° C.

Disruptive strength of insulation after full-load run, between coils and between primary coil and iron, at least 10 times the primary voltage. Insulation resistance to be not less than 10 megohms, and guaranteed not to deteriorate with reasonable service.

NOTE. — See previous matter as to test voltage.

Exciting current for 1000-volt transformers not to exceed values given in the above table, when the frequency is above 100. The exciting current *increases* as the frequency *decreases*, and varies inversely as the voltage. For intermediate capacities proportional values may be expected.

He further says: "*Transformers which do not meet the insulation and heating guaranties are unsafe to use upon commercial electric lighting and motor circuits, while those which do not meet the iron loss, regulation, and exciting current guaranties waste the company's money.*"

The characteristics of a transformer, to be determined by tests, are as follows:

(1) Insulation strength between different parts.
(2) Core loss and exciting current.
(3) Resistances of primary and secondary and I^2R.
(4) Impedance and copper loss, direct measurement.

(5) Heating and temperature rise.
(6) Ratio of voltages.
(7) Regulation and efficiency, which may be calculated from the results of tests (2), (3), and (4), or may be determined directly by test.
(8) Polarity.

The instruments required to make these tests should be selected for each particular case, and consist of ammeters, voltmeters, and indicating wattmeters.

For central station work, the following instruments will suffice for nearly any case which may come up in ordinary practice.

A. C. voltmeter, reading to 150 volts, and with multiplier to say 2500 volts.

A. C. ammeter, reading to 150 amperes, with shunt multiplier if necessary to carry the greatest output.

Indicating wattmeter, reading to 150 or 200 watts.

NOTE. — *For full data and examples of transformer testing, see pamphlet No. 8126, “Transformer Testing for Central Station Managers,” by General Electric Company.*

Insulation Test.

This is the simplest and most important test to be made, for the reason that one of the principal functions of a transformer is its ability to thoroughly and effectually insulate the secondary circuit from the primary circuit.

Tests of the insulation of practically all high potential apparatus are now carried out by high pressure, rather than by test of the insulation resistance by galvanometer. Some insulations will show a very high test by galvanometer, but will fail entirely under test with a voltage much exceeding that at which it is to be used. On the other hand, it is not uncommon to find insulation such that, while the galvanometer tests show low resistance, it will not break down at all under the ordinary voltages. For this reason, it is common practice among manufacturers of transformers to apply a moderately high voltage, from two to three times the working voltage, for a short period, usually about one minute.

According to the Committee on Standardization of the A. I. E. E., the tests should be made with a sine wave of electromotive force, or where this is not available, at a voltage giving the same striking distance between needle points in air as a sine wave of the specified E.M.F., except where expressly specified otherwise. For needles, new sewing-machine needles should be used. It is recommended that the apparatus be shunted during test by the spark gap set for a voltage exceeding the required voltage by 10 per cent.

The committee also recommends the following voltages for use in testing:

In electric circuits of rated voltage up to 500 volts.

Apparatus of 10 k. w. capacity or less	1000 volts.
Apparatus over 10 k. w. capacity	1500 “

Of rated voltage over 500 but less than 1000 volts.

Apparatus of 10 k. w. capacity and less	2000 volts.
Apparatus over 10 k. w. capacity	3000 “

Of 1000 and more but less than 2500 volts	5000 volts.
“ 2500 “ “ “ “ “ 3500 “	7000 “
“ 2500 “ “ “ “ “ 6600 “	10000 “
“ 6600 “ “ “ “ “	1½ times rated voltage.

In standard transformers these insulation tests should be (1) between primary and secondary, and between primary and core and frame; (2) between secondary and core and case.

To obviate any induced potential strain, the secondary should be grounded while making the test between the primary and secondary, and between primary and core and case.

In testing between the primary and secondary, or between the primary and core and frame, the secondary must be connected to the core and frame.

It is also important that all primary leads should be connected together as well as all secondary leads, in order to secure throughout the winding a uniform potential strain during the test.

NOTE. — *See index for sparking-gap curve, and use new needles after every discharge.*

From one point of view, the factor of safety of the secondary need not be greater than that of the primary, and if 10,000 volts is considered a sufficient test for a 2000-volt primary, 1000 volts might be sufficient for a 200-volt secondary. But a thin film of insulation may easily withstand a test of 1000 volts, although it is so weak mechanically as to be dangerous. A 200-volt secondary should therefore be tested for at least 2500 volts in order to guarantee it against breakdown due to mechanical weakness.

The duration of the insulation test may vary somewhat with the magnitude of the voltage applied to the transformer. If the test is a severe one, it should not be long continued; for while the insulation may readily withstand the momentary application of a voltage five or ten times the normal strain, yet continued application of the voltage may injure the insulation and permanently reduce its strength.

Attention has been called to the fact that in testing between the primary and the core or the secondary, the secondary should be grounded. In testing between one winding and the core, for example, an induced potential strain is obtained between the core and the other winding which may be much greater than the strain to which the insulation is subjected under normal working conditions, and greater therefore than it is designed to withstand. In testing between the primary and the core, the induced potential between the secondary and the core may be several thousand volts, and the secondary may thus be broken down by an insulation test applied to the primary under conditions which do not exist in the natural use of the transformer.

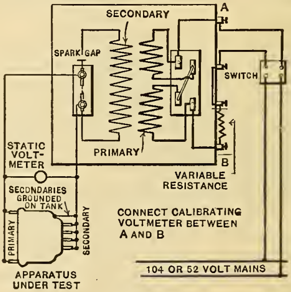


FIG. 61.

Attention is further called to the fact that during the test all primary leads as well as all secondary leads should be connected together. If only one terminal of the transformer winding is connected to the high potential transformer, the potential strain to which it is subjected may vary throughout the winding, and may even be very much greater at some point than at the terminals to which the voltage is applied. Under such conditions the reading of the static voltmeter affords no indication of the strain to which the winding is subjected.

Indications which are best learned by experience reveal to the operator the character of the insulation under test. The transformer in test requires a charging current varying in magnitude with its size and design. From the reading of the ammeter, placed in the low potential circuit of the testing transformer, the charging current may be ascertained. It will increase as the voltage applied to the insulation is increased.

If the insulation under test be good there will be no difficulty in bringing the potential up to the desired point by varying the rheostat. If the insulation be weak or defective, it will be impossible to obtain a high voltage across it, and an excessive charging current will be indicated by the ammeter.

Inability to obtain the desired potential across the insulation may be the result merely of large electrostatic capacity of the insulation and the consequent high charging current required, so that the high potential transformer may not be large enough to supply this current at the voltage desired.

A breakdown in the insulation will result in a drop in voltage indicated by the electrostatic voltmeter, an excessive charging current, and the burning of the insulation if the discharge be continued for any length of time.

Core Loss and Exciting Current.

In taking measurements of core loss and exciting current, the instruments required are a wattmeter, voltmeter, and ammeter.

One of the two following described methods for connecting up the instruments is usually employed, although several others might be shown. These methods differ only in the way of connecting up the instruments, and are as follows:

Method 1. — The voltmeter and pressure coil of the wattmeter are connected directly to the terminals of the test transformer. When the pressure of the voltmeter is at the standard voltage the reading of the wattmeter will be the core loss in watts. It is evident from an inspection of diagram 62 that the wattmeter will indicate, in addition to the watts consumed by the test transformer, the I^2R or copper loss in both the pressure coil of the wattmeter and voltmeter. This error, however, being constant for any pressure, is easily corrected. This method is very good for accurate results, and where the quantities to be measured are small it is most desirable.

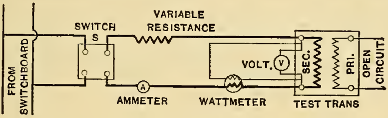


FIG. 62. Core Loss (Method 1).

Method 2. — The current coils of the wattmeter are inserted between a terminal of the test transformer and the terminal of the voltmeter and pressure coil of the wattmeter (see diagram 63). In this method the error introduced is the I^2R loss in the current coil of the voltmeter. This is a very much smaller error than in Method 1, but does not allow of an easy or accurate correction, and the results obtained by it must, therefore, be taken without correction. For this reason Method 2 is more convenient, and for the measurement of large core losses, and for commercial purposes, it is sufficiently accurate.

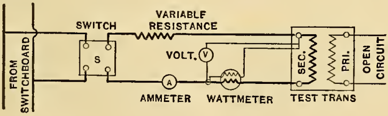


FIG. 63. Core Loss (Method 2).

Core losses and exciting current should be measured from the low-potential side of the transformer to avoid the introduction of high voltage in the test.

Notes on Core Loss and Excitation Current.

In an ordinary commercial transformer, a given core loss at 60 cycles may consist of 70 per cent hysteresis and 30 per cent eddy current loss, while at 125 cycles the same transformer may have 55 per cent hysteresis loss and 45 per cent eddy current loss.

The core loss is also dependent upon the wave form of the impressed E.M.F., a peaked wave giving somewhat lower core losses than a flat wave. It is not uncommon to find alternators having such a peaked wave form that the core loss obtained, if the transformer is tested with current from them, will be 5 per cent to 10 per cent less than that obtained if the transformer is tested from a generator giving a sine wave. On the other hand, generators are sometimes obtained which have a very flat wave form, so that the core loss obtained will be greater than that obtained from the use of a sine wave.

The magnitude of the core loss depends also upon the temperature of the iron. Both the hysteresis and eddy current losses decrease slightly as the temperature of the iron increases. It is well known that if the temperature be increased sufficiently, the hysteresis loss disappears almost entirely, and since the resistance of iron increases with the temperature the eddy current losses necessarily decrease. In commercial transformers, an increase in temperature of 40° C. will cause a decrease in core loss of from 5 per cent to 10 per cent. An accurate statement of core loss thus necessitates that the temperature and wave form be specified.

If, in the measurement of core loss, the product of impressed volts and excitation current exceeds twice the measured watts, there is reason to suspect poorly constructed magnetic joints or higher iron densities than are allowable in a well-designed transformer.

Measurement of Resistance.

Resistance of the coils can be measured by either the Wheatstone Bridge or Fall of Potential Method.

For resistances below one or two ohms it is generally more accurate to use the Fall of Potential Method.

Resistances should always be corrected for temperature, common practice being to correct to 20° centigrade. For pure soft-drawn copper this correction is .4 % per degree centigrade. Readings should be taken at several different current values, and the average value of all the readings will be the one to use. (See Index for correction for rise of temperature.)

Having obtained the resistance of the primary and secondary coils, the I^2R of both primary and secondary can be calculated; the sum of the two being (very nearly) equal to the copper loss of the transformer. If it is preferred to measure the copper loss directly by wattmeter, then we must make test No. 4.

The fall of potential method is subject to the following sources of error:

(1) With the connections as ordinarily made the ammeter reading includes the current in the voltmeter, and in order to prevent appreciable error the resistance of the voltmeter must be much greater than that of the resistance to be measured. If the resistance of the voltmeter be 1000 times greater, an error of $\frac{1}{10}$ of 1 per cent will be introduced, while a voltmeter resistance 100 times the coil's resistance will mean the introduction of an error of 1 per cent. Correction of the ammeter reading obtained in (3) may thus become necessary, but whether or not it be essential will depend upon the accuracy desired. (See example below.)

(2) The resistance of the voltmeter leads must not be sufficient to affect the reading of the voltmeter.

(3) Since the resistance of copper changes rapidly with the temperature, the current used in the measurement should be small compared with the carrying capacity of the resistance, in order that the temperature may not change appreciably during the test. If a large current is necessary, readings must be taken quickly in order to obtain satisfactory results. If a gradual increase in drop across the resistance can be detected within the length of time taken for the test, it is evident that the current flowing through the resistance is heating it rapidly, and is too large to enable accurate measurement of resistance to be secured.

It is quite possible to use a current of sufficient strength to heat the winding so rapidly as to cause it to reach a constant hot resistance before the measurement is taken, thus introducing a large error in the results. Great care should be taken, therefore, in measuring resistance to avoid the use of more current than the resistance will carry without appreciable heating.

(4) Considerable care is necessary to determine the temperature of the winding of the transformer. A thermometer placed on the outside of the winding indicates only the temperature of the exterior. The transformer

should be kept in a room of constant temperature for many hours in order that the windings may reach a uniform temperature throughout. The surface temperature may then be taken as indicative of that of the interior.

Impedance and Copper-Loss Test.

Method 1. — In this method, which was first described by Dr. Sumpner, the secondary coil is short-circuited through an ammeter. A wattmeter and a voltmeter are connected up in the primary circuit in a manner similar to either of the two methods described for the core-loss test. An adjustable resistance or other means for varying the impressed voltage is placed in series with the primary circuit.

To make the test, the voltage is raised gradually until the ammeter shows that normal full-load current is flowing through the secondary circuit. Readings are then taken on the wattmeter and voltmeter.

This method of measuring the impedance and copper loss of a transformer is now seldom used, on account of the liability to error due to the insertion of the ammeter in the secondary. In addition to being inaccurate, it usually requires an ammeter capable of measuring a very heavy current.

Method 2. — This method differs from Method 1 only in that the secondary is short-circuited directly on itself, an ammeter being inserted in the primary circuit. The diagram of connections is shown in Fig. 64. In connecting up the voltmeter and the potential coil of the wattmeter, the same corrections hold as in the measurement of core loss and exciting current, and connections made according to whether accuracy of results or simplicity of test is the more imporant.

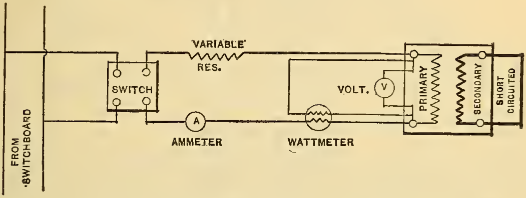


FIG. 64. Impedance Test with Wattmeter.

Having the readings of amperes, volts, and watts, we obtain from the first two the impedance of the transformer. This impedance is the geometrical sum of the resistance and reactance, and is expressed algebraically as follows:

$$z = \sqrt{R^2 + (2\pi n L)^2},$$

where z = Impedance,
R = Resistance,
L = Coefficient of self-induction,
I = Current in amperes,
n = Frequency in cycles per second,
$2\pi\, n\, L$ = reactance of the circuit.

In a test on a transformer with secondary short-circuited as in Fig. 64 above, and primary connected to 2000 volts, the impedance volts were 97 at full-load primary current of 2.5 amperes, then

$$\text{Impedance} = \frac{97}{2.5} = 38.8 \text{ ohms},$$

and

$$\text{Impedance drop} = \frac{97 \times 100}{2000} = 4.85 \text{ per cent.}$$

The reading on the wattmeter indicates the combined I^2R of the primary and secondary coils, and in addition includes a very small core loss, which can be neglected, and an eddy current loss in the conductors.

In standard lighting transformers, the impedance voltage varies from 2 per cent to 8 per cent. In making this test, careful record of the frequency should be made, as the impedance voltage will vary very nearly with the frequency.

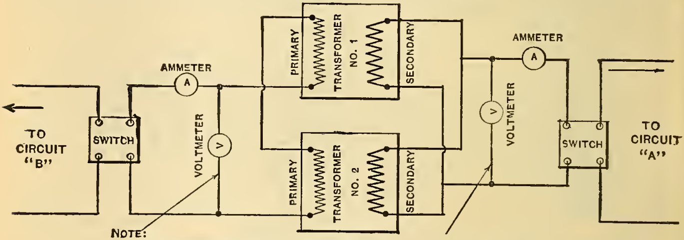
Heat Tests.

To test the transformer for its temperature rise, it is necessary to run it at full excitation and full-load current for a certain length of time. An eight-hour run at full load will usually raise the temperature to its highest point, and in the case of lighting transformers a full-load run very seldom continues longer than eight hours in practice. If it is desired to find just what is the final temperature rise under full load (as is often the case with transformers for power work) the transformer can be operated for two or three hours at an overload of about 25 %, after which the load should be reduced to normal, and the run continued as long as may be necessary.

There are several methods for making heat runs of transformers, and all of them approximate the condition of the transformer in actual service.

Heat Test, Method 1. — The primary is connected to a circuit of the proper voltage and frequency, and the secondary loaded with lamps or resistance until full-load current is obtained. The temperature of all accessible parts should be obtained by thermometer, and the temperature rise of the coils determined by increase of resistance. Frequent readings should be taken during the run to see to what extent the transformer is heating.

Heat Test, Method 2. — Where the transformer is of large size, or sufficient load is not obtainable, the motor generator method of heat test is preferable. Two transformers of the same voltage, capacity and frequency are required, and are connected up as shown in Fig. 65.



NOTE:
THIS VOLTAGE TO BE APPROX. TWICE THE IMPEDANCE VOLTAGE OF EACH TRANSFORMER, IT MUST BE ADJUSTED UNTIL FULL LOAD CURRENT FLOWS IN TRANSFORMERS.

NOTE:
THIS VOLTAGE TO BE THAT OF THE SECONDARY OF EACH TRANSFORMER

FIG. 65.

The two secondaries are connected in parallel, and excited from circuit A at the proper voltage and frequency. The two primaries are connected in series in such a way as to oppose each other.

The resultant voltage at B will be zero, however, because the voltage of the two primaries is equal and opposite. Any voltage impressed at B will thus cause a current to flow independent of the exciting voltages at the transformer terminals, and approximately twice the impedance voltage of one transformer will cause full-load current to flow through the primaries and secondaries of both transformers.

The total energy thus required to run two transformers at full load is merely the losses in the iron and copper. Circuit A supplies the exciting current and core losses, and circuit B the full-load current and copper losses.

Heat Test, Method 3. — When only one transformer is to be tested, and this transformer is of large capacity, a modification of the motor generator method can be used as described below:

This method was first used in testing an 830 k.w. 25-cycle transformer made for the Carborundum Company of Niagara Falls. The connections are shown in Fig. 66.

Both primary and secondary windings are divided into two parts, the primary coils x and y being connected in multiple to the dynamo circuit, but an auxiliary transformer capable of adding a few per cent E.M.F. to that half of the primary is connected as shown in the y half.

By this means the primary coils are properly magnetized, and full-load currents can be passed through them by varying the auxiliary E.M F.

The two halves of the secondary coils are connected in series in opposition to each other, and are subject to an auxiliary E.M.F. from the same generator, but reduced to the proper voltage by the auxiliary transformer B.

The currents were measured in all three transformer circuits, and the E.M.F. of one-half the secondary was measured.

The method is accurate enough for large units, and is quite handy where no large dynamo can be gotten for supplying full-load currents, as in this case current is required only for the transformer losses and for supplying the auxiliary transformers.

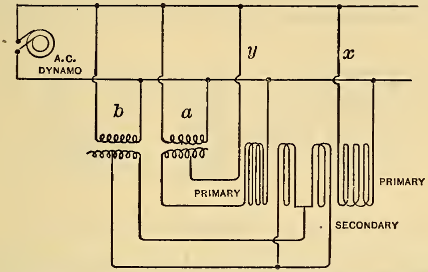


FIG. 66. General Electric Method of Testing One Large Transformer.

Temperature Rise.

To ascertain the temperature rise of the different parts of a transformer, thermometers are placed on the various parts, and readings taken at frequent intervals. These readings, however, indicate only the surface temperature of a body and not the actual internal temperature.

The average rise of temperature of the windings can be more accurately determined by means of the increase of resistance of the conductor, and is determined by knowing the resistances hot and cold.

Let $R_c =$ resistance of one coil, cold.
$R_h =$ resistance of one coil, hot.
$T_c =$ temperature of one coil in cent. degrees, cold.
$T_h =$ temperature of one coil in cent. degrees, hot.
$K =$ temperature of coefficient of copper .004.

$$T_h = \frac{R_h\,(1 + .004\,T_c) - R_c}{.004\,R_c}.$$

This equation is based on the assumption that the resistance of pure copper increases .4 % of its value at zero for every degree centigrade rise in temperature.

If it be desired to know the temperature rise of both primary and secondary coils, their hot and cold resistances must be determined separately; but it is customary to determine the temperature rise by resistance of only one coil, usually the primary, and comparing the secondary temperatures by the thermometer measurements. The method for taking these measurements is described in the paragraph in this section on measurement of resistance.

Ratio.

As a check against possible mistakes in winding the coils and connecting up. a test should be made for ratio of voltages.

The ratio test is made at a fractional part of the full voltage at no-load current, and should not be substituted for a regulation test. An error of one or two per cent is quite admissible in making this test, because of its being taken at partial voltages.

Regulation.

The regulation of a transformer can be determined either by direct measurement or by calculation from the measurements of resistance and reactance in the transformer. Since the regulation of any commercial transformer is at the most but a few per cent of the impressed voltage, and as errors of observation are very liable to be fully one per cent, the direct method of measuring regulation is not at all reliable.

Regulation by Direct Measurements.

Connect up the transformer with a fully loaded secondary, as in Fig. 67. If the primary voltage is very steady, voltmeter No. 2 only will be necessary, but it is better to use one on the primary circuit also as shown. A reading of voltmeter No. 2 is taken with no load, and again with load, the difference in the two readings being the drop in voltage on the secondary.

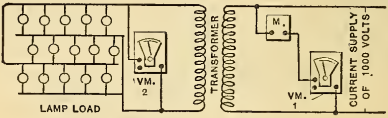


FIG. 67. Test for Regulation of Transformer.

We, therefore, have,

$$\% \text{ Regulation} = 100 - \left(\frac{100 \times \text{reading at no load}}{\text{Reading at full load.}}\right)$$

Regulation by Calculation.

Several methods of calculating the regulation of transformers from the measurements of resistance and reactive drop have been devised.

Below is a method by Mr. A. R. Everest, and recently published in the electrical journals, which has been found to answer the requirements of daily use.

Let $IR =$ Total resistance drop in transformer expressed as per cent of rated voltage.

$IX =$ Reactive drop, similarly expressed.

$P =$ Proportion of energy current in load or power factor of load. For non-inductive load $P = 1$.

$W =$ Wattless factor of primary current.

(With non-inductive load, $W =$ Magnetizing current expressed as a fraction of full-load current. With inductive load, $W =$ Wattless component of load, plus magnetizing current.)

Then if volts at secondary terminals $= 100\%$,

Primary voltage —

For Non-Inductive Load.

$$E = \sqrt{(100 + PCR + WIX)^2 \pm (IX)^2}.$$

For Inductive Load:

$$E = \sqrt{(100 + PIR + WIX)^2 + (PIX + WIR)^2}.$$

In each of these equations the last expression within parentheses represents the drop "in quadrature."

$$\text{The magnetizing current} = \sqrt{\text{Exciting current} - \left(\frac{\text{Core loss}^2}{\text{Voltage}}\right)}$$

For frequencies of 60 cycles or higher, magnetizing current may be taken as 75 per cent of the exciting current.

Extracting the square root in the expression for regulation may be avoided in the use of the following table:

Quadrature Drop.	Increase in Primary Voltage.
2.5 per cent.	.025 per cent.
3 " "	.04 " "
3.5 " "	.06 " "
4 " "	.08 " "
4.5 " "	.10 " "
5 " "	.13 " "
5.5 " "	.15 " "
6 " "	.18 " "
6.5 " "	.21 " "
7 " "	.24 " "
7.5 " "	.27 " "
8 " "	.31 " "
8.5 " "	.35 " "
9 " "	.39 " "
9.5 " "	.45 " "
10 " "	.50 " "

As an example, take a 2 k.w. transformer having the following losses:

IR drop $= 2\%$.

IX drop $= 3.5\%$.

Exciting current $= 4\%$ or .04; then magnetizing current $= 75\%$ of this, or .03.

1. Non-Inductive Load.—Secondary voltage $= 100\%$.

Primary voltage in phase $= 100 + 2\% + (.03 \times 3.5\%) = 102.1\%$.

Quadrature drop $= 3.5\%$; this from table adds .06% of total primary voltage $= 102.16\%$.

The drop is 2.16% of secondary voltage, or $\frac{2.16}{102.16} = 2.11\%$ of primary voltage, which is the true regulation drop.

2. Inductive Load.—With a power factor of .86, wattless factor of load $= .5$, and adding magnetizing current (which in most cases might be neglected on inductive load), W becomes .52.

The primary voltage in phase is now $100\% + 2\% \times .86 + 3.5 \times .52 + 103.18\%$.

The quadrature drop is $.86 \times 3.5\% \times .52 \times 2\% + 2.76\%$.

From this table this adds .03.

Primary voltage $= 103.21\%$.

Regulation drop $= \frac{3.21}{103.21} = 3.11\%$ of primary voltage. Regulation drop should always be expressed finally in terms of primary voltage.

The above described methods of transformer testing are in use by one of the large manufacturers, and present average American shop practice.

The following matter is largely from the important paper by Mr. Ford and presents the commonest theoretical test methods.

EFFICIENCY.

The efficiency of a transformer is the ratio of its net power output to its gross power input, the output being measured with non-inductive load. The power input includes the output together with the losses which are as follows:

(1) The core loss, which is determined by test at the rated frequency and voltage.

(2) The $I^2 R$ loss of the primary and the secondary calculated from their resistances.

Example.

Transformer, Type H, 60 Cycles, 5 k.w., 1000–2000 Volts Prim., 100–200 Volts Sec.

AMPERES.	
Primary, at 2000 volts	2.5
Secondary, at 200 volts	25

RESISTANCE.	OHMS AT 20° C.
Primary	10.1
Secondary	0.067

At Full Load.

LOSSES.	WATTS.
Primary $I^2 R$	63
Secondary $I^2 R$	42
Total $I^2 R$	105
Core Loss	70
Total Loss	175
Output at Full Load	5000
Input " " "	5175
Efficiency	5000/5175 or 96.6%

At Half Load.

LOSSES.	WATTS.
Total $I^2 R$	26
Core Loss	70
Total Loss	96
Output	2500
Input	2596
Efficiency	2500/2596 or 96.2%

The all-day efficiency of a transformer is the ratio of the output to the input during 24 hours. The usual conditions of practice will be met if the calculation is based on 5 hours at full load, and 19 hours at no load.

OUTPUT.	WATT HRS.
5 Hours at Full Load	25000
19 Hours at No Load	0
Total, 24 Hours	25000
INPUT.	
5 Hours at Full Load	25875
19 Hours at No Load (Neglecting $I^2 R$ Loss due to Excitation Current)	1330
Total, 24 Hours	27205
All-day Efficiency	25000/27205 or 91.9%

In calculating the efficiencies in both of the above examples, the copper loss due to excitation current of the transformer has been neglected. This current, in the example given above, is less than 3%, and its effect on the loss of the transformer is thus negligible. Even at no load the total $I^2 R$ loss introduced by it is less than one watt. It is quite necessary, however, that the loss introduced by the excitation current should be checked in all cases. In some transformers, for example, the excitation current may reach 30% of the full-load current, and thus its effect is noticeable at large loads, while at ¼ load the loss in the primary winding due to excitation current is greater than the loss due to the load current.

Inasmuch as the losses in the transformer are affected by the temperature and the wave form of the E.M.F., the efficiency can be accurately specified only by reference to some definite temperature, such as 25° C., and by stating whether the E.M.F. is sine or otherwise.

The foregoing method of calculating the efficiency neglects what are known as "load losses," *i.e.*, the eddy current losses in the iron and the conductors caused by the current in the transformer windings. The watts measured in the impedance test include "load losses" and $I^2 R$ losses together with a small core loss. Considering the core loss as negligible, the "load losses" are obtained by subtracting from the measured watts the I^2R loss calculated from the resistance of the transformer. It is sometimes assumed that the "load losses" in a transformer when it is working under full-load conditions are the same as those obtained with short-circuited secondary, and it is stated that these losses should enter into the calculation of efficiency. Many tests have been made to determine whether or not the above assumption is correct, and while the results cannot be considered as conclusive, they indicate in every case that, under full-load conditions, the "load losses" are considerably less than those measured with short-circuited secondary. Inasmuch as these losses, in general, form a small percentage of the total loss in a transformer, and in view of the difficulty in determining them with accuracy, they may be neglected in the calculation of efficiency for commercial purposes. The measurement of watts in the impedance test is, however, useful as a check on excessive eddy current losses in a poorly designed transformer.

POLARITY.

Transformers are generally designed so that the instantaneous direction of flow of the current in certain selected leads is the same in all transformers of the same type. For example, referring to Fig. 68, the transformer there shown is designed so that the current at any instant flows into the primary at A, and out of the secondary at C. Some such system is necessary, in order that transformers may run in parallel when similar primary and secondary leads on different transformers are connected together. The test which is made to determine whether a given transformer is identical in this respect with other transformers of the same type is known as the polarity test.

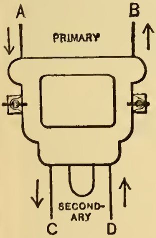


Fig. 68.

The polarity test should be unnecessary when banking transformers of the same type and design. When, however, transformers manufactured by different companies are to be run in parallel, it is necessary to test them in order to avoid the possibility of connecting them in such a way as to short circuit the one on the other. Their polarity may be determined by one of the following methods.

In Fig. 68 primary lead A should be of the same polarity as the second lead C. Connect the primary lead B to the secondary lead C. Apply 100 volts, say, to the primary AB of the transformer. The voltage measured from A to D should be greater than the applied voltage if the transformer is of the correct polarity. In other words, a transformer connected as shown should act as a booster to the voltage. If the leads A and C are not of the same polarity, the voltage measured from A to D should be less than that applied at AB.

If a standard transformer, known to have correct polarity and the same ratio as the test transformer, is available, the simplest method for testing the polarity is to connect the primaries and secondaries of the transformer in parallel, placing a fuse in series with the secondaries. On applying voltage to the primaries of the transformers, if they are of the same polarity and ratio, no current should flow in the secondary circuit, and the fuse will remain intact. If the transformers are of opposite polarity, the connection will short circuit the one transformer on the other, and the fuse selected should therefore be small enough to blow before the transformers are injured.

In nearly all transformers there will be a slight current in the secondaries when connected as above. This current is known as the exchange current, and should be less than 1% of the normal full-load current of the transformer.

DATA TO BE DETERMINED BY TESTS.

Partly from a paper by Arthur Hillyer Ford, B. S.

I. Copper loss, to determine the efficiency.
II. Iron-core loss, hot and cold, to determine the efficiency: to separate the hysteresis from the foucault current loss.

If

$W =$ watts output,
$I =$ watts iron-core loss,
$C =$ watts copper loss,

then the

$$\text{Efficiency} = 100 - \left(\frac{W}{W + I + C} \times 100 \right)$$

Foucault currents loss should decrease with an increase in temperature.

Hysteresis loss is supposed to be constant regardless of heat.

III. Open circuit or exciting current.
IV. Regulation, to determine the magnetic leakage.
V. Rise in temperature in case and out of case, for no load and full load; with and without oil.
VI. Insulation.

Methods.

Opposition Method of Ayrton and Sumpner.—This method is especially valuable where the transformers to be tested are of large capacity, and a source of power great enough to put them under full load in the ordinary way is unavailable. A supply of current of an amount somewhat greater than the total losses of both transformers is all that is necessary. Following is a diagram of the connections, by which it will be seen that the transformers are so connected that one feeds the other, or they work in opposition.

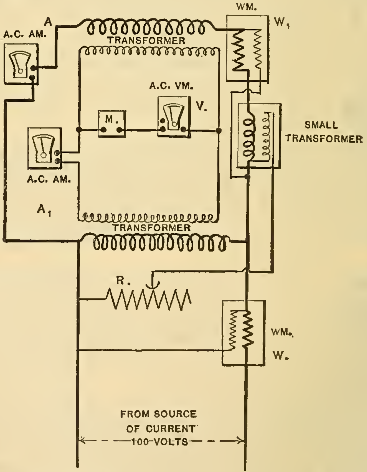


Fig. 69. Diagrams of Connections for Ayrton and Sumpner Opposition Method of Testing Transformers.

In making the test, current is turned on and the resistance R adjusted until full-load current flows in the secondary, as shown by the ammeter A, and the primary current and voltage in A and V is up to standard. Then the watts read on W are equal to the iron losses in both transformers, and W, the losses in the copper of the transformers plus the copper loss in the leads and in the current coils of W, and A.

The total loss in both transformers is watts loss $= \mathrm{W} + \mathrm{W}_{,} - a$, where a is the loss in the leads and instruments which may be calculated by I^2R.

Method of Dr. Sumpner. Iron Loss. — The following diagram shows the connections for Dr. Sumpner's test for iron losses. The low-pressure side is connected to a source of current of the same pressure at which the transformer is expected to work, thus producing the same primary voltage in the high-pressure side at which it is expected to work. With the primary circuit open, the iron losses in the transformer are read directly in watts on the wattmeter.

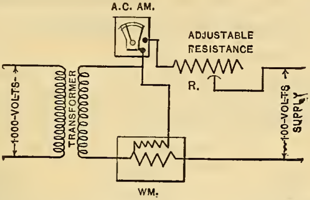


FIG. 70. Dr. Sumpner's Test for Iron Losses.

Copper Loss. — The next diagram shows the connections for determining the copper losses. The low-pressure side is short-circuited through an ammeter, the high-pressure side being connected to the 100-volt supply-mains. The resistance R is then adjusted to obtain full-load or any other desired current in the secondary, as shown by the ammeter. The reading of the wattmeter will then show the total copper losses in the transformer and in the ammeter plus a very small and entirely negligible iron loss. The ammeter losses and that in the leads may be calculated by I^2R. The small iron loss can be separated or determined by disconnecting the ammeter and adjusting R until the pressure on the primary is the same as in the copper-loss test; the wattmeter will then show the small iron loss.

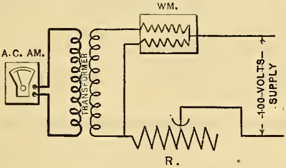


FIG. 71. Dr. Sumpner's Test for Copper Losses.

The iron loss is proportional to $\mathcal{B}^{1.6}$ and $\mathcal{B}$, the magnetic density is proportional to the pressure at the terminals of the transformer, therefore the iron loss is equal to $K.\mathcal{B}^{1.6}$ where K is a constant and $\mathcal{B}$ the voltage. In the iron-loss test the $\mathcal{B} = 1000$ and in the copper-loss test

$\mathcal{B} = 100.$

$$K \times 1000^{1.6} = 63{,}000\ K$$
$$K \times 100^{1.6} = 1{,}600\ K = 2.5\ \%\ \text{of total iron loss.}$$

Heating. — Tests should be made at no load, at full load, and at intermediate loads for rise of temperature of the transformers out of their cases, in their cases, without oil and with oil, if full data is wanted. If a strictly commercial test is all that is necessary, a test with the transformer at full load and set up in the condition it is to be run, will be sufficient.

Surface temperatures can be taken by thermometers laid on and covered with cotton waste. In oil-insulated transformers the temperature of the oil should be taken in two places, — inside the coil, and between the coil and case.

Leakage Drop. — The drop in the secondary due to magnetic leakage can be found by deducting from the measured total drop the I^2R drop due to the resistance of the coil.

ELECTRIC LIGHTING.

LIGHT.

Velocity of light approximately 192,000 miles per second.

Composition of Sunlight.

Violet, the maximum chemical ray.
Indigo. Blue. Green.
Yellow, the maximum light ray.
Orange.
Red, the maximum heat ray.

Colors.

Primary.	Red,	Yellow,	Blue.
Secondary.	Orange,	Purple,	Green.
Tertiary.	Brown,	Gray,	Broken green.

Intensity of Illumination on a surface is inversely as the square of the distance between the surface and the source of light.

or

$$\text{Intensity} = \frac{\text{Quantity of light}}{4\pi \times \text{distance}^2}.$$

If light strikes the surface obliquely,

then

$$\text{Intensity} = \frac{\text{Quantity} \times \text{Cos.}\, i}{4\pi \times \text{distance}^2}.$$

Where i is the angle of incidence, or the angle which the rays make with the normal to the surface.

Intensity of light in a given direction is proportional to the cosine of the angle, the direction and the normal to the element of the luminous surface from which the light is emitted.

Trotter gives in the following table the intensities of different sources of light.

Intensities of Different Sources of Light.

(Trotter.)

	C. P. per Sq. In.		C.P. per Sq.Cm.	
	Red.	Green.	Red.	Green.
Platinum (Violle standard)	120	120	18.5	18.5
Sun's disk	487,000	1000000	75.500	155,000
Sky, near sun	120	120	18.5	18.5
Albo carbon on edge	73.5	60.7	11.4	9.4
White paper, horizontal, exposed to summer sky, noon	16.5	35.2	2.56	5.45
White paper, sun 60° high, paper facing sun	8.25	17.2	1.28	2.67
Albo carbon, flat	10.5	8.7	1.63	1.35
Argand	6.8	5.24	1.05	0.82
Black velvet, summer sky, noon	0.0333	0·07	0.0052	0.0109
White paper, reading without straining	0.0018	0.0024	0.00028	0.0003

Intensities of Different Sources of Light—*Continued.*

	White.	White.
Sperm candle	2	0.31
Moon, 35° above horizon	2	0.31
Moon, high	3	0.46
Batswing (whole flame)	2.25	0.35
Methven standard	4.3	0.666
Incandescent carbon filament (glow lamp	120	18.5
Crater of electric arc	45,000	7,000

Mean Spherical Intensity is the intensity which the light from the given source would have at unit distance, if it radiated uniformly in all directions, the total quantity remaining unchanged.

Units of Light.

The quantity of light emitted from any source of light is expressed in terms of that of some specified standard of reference.

No very satisfactory standard for all purposes has as yet been selected, but those listed below are among the best in use or proposed.

a. The British standard candle, a spermaceti candle seven-eights of an inch in diameter, weighing one-sixth pound, and burning at the rate of 120 grains per hour. A rough and ready standard, not very accurate.

b. The French stearine candle weighs one-fifth pound, and burns at the rate of 117.3 grains per hour, giving a light equivalent to 1 to 1.4 British candles, and is equally unsatisfactory and inaccurate.

c. The Methven screen, an Argand burner of 16 candle-power, before which is placed a screen having a small rectangular aperture so placed in the screen in relation to the position of the flame that the light passing through equals two British candles. Methven claims the amount of light passing through the aperture is not affected by quality of the gas if the flame is kept at a constant height. The value of this standard is questioned by some authorities.

d. The Harcourt pentane air-gas lamp, burning a mixture of 576 volumes of air to one of liquid pentane, or 20 volumes of air to seven of pentane gas —at 60° F., is very satisfactory when carefully protected from draughts of air.

The height of flame is 2½ inches and diameter of burner ¼ inch, the light being equivalent to one British candle.

e. The Carcel lamp, the principal French standard, equals 9½ British candles, and burns 42 grammes of purified colza oil per hour, the flame being 40 mm. high. MM. Regnault and Dumas have proven by experiments that when the consumption of colza is at a rate between 40 and 44 grammes per hour, the light emitted by this standard is proportional to the weight of colza burned. Following is a table showing the proper dimensions of this standard.

Dimensions of Carcel Lamp.	mm.
External diameter of burner	23.5
Interior diameter of inner air current	17.0
Interior diameter of outer air current	45.5
Total height of chimney	290
Distance from elbow to base of glass	61
Exterior diameter at level of bend	47
Interior diameter of glass at top of chimney	34
Mean thickness of glass	2

Use lighthouse wick weighing 3.6 grammes per decimeter and woven with 75 strands. This standard is quite satisfactory if carefully used.

f. The Amyl-Acetate-lamp is substantially a well designed spirit lamp having a flame 40 mm. high, and gives a light equal to one British candle. This is quite a satisfactory standard for a simple one.

g. The platinum standard proposed by MM. Cornu and Violle is the light emitted by one square centimeter of platinum at its melting-point. Violle shows that the light emitted by this unit is equivalent to 19½ to 19¾ British candles, and experiments by Prof. C. R. Cross show that the light emitted by various specimens of platinum at the melting-point, is quite constant for a wire of definite dimensions. This standard is highly thought of by scientists.

The surface illumination is the quantity of light received by the surface of a body per unit of surface from a standard source and at a definite distance from it. Sir. W. H. Preece has proposed to give to the unit of surface illumination the name of *lux*, which would mean the quantity of light received by a square foot of surface from one carcel at a distance of one meter.

By this standard one 16 c.p. lamp would give a surface illumination of one lux at a distance of 4 ft. 2¾ in., and 1000 c.p. lamps would give a surface illumination of a lux at a distance of 33 ft. 5½ in.

The Director of the Central Laboratory of Electricity of Paris, M. de Nerville, has employed for the measurement of surface illumination a unit called the bougie-meter, the bougie being one-tenth of a carcel, and equivalent to one British candle at a distance of 3.34 feet. This is a convenient standard.

German Standards. — The standard German candle is made of paraffine after an elaborate specification, and is used to some extent in approximate work. Its flame is somewhat longer than that of the English candle, being some two inches in height for the standard, and is about 10% more powerful.

The legal standard in Germany is the so called *Hefner unit*, which is the light given by the amylacetate lamp mentioned on the previous page. This lamp has been exhaustively investigated by the Reichanstalt, which furnishes certified tested standard lamps, making this unit more nearly an international standard than any of the others named; its intensity is about 10% less than that of the English candle, and its normal flame is 40 Milimeters high. It is very steady, and owing to the fact that lamps of certified value can be so readily obtained it is widely used not only in Germany but elsewhere. Careful instructions are issued with each lamp, and when used in accordance with these instructions the errors of measurement are not more than half those met with in the use of standard candles. The color is somewhat against this unit, being a distinctly reddish orange, which is a rather serious objection when used as a working standard in measurements of Welsbach burners or incandescent and Nernst lamps. Even with its faults though, it is probably the best primary standard that we have, as it can be reproduced accurately to a most unusual degree.

As photometry is perhaps more generally practiced in connection with incandescent electric lamps than with any other source of light, it is only natural that the incandescent lamp should have come into very general use as a secondary standard; and it is probable that a well seasoned incandescent lamp makes the very best and most reliable standard for this purpose that can be found. Care must be taken that the filament is not worked at too high a temperature, and that it is aged by several hundred hours of preliminary burning before being used as a standard. When burned at a fixed and uniform voltage, comparison with a good primary standard will determine its intensity, which will remain very nearly uniform if carefully used, its only change being a small and perfectly ascertainable decrement with time. Various attempts have been made to use an incandescent lamp of special design as a primary standard, but so far the results have not been at all satisfactory.

Following is a table which shows the comparative value of the various primary standards :

	Bougie-meter.	Carcel.	Hefner unit.	German candle.	English candle.	French candle.
Bougie-meter . . .	1.	0.104	1.13	0.955	0.97	
Carcel	9.6	1.	10.9	9.20	9.6	7.00
Hefner unit	0.88	0.92	1.	0.815	0.91	0.65
German candle . .	1.05	0.109	1.23	1.	1.09	0.78
English candle . .		0.104	1.099	0.915	1.	0.714
French candle . . .		0.145	1.538	1.281	1.40	1.

Measurement of Intensity of Light.

The instrument used for determining the relative intensities of lights is called a *photometer;* following is a list of some of the better types, with a short explanation of their principles.

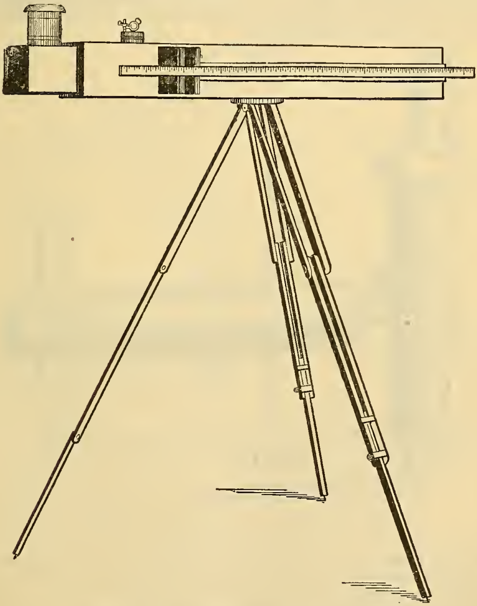


FIG. 1. Portable Bunsen Photometer.

In all types let the following symbols mean the same.

i = intensity of one light at the distance d.

i_1 = intensity of the other light at the distance d_1.

Rumford's photometer compares the shadows of an opaque rod thrown on a white screen by two lights.

When the shadows are of equal density,

$$\frac{i}{i_1} = \frac{d^2}{d_1^2}.$$

In **Bunsen's** photometer a piece of white paper, blotting-paper is good, with a grease spot in its center, is placed between the two lights, with its surface at right angles to the line of the rays; moving the paper back and forth between the lights until the grease spot disappears; then the two lights are to each other as the squares of the distances between each and the screen: or

$$\frac{i}{i_1} = \frac{d^2}{d_1^2}.$$

If the lamp under test be at a height h above the horizontal plane of the photometer and standard lamp or candle, other symbols remaining the same, and the standard be one c.p., then

$$\text{c.p. of the lamp} = \frac{(h^2 + d_1^2)^{\frac{3}{2}}}{d^2 \times d_1}.$$

In **Ritchie's** photometer two equal white surfaces are placed at an angle with each other, and with the line of light and their brightness compared, moving back and forth on the line of light until both surfaces are alike in illumination; the relative intensities of the lights are then the same as with the *Bunsen* instrument.

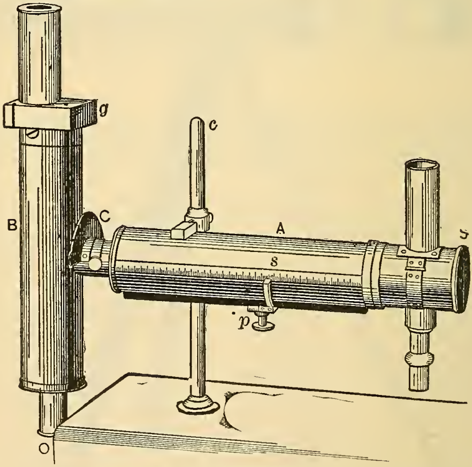


FIG. 2. Prof. L. Weber's Portable Photometer.

Ayrton and Perry use what they call a dispersion photometer, in which a concave lens is used in the path of the stronger light to reduce its intensity by dispersion of its rays to a known degree.

This instrument is useful in measuring arc lamps.

Sabine's wedge photometer reduces the stronger light a known degree by passing it through a medium of neutral tinted glass, which also allows of the colored rays being compared.

In **Joly's** photometer, two slabs of paraffin wax, or translucent glass about 3″ x 2″ x ½″, are fastened together back to back by Canada balsam, a sheet of paper or silver foil being first interposed, after which the edges and surfaces are ground smooth.

This slab is placed between the two lights, with the plane of the joint at right angles to the line between the lights, and moved back and forth on that line until the observer looking at the edge of the slab finds both sides equally illuminated, when the relative intensities are as before. By reversing the slab, a check can be had on the observation.

Prof. L. Weber has invented one of the handiest and most accurate photometers, description of which follows.

The apparatus consists of a tube, *A*, about 30 cm. long, which can be moved up and down and swung in a horizontal plane on the upright, *c*. The standard light, *S*, a benzine lamp, is contained in a lantern fastened to the right end of the tube, *A*. Within the tube, *A*, a circular plate of opal glass can be moved from or towards the light, *S*; its distance from *E* is read in centimeters on the scale, *s*, by means of an index fastened to the pinion, *P*. At right angles to tube, *A*, a second tube, *B*, is fastened. This tube can be rotated in a vertical plane, and its position in reference to the horizontal is read on the graduated circle, *C*. A rectangular prism contained in tube *B* in its axis of rotation receives light from the opal glass plate in tube *A*, and reflects this light towards the eye-piece, *O*, so that the right half of the field of vision is illuminated by this light, the left half is illuminated by the light entering the tube, *B*, through *g*.

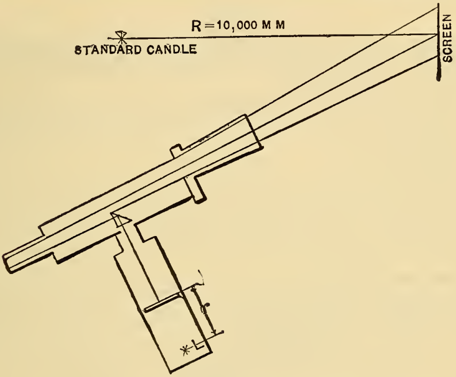


FIG. 3.

In making measurements, the tube *B* is pointed toward the source of light to be measured. The light has to pass through a square box, *g*, in which may be inserted one or more opal glass plates, in order to diminish the intensity of the light, and thus to make it comparable with the standard light. The apparatus permits the measurement of light in the shape of a flame, as well as the measurement of diffused light.

Since the measurement of diffused light interests us most at present, a short description of the method will not be out of place.

A white screen, the surface of which is absolutely without luster, furnished as part of the apparatus, is placed in a convenient position, either horizontal or vertical, or at any desired inclination, toward the source of light.

The photometer having been located at a convenient distance from the screen, the tube *B* is pointed to the center of the screen. The distance of the phonometer from the screen can be varied within very wide limits, the only restrictions being that the field of vision receives no other light than that emanating from the screen. The necessary precautions for adjustment having been observed, the opal glass plate in the tube *A* is moved until both halves of the field of vision appear equally illuminated. The distance, *r*, of this glass plate from the standard light at the moment of equal illumination is read on the scale on tube A in millimeters, and the intensity of illumination on the white screen is calculated from the formula,

$$I = \frac{10000}{r^2} K.$$

The constant K is previously determined as follows:

A standard candle is placed exactly one meter distant from the white screen, and the tube, B, of the photometer is pointed towards the screen, so that the center of the screen, which is marked by a cross, is seen in the center of the field of vision. As indicated in Fig. 3, the photometer must be so placed that the eye looking through the eye-piece, sees nothing but the white screen. The angle of inclination under which the screen is observed may be varied within wide limits without influencing the result; it should, however, not exceed 60 degrees from the normal to the screen.

Equal illumination of both halves of the field of vision having been obtained by means of adjusting the opal glass plate in tube A, the constant, K, is found by calculation;

$$K = \frac{r^2}{R^2}.$$

Since r is read in millimeters, and R is made 1 meter or 10000 millimeters, 10000 instead of 1 must be taken in the formula for calculating the intensity of illuminating in meter candles.

A second method permits of measurements of diffused light without the intervention of a screen; but for further details the reader is referred to the description of the apparatus by Professor Weber, *Elekrotechnische Zeitschrift*, vol. v., p. 166.

Since the whole apparatus can easily be taken apart, and packed in a box about 24x8x12 inches, it recommends itself extremely well for out-of-door work. In this case the benzine lamp might well be replaced by a small incandescent lamp, provided this lamp is standardized before and after each set of experiments. Such miniature lamps been have found very convenient, and quite sufficiently constant in candle-power for several hundred observations.

In the **Lummer-Brodhun** photometer, cut of the carriage of which is shown below, the rays of light from the two sources under comparison enter at the sides so as to strike the surfaces of the opaque gypsum screen. Diffused light from these white surfaces reaches two parallel mirrors (inside) at an angle of 45°, and is reflected to right angled prisms which have the outer portions of their hypothenuse surfaces cut away and coated with asphalt varnish to secure complete absorption. Light entering the prisms from the mirrors is either transmitted or totally reflected at their surface of contact, so that an observer at the telescope tube sees a circular disk of light

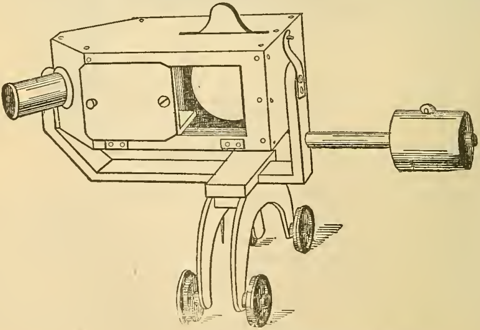


FIG. 4. Lummer-Brodhun Photometer Carriage.

from one side of the gypsum screen surrounded by an annular ring of light from the other side, the boundary line between the two being sharply defined. The sensibility of this instrument as proved both theoretically and practically, is between three and four times that of the Bunsen grease spot.

Illuminating Power for internal lighting varies according to the nature and color of the walls and objects inside of the room. Dark walls require more lighting than light walls. Dr. Sumpner finds that dull walls only reflect about 20 per cent of the light incident upon them, whilst ordinary tints reflect 40 to 50 per cent, clean white surfaces 80 per cent, ordinary mirrors 80 per cent, and very good mirrors 90 per cent. Hence well-whitened rooms require only one-fifth of the light required with dull walls. The amount of light also depends upon the height of the room. In rooms about 10 ft. high, a 16-c.p. lamp placed 8 ft. from the floor gives 1 candle-foot on the table and ¼ candle-foot on the floor. The following table may be used as a rough guide, subject to the above conditions :

No. of 16-c.p. Lamps per 100 Square Feet.	No. of Watts per sq. ft. if 16-c.p. Lamp Takes 50 Watts.	Approximate Effect.
1	0.5	Dull.
1.5	0.75	Medium.
2	1.0	Good.
3	1.5	Bright.
4	2.0	Brilliant.

Forée Bain gives the following table for number of incandescent lamps required for good illumination :

Dimensions of Rooms in Feet.			Number of Lamps, Each 8 to 10 Candle-powers.	Height of Lamps above Floor.	
Length.	Width.	Height.		Feet.	Inches.
15	15	12	2 to 3	6	9
18	18	15.1	5 " 6	7	0
24.6	24.6	17	9 " 12	8	1
33	33	22.5	16 " 20	2	3
40	40	30	25 " 30	11	4
65	65	45	40 " 50	13	2
72	72	50	100 " 120	18	6

With 16 candle-power lamps 75 per cent, and with 20 candle-power lamps 65 per cent of the above numbers will give equal illumination.

ARC LAMPS.

In the United States, arc lamps may be classed somewhat as follows :

Continuous Current Arc Lamps.

Low Potential, high current, using about 20 volts across the terminals, and 30 amperes of current; formerly largely in use; now no longer manufactured.

High Potential: using 45 to 60 volts and 9.6 to 10 amperes for a nominal 2000-c.p. standard lamp. This lamp is more used than any other for street lighting, and with the 1200-c.p. lamp, so called, taking 6.8 amperes and 45 to 50 volts, includes the larger part of all arc lighting in the United States.

Inclosed Arc, taking 5 amperes and about 80 volts; this lamp is now much used, as it needs recarboning but about once a week (100 to 150 hours).

The first of the three classes of arc lamps mentioned above is no longer in use except on old circuits, but is always connected in series on constant current dynamos.

The **high potential** and **inclosed arc** lamps are connected in series on constant current dynamos; and with some slight difference in mechanism are also connected to constant potential circuits.

Alternating Current Arc Lamps.

Alternating current arc lamps are made in great variety, and average about 15 amperes for the 2000-c.p. arc, at 28 or 30 volts, but require about 35 volts to start promptly; and are made for series or parallel circuits.

They are used largely on constant potential circuits in connection with the regular transformer, or in connection with specially-designed series transformers or regulators, for the description of which see chapter on "Transformers." Owing to the reactive effect of these lamps, they can be run one lamp across the terminals of a 100-volt circuit. Some types use a resistance, others use a compensating coil, and still others are so designed as to the actuating magnets as to require no extra reactance in series with the lamp across a 100 or 104 or 110 volt constant potential circuit.

The Westinghouse Electric and Mfg. Co. and others use, where required, what is called an "economy coil," which is something like a small transformer placed across the terminals of a 100-volt a.c. circuit.

Three a.c. arc lamps can be connected to the terminals of this coil and if one lamp goes out, the current drops in the main, but keeps automatically the same in each remaining lamp circuit, as the coil not in use on a lamp assists the adjacent coils. Following is a diagram of the arrangement.

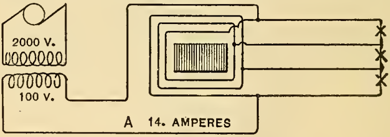


FIG. 5.

The Inclosed Arc Lamp is the only radical change in arc lamp practice during a number of years past, and is now being used for a great part of all new work installed.

It has been found that by inclosing the tips of the carbons in a small receptacle more or less approaching air-tight conditions, that combustion of the carbons is practically complete, leaving no dust, and takes place at a much slower rate, burning with the ordinary 12″ × ½″ carbons from 50 to 150 hours continuously, according to the design of the lamp. The potential at the arc is 75 or 80 volts, and according to the best modern practice the current used is from 4.5 to 6 amperes. With this high voltage it is usual to place an adjustable resistance in the top of the lamp, or near by, and one lamp can then be connected directly across constant potential circuits of 100 to 125 volts.

Although there may be some question as to the lighting efficiency of the inclosed arc, the very great advantages from carbon economy and infrequent trimming, as well as lack of dirt from carbon dust, render it very desirable in practical use.

As the upper carbon stump can often be used as the lower when retrimming, ordinary commercial lamps will require trimming not oftener than once a month.

The safety of inclosed arcs appeals strongly to the underwriters, who have no fear of sparks floating away from them to set goods afire in shops and factories.

As the consumption of carbon is so slow, the feeding mechanism can be very simple and the feed very regular, and if in addition to this a good quality of carbon be used, the light is extremely steady and of the very best quality.

If care is taken in selecting the globes, shadows of frame and arc can be reduced to the last degree.

Methods of Regulation in Arc Lamps may be classified as follows :—

Carbons lifted or separated by direct or main magnet; shunt magnet acting on a variable resistance to cut out the main magnet in feeding.

Carbons lifted by main magnet as before, and shunt acting to put the main magnet (made movable) into position for feeding.

Carbons separated by main magnet armature ; shunt circuiting magnet acting to divert or shunt the magnetism of the main magnet from its armature.

Carbons separated by main magnet and shunt acting to free the carbonholder, independently of the support given by the main magnet.

Carbons separated by a spring allowed to act by the main magnet lifting a weight which otherwise holds the spring from acting ; shunt magnet acts against the spring, to feed and regulate the length of arc.

One carbon, generally the lower, separated by main magnet, while the other holder is released for feeding only, such feeding being under the control either of a differential system or a shunt magnet only.

Carbons separated by main magnet, which lifts the shunt and its armature together, while the shunt magnet armature, acting on the feeding mechanism, controls the arc and feed of the carbons.

Carbon feeding mechanism independently attached to main magnet armature and to shunt armature so as to receive opposite movements of separation, and feed from each respectively.

Carbons separated by a feeding mechanism moved by the main magnet, and fed by a further movement of said mechanism, causing release or return of same under the accumulated force of both shunt and main magnets, acting in the same direction.

Differential clock gear for separation and feed of carbons under control of the regulating magnet system, either simple or differential. Some of the older clockwork lamps embodied this principle.

Carbons controlled by armature of a small electric motor under control of a differential field which turns the armature in one direction for separating and in the other or reversed direction for feeding the carbons.

Carbons controlled by a motor running at a certain speed when the arc is of normal length, and varying in speed when the arc is too short or too long, combined with a centrifugal governor on the shaft of the motor, acting on variations of speed to gear motor shaft to screw carbons together or apart, as needed to maintain the normal arc. This mechanism has been applied to large arc lamps, such as naval search-lights, and has the advantage of great positiveness, and an ability to handle heavy mechanism.

There are also a considerable number of modifications of these principles.

Searchlight Projectors and focusing lamps for theatrical use and for photo-engraving, etc., take large and varied quantities of current, as they are always connected across the terminals of constant potential circuits, with a regulating resistance in series with the lamp. The General Electric Company state in one of their bulletins the following as being the approximate currents taken by the different sizes of searchlights :

DIAM. OF PROJECTOR.	AMPERES.
12 inch	18 to 20
18 "	30 " 35
24 "	50 " 60
30 "	75 " 90
36 "	90 " 100
60 "	125 " 150

Tests for Arc Light Carbons.

For Open Arcs.

The satisfactory working of arc lamps is largely dependent upon the quality of the carbons used. If carbons are made of impure materials, they will jump and flame badly. If not baked properly, they may cause annoyance by excessive hissing or flaming, or become too hot because of high resistance. If the material of which they are made has not been properly prepared in its preliminary stages, the carbons will have either too short a life, through giving a good quantity and quality of light, or will have good life, but will burn with an excessive amount of violet rays, hence with poor illumination.

For indoor use a free-burning, uncoated carbon of medium life should be used, so as to give a good quality and quantity of light. If longer life is desired they may be lightly coated with copper without materially interfering with the light. (About $1\frac{1}{2}$ lbs. to 2 lbs. of copper per thousand, $\frac{7}{16}''$ x $12''$ carbons, and a half pound more for $\frac{1}{2}''$ x $12''$ carbons will give good results, increasing the life from an hour to an hour and a half.)

For out-door use a more refractory burning carbon may be used to advantage, giving a longer life, as the quality of the light is not so important. Copper-coated carbons are also usually employed, and may have about four pounds of copper per thousand for $\frac{7}{16}''$ x $12''$ carbons, and five pounds for $\frac{1}{2}''$ x $12''$. Other sizes in proportion.

All plain molded carbons, and most of the forced carbons, deposit dust when burned in the open arc. Those depositing the most dust give out the most light, but have the least life. Those depositing the least dust usually have the longest life, but the light is of inferior quality on account of the increase in the proportion of violet rays.

The quality of any carbon may be very quickly tested in any station by using the following method, which has been largely employed by carbon manufacturers.

The important points to be determined are the **range**, including the *hissing*, *jumping*, and *flaming* points, the **resistance**, and the **life**.

The **Range** is found by trimming a lamp with the carbons to be tested, allowing them to burn to good points and the lamps to become thoroughly heated; then connect a voltmeter across the lamp terminals, and very slowly and steadily depress the upper carbon until the lamp hisses, when the voltage will make a sudden drop. This is called the **Hissing-Point**, and varies according to the temper of the carbon. It should be between 40 and 45 volts — preferably 42 volts. Then lengthen the arc somewhat, and allow it to become longer by the burning away of the carbons. Presently the arc will make small jumps or sputters out of the crater in the upper carbon. This is the **Jumping-Point**, and should be not less than 58 or 60 volts. Let the arc still increase in length, carefully watching the voltage, and in most carbons there will soon be a decided flaming. This is the **Flaming-Point**. This should not be less than 62 to 65 volts. Very impure carbons will commence to jump and flame almost as soon as the voltage is raised above the hissing-point, and even the hissing-point in such cases is very irregular and difficult to find. The *Range* is important as being a practical test of the purity of the material used in the manufacture of the carbon, an increase of a quarter of one per cent of impurity making a very decided reduction in the extent of the Range. The hissing-point should be 4 or 5 volts below the normal adjustment of the lamp to insure steady burning.

Resistance. — The resistance is measured on an ordinary Wheatstone bridge. Care must be taken that the contact points go slightly into the carbon. A $\frac{7}{16}''$ x $12''$ plain carbon should have a resistance of between .16 and .22 ohms, and $\frac{1}{2}''$ x $12''$ between .14 and .18 ohms. $\frac{7}{16}''$ x $12''$ carbons coated with three pounds of copper per thousand, have a resistance between .05 and .06 ohms, and $\frac{1}{2}''$ x $12''$ with four pounds of copper between .04 and .05 ohms.

Life. — The life of a carbon is most easily tested by consuming it entirely in the lamp, observing, of course, the current and average voltage during the entire time. A very quick and accurate comparative test of different carbons can be made, however, by burning the carbons to good points, then weighing them, and let them burn one hour, then weigh them again. The amount burned by both upper and lower carbons shows the *rate* of consumption which will accurately indicate the comparative merits of the carbons tested as to life.

To calculate the life from a burning test of one hour, both carbons should be first weighed, the upper carbon broken off to a 7-inch length, in order to make the test at the average point of burning, and with the lower carbon, burned to good points, weighed again, and after burning one hour in a lamp that has already been warmed up, taken out and weighed. The amount of two carbons 12 inches long consumed in a complete life-test is 63 per cent of the combined weight of both upper and lower carbons. Therefore 63 per cent of the weight of the two carbons, divided by the rate per hour obtained as above, will give the life approximately.

Dust. — The dust from burning carbons can be collected in the globe, or better, in a paper bag suspended below the lamp. In an ordinary plain-molded carbon this dust amounts to 4 per cent of the weight of the upper carbon. A variation below this amount will indicate good life, but inferior light. An excessive amount of dust would show a short life, but usually a good quantity and quality of light. Coating a carbon with copper eliminates this deposit of dust entirely.

Inclosed Arc Carbons.

Carbons for inclosed arcs can be very conveniently tested as to their relative values in an open arc lamp as described above. As their diameters regulate the admission of air to the inclosing globe, thus greatly affecting their life, they should be carefully measured with micrometer calipers. A greater variation than .005″ from the required diameter should not be permitted. The deposit on the inside of the inclosing globe is caused by impurities, principally in the core. The relative injurious amount of this deposit can be measured by carefully taking the globes off the lamps after burning, and measuring the amount of light absorbed by them with an ordinary photometer, using an incandescent lamp as a source of light, and cutting the light down by means of a hole in a screen so that it will pass through the part of the globe to be measured. Twice the light so measured through the globe, divided by the amount coming through the unobstructed hole, will give the per cent of the light transmitted through the globe from the arc. That carbon whose globe absorbs the least amount of light is, of course, the most desirable.

The resistance of forced carbons, whether cored or solid. used in inclosed arc lamps, is very important. Carbons of high resistance are difficult to volatilize, and hence there is trouble in establishing the arc where small currents are used, and in case of any interruption in reëstablishing it afterwards. This is especially true of carbons used in alternating arcs, and of cored carbons. The resistance of forced carbons is usually much higher than that of molded, ranging from two to four times as much. This will undoubtedly be corrected when the manufacturers become more familiar with the requirements. The lower the resistance the better the quality of the light and the operation of the lamp.

Sizes of Carbons for Arc Lamps.

Open Arcs.	Continuous Current.	
	Upper.	Lower.
6.8 amperes.	12 in. × $\frac{7}{16}$ in.	7 in. × $\frac{7}{16}$ in.
9.6 "	12 " × $\frac{1}{2}$ "	7 " × $\frac{1}{2}$ "
9.6 "	11 " × $\frac{5}{8}$ "	8 " × $\frac{1}{2}$ "
	Alternating Current.	
15 amperes.	9½ in. × $\frac{5}{8}$ in.	9½ in. × $\frac{5}{8}$ in.
Inclosed Arcs.	Continuous Current.	
5 amperes.	12 in. × $\frac{1}{2}$ in.	5½ in. × $\frac{1}{2}$ in.
3 "	12 " × $\frac{3}{8}$ "	6 " × $\frac{3}{8}$ "

Some variations are made on the above sizes to change the candle-power, or to burn longer. An elliptical carbon ⅞ inch × 7/16 inch × 12 inches is sometimes used in a single carbon lamp for all-night service; and the 12 and 14 inch × ⅝ inch is also used for the same purpose.

Carbons Recommended for Searchlight Projectors.

(Hardtmuth or Schmeltzer.)

Size of Lamp.	Positive. Cored.	Negative. Solid.
12 inch	6 in. × ⅝ in.	3½ in. × 9/16 in.
18 “	12 “ × 13/16 “	7 “ × ¾ “
24 “	12 “ × 1 “	7 “ × ¾ “
30 “	12 “ × 1⅛ “	7 “ × ⅞ “
36 “	12 “ × 1¼ “	7 “ × 1 “
60 “	12 “ × 1½ “	7 “ × 1¼ “

Carbons Recommended for Automatic and Hand-Feed Focusing Lamps.

Continuous Current.		
Amperes.	Positive. Cored.	Negative. Solid.
5 to 10	6 in. × 7/16 in.	6 in. × 7/16 in.
10 “ 18	6 “ × ½ “	6 “ × ½ “
18 “ 20	6 “ × ⅝ “	6 “ × ⅝ “
25 “ 30	6 “ × ¾ “	6 “ × ¾ “
Alternating Current.		
5 to 10	6 in. × 7/16 in.	Same as for Positive.
10 “ 18	6 “ × ½ “	
18 “ 20	6 “ × ⅝ “	
25 “ 30	6 “ × ¾ “	

Candle-power of Arc Lamps.

The candle-power of an arc lamp is one of the most troublesome things to determine in all electrical engineering; the variations being great the arc unsteady, and the implements for use in such determination being so liable to error. Again, what is the candle-power of an arc lamp, or rather, what is the meaning of the term?

When the lamp was first put forward, for some reason, now in great obscurity, the regular 9.6 ampere lamp was called 2000 candle-power, and it has always since been so called, although the word "nominal" has been tacked on to the candle-power to indicate that it is a rating, and not an actual measurement.

The candle-power of the arc varies with the angle to the horizon on which the measurement is made; in continuous current arcs the maximum candle-power is at a point about 45 degrees below the horizontal if the upper carbon is the positive, and of course above the horizontal if the negative carbon is above.

In alternating current lamps the total light from the arc is somewhat more regular in intensity, as both carbon tips are practically the same shape. In the arc there are two points of maximum light, one about 60 degrees above the horizontal, and the other about the same angle below the line, and the mean horizontal intensity also bears a greater ratio to the mean spherical intensity than in the d.c. arc. In the a.c. arc much of the light is above the horizontal plane, and it is necessary to arrange a reflector above the arc to throw that portion of the light downward; and this, together with a disagreeable hum inherent in the a.c. arc, has much reduced the use of that class of lamps except for street-lighting.

Mean Spherical Candle-power is the mean of the candle-power measured all over the surface of a sphere of which the arc is the center, usually about one-third of the maximum candle-power. In practice the spherical candle-power is seldom fully determined, but a fair approximation may be had by the following formula:

Let $S =$ mean spherical candle-power,
$H =$ horizontal candle-power,
$M =$ candle-power at the maximum.

Then $S = \frac{H}{2} + \frac{M}{4}$.

In a test of arc lamps in November, 1889, for the New York City Bureau of Gas, Captain John Millis found the following results in his trial of the Thomson-Houston lamps.

The same lamp was used, but connected to the different street circuits, all measurements were made at 40 degrees below the horizontal, and $\frac{9}{16}$-inch copper-plated carbons were used.

Ten readings were taken on each of four sides of the lamp when connected to each circuit, with the following results:

	CANDLE-POWER.	WATTS.
Circuit No. 1.	2072.7	482.88
" " 2.	1981.0	485.10
" " 3.	2048.5	493.22
" " 4.	2000.2	494.40
" " 5.	2067.0	495.36
Means	2033.9	490.19

Mean current, amperes 10.36
Mean volts 47.32

The results of tests of candle-power of arc lamps at the Antwerp Exposition, shown in the table below, would tend to verify the above trials.

Amperes.	Volts.	Maximum C. P.	Horizontal C.P.	Upper Hemisphere Mean C. P.	Lower Hemisphere. Mean C.P.	Mean C.P.	Watts.
4	37.2	390	74	17	119	136	157
6	46.2	1090	168	63	298	361	259
6.8	46	1240	240	65	320	385	313
8	46	1550	334	70	385	454	350
10	45.5	2070	421	102	640	750	491

Arc Lamp Efficiency. — The efficiency of an arc lamp is the ratio of its mean spherical candle-power to the watts consumed between the lamp terminals. Some energy is used up in the lamp-controlling mechanism, in the carbons themselves, and the remainder is used on the arc. Arc-lamp efficiency is sometimes described as the ratio of the watts used in the arc to the watts used between the lamp terminals. This is true of the lamp as a machine; but the first statement is the correct one, as it is light that is turned out, and not watts consumed in the arc that is the object of the lamp, and the two depend so much on quality and adjustment of carbons, even with the same consumption of current, as to make the latter method erroneous.

The steadiness of the arc depends somewhat upon the mechanism of the lamp, but more largely on the quality of the carbon used.

The mechanism must be sensitive enough to keep the tips of the carbons at practically the same distance apart; and the quality of carbon must be such as to keep the arc steadily in the center, or in the axis of the carbons, for if the carbon mixture is not homogeneous, the arc will travel about at the outer edge of the carbons, producing bad shadows, Cored carbons, having the central axis of the carbon filled with a softer and more volatile material, are used for the steadiest light, and in combination with a solid negative carbon of a diameter somewhat less than that of the cored positive produces most excellent results.

If $W =$ total watts supplied at terminals,
$w =$ watts used in the arc,
$I =$ current supplied at lamp terminals,
$E =$ potential between the lamp terminals,
$i =$ current through carbons or series coil, then the efficiency of the lamp as a mechanism is

$$\frac{w}{W} = \frac{ei}{BI}.$$

Heat and Temperature Developed by the Electric Arc.

The temperature of the crater, or light-emitting surface of the arc, is the same as the point of volatilization of carbon, and therefore constant under constant atmospheric pressure. This temperature is variously stated by different investigators: Dewar gives it as 6000° C.; Rosetti, the positive as 3200° C., and the negative 2500° C.

The carbon in the crater is in a plastic condition during burning; and with the same adjustment of carbons, as to length of arc, the light per unit of power increases with the current.

Hissing, flaming, and rotating of the arc are some of the defects. Hissing is due to a short arc, and was a constant accompaniment of the low potential, high current arc so prevalent during the earlier days of arc lighting.

Flaming and rotating are due to long arcs, and to impure carbons, or carbons not properly baked.

With good carbons the length of arc, or distance between carbon tips recommended by the Thomson-Houston Company, was for 6.8 ampere lamp, $\frac{3}{64}$ inch, and for 9.6 or 10 ampere lamps, $\frac{1}{16}$ to $\frac{3}{32}$ inch.

Heat developed by the electric arc in a given time is as follows:

Let $H =$ heat in gramme-centigrade degrees.
$E =$ difference of potential of arc.
$I =$ current in amperes.
$T =$ time in seconds.

Then

$$H = .24\,EIT.$$

Balancing Resistance for Arc Lamps on Constant Potential Circuit.

As the ordinary arc lamp takes but 45 to 50 volts, when used on constant potential circuits of more than 50 volts, it is necessary to introduce a certain resistance in series, in order, first, to take up part of the voltage, and second, to act in a steadying capacity to the arc; in fact, until the dead resistance was introduced in series with the arc lamp on constant potential circuits, such lamps were entirely unsuccessful.

Prof. Elihu Thomson says, "a certain line voltage as a minimum is absolutely necessary in working arc lamps on constant potential lines, whether they be open arcs or inclosed arcs. Thus two 45 volt arcs in series, with uncored carbons like the brand known as 'National,' cannot be safely worked below 110 volts on the line without resistance in series with them. More than 100 volts should, of course, be maintained for safety of the service.

"The tests show, also, that with a cored upper carbon, the limit is lowered several volts on the average, and it is known that the voltage of the arcs may be safely reduced somewhat when cored positives are used.

"It is also shown that a 75 to 80 volt arc, run upon a constant potential line, is stable at a considerably less line voltage than the open arc. It would appear, also, that with either open or inclosed arcs at ordinary current strengths of from 5 to 10 amperes, the steadying resistance in the branch is required to cause a drop of about 15 to 20 volts, or waste energy at the rate in watts of 15 to 20, multiplied by the amperes of current used in the lamp."

Let $E =$ E.M.F. or difference of potential between the circuit leads
$e =$ E.M.F. required at arc lamp terminals.
$i =$ current required by the arc lamp.
$R =$ dead resistance to be put in series.
$r =$ resistance of the arc lamp burning.
$r_{\prime} =$ total resistance of dead resistance + lamp.

Then

$$r = \frac{e}{i} \qquad (1)$$

$$r_{\prime} = \frac{E}{i} \qquad (2)$$

$$R = r_{\prime} - r \qquad (3)$$

As the E.M.F. of most of the circuits on which lamps of this type are used is more than 100 volts, it is customary, and in fact economically necessary to place two arc lamps in series, and the formula (3) then becomes

$$R = r_{\prime} - 2r.$$

Street Lighting by Arc Lamps.

In New York City 10 ampere arcs are placed at street corners 250 feet apart, giving excellent results. On Fifth avenue, New York, two 5 ampere lamps on posts placed 125 feet apart, give good results.

St. Louis, Mo., one arc lamp on every other corner, illumination poor on unlighted corner. Favorite distance in United States 200 to 300 feet.

For good illumination distance apart of arc lamps should not exceed six times height of arc from ground.

For railroad yards 10 ampere arc lamps 30 feet from the ground and about 200 feet apart are found to give good results.

The following table shows some arrangements of arc lamps in foreign cities:

Arc Lamps in Foreign Cities.	Amperes per Arc.	Distance apart in Ft.	Height of Arc in Ft.
City of London Streets	10	115	17.6
Glasgow Streets	10	160	18.0
Hastings Streets	10	300	18.0
Berlin Streets	15	137	26.7
Milan Streets	. . .	80 to 100	25.0
Charing Cross Railroad Station . . .	10	90	18.0
Cannon Street Railroad Station . . .	15	180	35.0
St. Pancras Railroad Station	10	60 to 80	14.0
Central Station, Glasgow	10	75	19.5
St. Enoch's Station, Glasgow	10	90	. . .
Edinburgh Exhibition, 1886	10	33	12.0
Edinburgh Exhibition, 1886	15	41	18.0

About ½ watt per square foot is a fair allowance for lighting large halls, exhibitions, etc.; 1 watt for large reading-rooms, libraries, etc.; 2 watts for intense illumination, such as is required at the South Kensington Museum.

Light Cut off by Globes.

Clear glass	10 per cent.
Light ground glass	30 per cent.
Heavy ground glass	45 to 50 per cent.
Strong opal	50 to 60 per cent.

Trimming Arc Lamps.

Good trimmer can clean and recarbon about 100 commercial arcs per day if the lamps are not too far scattered.

For street lamps at ordinary distances trimmer should not be required to recarbon and clean more than 80 double lamps per day.

INCANDESCENT LAMPS.

Temperature of filament should be as high as practicable commensurate with an economical life; it is generally about 2500° F.

At a temperature of 1800° F. it is said that an increase of 20° in temperature will increase the candle-power about 40 times.

Energy required for incandescent lamps is I^2R or $E\,I$; R being the hot resistance of the lamp.

Heat units H required is

$$H = \frac{E\,I\,t}{17.7} \text{ where } t = \text{time in minutes.}$$

Candle-power of a given current varies nearly as the fourth power of the difference between the given current and the current required to produce visible rays.

At and near normal candle-power the light varies as the sixth power of the current, or

$$I = i\,\sqrt[6]{\frac{\text{c. p.}}{\text{c. p.}_{,}}}$$

where $I =$ current for c. p.
and $i =$ current for c. p.$_{,}$

Efficiency of Incandescent Lamps.

By efficiency is understood the ratio of the candle-power to the watts consumed. It varies from 1 watt to 10 watts per candle, and even more in old lamps, but generally in new lamps from 2½ to 4 watts are required. The most economical efficiency, i.e., at which the cost of operating the lamp is a minimum, depends upon the cost of the energy supplied, and of the lamp renewal. When the former is cheap and the lamps poor and expensive, the efficiency should be low; when the reverse holds, the lamps should be run at a high efficiency. It has been shown that the total cost of energy and lamp renewals is a minimum, where the cost of lamp renewals is about 15 per cent of the whole. If the renewals cost more than 15 per cent, the lamps are being used at too high an efficiency, and *vice versa*.

The efficiency of incandescence lamps with direct or alternating currents is the same. (*Ayrton* and *Perry*.)

$$\left.\begin{array}{l}\text{Watts consumed in incandescent}\\ \quad\text{lamps worked by alternating cur-}\\ \quad\text{rents}\end{array}\right\} = \frac{r\left(\frac{\tau}{2}\right)\sqrt{\overline{I^2}\,\overline{E^2}}}{\sqrt{l^2\,\pi^2 + r^2\left(\frac{\tau}{2}\right)^2}}$$

where

$\sqrt{\overline{I^2}}$ = square root of mean square of current measured on electrodynamometer.

$\sqrt{\overline{E^2}}$ = square root of mean square of voltage measured on non-inductive voltmeter.

τ = the duration of one complete alternation.
r = resistance of filament in ohms.
l = coefficient of self-induction of filament.

Smashing Point.—It is wasteful to run lamps invariably until they break, owing to the decrease in efficiency as the lamp is used. In some cases old lamps having very long lives have been found to take as much as 17 watts per candle. The point at which it is most economical to renew the lamp has been termed the "smashing-point," and the following formula may be used, on the assumption that the increase in watts per candle-power is uniform, or approximately so.

If

B = cost of lamps per candle-power,
C = total cost of a candle-power of light for a given time b,
D = average cost per hour per candle during the given time b,
E = cost of energy per 1000 watt-hours,
a = initial power in watts per candle,
b = hours lamp should be burned, i.e., "smashing-point,"
c = increase of watts per candle for each hour of use ;

Then

$$C = B + \left(a + c\frac{b}{2}\right) E \frac{b}{1000}$$

$$D = \frac{C}{b} = \frac{B}{b} + \left(a + c\,\frac{b}{2}\right)\frac{E}{1000}$$

$$D \text{ is minimum when } b = \sqrt{\frac{2000\,B}{E\,c}}$$

and

$$b = 1410\ \sqrt{\frac{B}{E}} \text{ when } c = .001$$

$$b = 1000\ \sqrt{\frac{B}{E}} \text{ when } c = .002$$

$$b = 815\ \sqrt{\frac{B}{E}} \text{ when } c = .003$$

The Proper Use of Incandescent Lamps.

(From a Circular of the General Electric Company.)

A lamp to give satisfaction must not only be properly made, but it must also be properly used. A lamp of the highest quality may be so misused as to give only a small fraction of its rated light capacity. Proper use, producing a maximum of light at a minimum expense, requires :

That the lamps be burned at marked voltage.
That the voltage be kept constant.
That lamps be replaced whenever they get dim.

The last requirement is not considered economical by many users who prize lamps that have long life, and insist on using them as long as they will burn. Let us see by an example if extremely long life is desirable.

As the cost of current varies greatly, we will assume an average cost of one-half cent per lamp hour. If a rated 16-candle-power lamp, burned for 1000 hours, be burned an additional 1000 hours, it takes practically the same current during the last period, but gives an average light of only about 8 candles. The cost of current for the 2000 hours is $10.00. A new lamp costs 20 to 25 cents; and had three lamps, with a life of about 700 hours each, been used during the entire period, the average light would have been fully doubled, at an added expense of not more than 50 cents, or 5 % of cost of current. In other words, by adding 5 % to operating expense (representing the cost of the two renewal lamps) the customer would add 100 % to the light given. One new lamp gives a light equal to two old ones at half the cost of current. If the old lamps gave light enough, the new lamps would halve the number of lamps in use, and produce the same light with half the current.

It is important to note that the above example is based on results obtained with the highest grade of lamps. With an inferior quality of lamp the argument against extremely long life would be still stronger and the necessity of frequent renewals of lamps much greater.

Thus, from any point of view, it is false economy to select lamps with a sole regard for long life. Lamps should be renewed when dim, for in no other way can light be produced economically.

The points to be remembered are as follows:

Do not run pressure above the voltage of the lamps. Increased pressure means extra power; and although the old lamps may thus give more light for awhile, every new lamp that does not break from the excessive pressure will deteriorate very rapidly and give greatly diminished light.

Do not treat incandescent lamps like lamp chimneys, and use them until they break. They should be renewed whenever they get dim.

Life and Candle-power of Lamps.

Since the prime function of an incandescent lamp is to give light, the best lamp is that which gives maximum light at minimum cost. This is an exceedingly simple axiom, and yet few users of lamps follow it out in practice. Lamps are repeatedly selected for long life, irrespective of good, uniform candle-power. Lamps are often continued in use long after their candle-power has seriously diminished.

An examination of the characteristics of an incandescent lamp will give a clear understanding of the principles applying to their selection and use. A theoretically perfect lamp would maintain its normal candle-power indefinitely, or until the lamp was broken. In practice the deterioration of the lamp filament causes a steady loss of candle-power.

Regarding Loss in Candle-power.—The drop in candle-power is a characteristic of an incandescent lamp always to be borne in mind. The relative drop or loss of candle-power, other things being equal, determines the comparative value of different lamps. We may have a lamp that loses 50 % in candle-power inside of 200 hours on a 3.1 watt efficiency basis. This type is almost invariably furnished by the inexperienced manufacturer, and there are many such lamps in the market. Considered from the standpoint of life only, such lamps are excellent, because their filaments deteriorate to such a degree that it is practically impossible to supply enough current to brighten them up to the breaking point, but no discerning station manager would want such dim lamps, even with unlimited life. As in the selection of incandescent lamps so in their use—the exclusive consideration of life leads to poor results. Loss of candle-power in a lamp sooner or later makes it uneconomical to continue in use.

There is no lamp yet made which it is economical to burn over 1000 hours, and in the great majority of cases the limit is under 600 hours.

An incandescent lamp is nothing more than a transformer, receiving current and transforming it into light. After a certain time this transformer may lose 50 % in efficiency, taking practically the same current, but giving only about one-half the light. A boiler or an engine suffering such loss in efficiency would be promptly repaired or replaced. The renewal of incandescent lamps is even more important. The old lamps jeopardize the customer's trade with their poor and expensive light. A customer cares little how efficiently a station is operated, but is much concerned about the quality of light furnished. At the present price of lamps, doubling the number of lamp renewals adds little to cost of operation, while it increases the lighting efficiency 40 % to 50 %. Some stations attempt to correct the dimness of old lamps by raising the voltage, but this is bad practice, for the increased pressure damages every new lamp placed in circuit. These principles are carefully observed by many of the large lighting companies, and a force of men is employed to weed out and replace all dim lamps. Some such means of keeping the average life below 600 hours should be adopted by every lighting company that has any regard for the economical production of light, or the satisfaction of their customers.

A simple method is to fix the average life at 600 hours or less, and then determine from the station record how many lamps should be renewed each month to keep the average life within this limit. The required number of lamps should be renewed each month.

If, for example, a station decides on an average life not to exceed 600 hours and the station records show that on the average 60,000 lamp hours of current are supplied monthly, then it would be necessary to renew $\frac{60,000}{600}$ or 100 lamps a month.

The Importance of Good Regulation.

Proper Selection and Use of Transformers.—Poor regulation of voltage probably results in more trouble with customers than any other fault in electric lighting service.

Some central station managers act on the theory that so long as the life of the lamp is satisfactory, an increase of voltage, either temporary or permanent, will increase the average light. The fact is that when lamps are burned above their normal rating the average candle-power of all the lamps on the circuit is decreased; and if the station is on a meter basis, it increases the amount of the customers' bills.

Evils of Excessive Voltage.—Excessive voltage is thus a double error—it decreases the total light of the lamps, and increases the power consumed. The loss of light displeases the customers and discredits the service. If light is sold by meter, the increased power consumption dissatisfies the customers; if light is sold by contract, the additional power is a dead loss to the station. If increased light is needed, 20 candle-power lamps should be installed, instead of raising the pressure. Their first cost is the same as 16 candle-power lamps; they take but little more current than 16 candle-power lamps operated at high voltage, and give greater average light.

Increased pressure also decreases the commercial life of the lamp; and this decrease is at a far more rapid rate than the increase of pressure, as shown in the following table. This table shows the decrease in life of standard 3.1 watt lamps, due to increase of normal voltage.

Per Cent of Normal Voltage.	Life Factor.
100	1.000
101	.818
102	.681
103	.662
104	.452
105	.374
106	.310

From this table it is seen that 3 % increase of voltage halves the life of a lamp, while 6 % increase reduces the life by two-thirds.

Irregular pressure, therefore, necessarily results in the use of lamps in which the power consumption per candle is greater than a well regulated pressure would allow. The result is reduced capacity of station, and reduced station efficiency.

These remarks apply with special force to alternating current stations, since we have here two sources of possible irregularity in voltage—the generator and the transformer. Poor regulation is most apt to occur in the transformers, and the utmost care should, therefore, be taken in their selection and use. The efficiency of the average lamp on alternating systems is nearly 4 watts per candle. With good regulation obtained by the intelligent use of modern transformers, the use of lamps of an efficiency of 3.1 watts per candle becomes practicable. It is thus possible to save 25 % in power consumption at the lamps, and increase the capacity of the station and transformers by the same amount.

In the past two years there has been a marked advance in the method of making transformer installations. The general adoption of higher voltage secondaries gives smaller loss in wires, and permits the use of larger transformer units, thus greatly improving the regulation. On this account 50-volt lamps are gradually going out of use. The replacement of a number of small transformers by one large unit, and of old, inefficient transformers by modern types, has also been of immense advantage to stations. A large number of stations, however, still retain these old transformers, and load their circuits with large numbers of small units. Such stations necessarily suffer from loss of power, bad regulation, and a generally deteriorated lighting service. Simply as a return on the investment, it would pay all such stations to scrap their old transformers and replace them with large and modern units.

Proper care in the selection of transformers considers the quality and the size. Quality is the essential consideration, and should have preference over first cost. No make of transformer should be permitted on a station's circuit that does not maintain its voltage well within 3 % from full load to no load. The simple rule regarding size is to use as large units as possible, and thus reduce the number of units as far as the distribution of service permits. Every alternating station should aim to so improve regulation as to permit the satisfactory use of 3-watt lamps.

Good regulation is eminently important to preserve the average life and light of the lamps, to prevent the increase of power consumed by the lamps, and to permit the use of lamps of lower power consumption, so that both the efficiency and capacity of the station may be increased.

Constant voltage at the lamps can be maintained only by constant use of reliable portable instruments. No switchboard instrument should be relied on, without frequent checking by some reliable standard. Owing to the varying drop at different loads, constant voltage at the station is not what is wanted. Pressure readings should be taken at customers' lamps at numerous points, the readings being made at times of maximum, average and minimum load. Not less than five to ten readings should be made at each point visited, the volt-meter being left in circuit for four or five minutes, and readings being taken every fifteen seconds. The average of all the readings gives the average voltage of the circuits. Lamps should be ordered for this voltage, or if desired, the voltage of the circuits can be reduced or increased to suit the lamps in use. The practical points are to determine the average voltage at frequent periods with a portable voltmeter at various points of the circuits, and then to arrange the voltage of the lamps and circuits so that they agree.

Candle-Hours—The Regulation of Lamp Value.

The amount of light given by lamps of the same efficiency is the only proper measure of their value. The amount of light given, expressed in candle-hours, is the product of the average candle-power for a given period by the length of the period in hours.

Many of the best central station managers consider that a lamp has passed its useful life when it has lost 20 % of its initial candle-power. In the case of a 16 candle-power lamp, the limit would be 12.8 candle-power. The period of time a lamp burns until it loses 20 % of its candle-power may therefore be accepted as its useful life. The product of this period in hours by the average candle-power gives the "candle-hours" of light for any given lamp.

The better a lamp maintains its candle-power under equal conditions of comparison the greater will be the period of "useful life," and therefore the greater will be the "candle-hours." This measure is, therefore, the only proper one with which to compare lamps and determine their quality.

The practical method of comparison is as follows: Lamps of similar candle-power and voltage are burned at the same initial efficiency of 3.1 watts per candle on circuits whose voltage is maintained exactly normal. At periods of 50, 75, or 100 hours the lamps are removed from the circuits and candle-power readings taken, the lamps being replaced in circuit at the end of each reading. Readings are thus continued until the candle-power drops to 80 % of normal. The results obtained are then plotted in curves, and the areas under these curves give the "candle-hours" and the relative value of the different lamps.

Variation in Candle-power and Efficiency.

In the following table is shown the variation in candle-power and efficiency of standard 3.1 watt lamps due to variation of normal voltage.

Per Cent of Normal Voltage.	Per Cent of Normal Candle-power.	Efficiency in Watts per Candle.
90	53	4.68
91	57	4.46
92	61	4.26
93	65	4.1
94	69½	3.92
95	74	3.76
96	79	3.6
97	84	3.45
98	89	3.34
99	94½	3.22
100	100	3.1
101	106	2.99
102	112	2.9
103	118	2.8
104	124½	2.7
105	131½	2.62
106	138½	2.54

Example: Lamps of 16 candle-power, 105 volts, and 3.1 watts, if burned at 98 % of normal voltage, or 103 volts, will give 89 % of 16 candle-power, or 14¼ candle-power, and the efficiency will be 3.34 watts per candle.

Lamp Renewals.

The importance and necessity of proper lamp renewals applies forcibly to all stations, regardless of the cost of power, and whether lamp renewals are charged for or furnished free. The policy of free-lamp renewals at the present low price of lamps is, however, preferable for both station and customer. Free-lamp renewals give a station that full and complete control of their lighting service so requisite to perfect results.

Since, however, a large number of companies charge for renewals, we offer some suggestions as to the best method of inducing customers to renew their old lamps, for it is evident that some inducement is necessary.

Offering new lamps in exchange for dim lamps at a reduction in price is one good method. A customer, for example, would save by paying, say half price, for the renewal of a dim lamp, instead of waiting and paying full price when the lamp burns out.

Another method is to offer lamps for renewals at less than cost, say 15 cents each, and reserve the right to say when lamps shall be renewed. Such a plan works well, as no customer can justly complain when the company renews lamps at less than cost.

As profit on the sale of lamps is certainly secondary in importance to the sale of current and the improvement in quality of light, either of the above plans should commend themselves to all Central Stations not furnishing free renewals.

Whatever method be adopted, the one chief principle of good economical lighting service should never be forgotten, viz.: that the average life of lamps should never exceed *600 hours.*

Points to be Remembered.

That a constant pressure at the lamps must be maintained.

That the lamps are not to be used to the point of breakage — they should be renewed when they become dim.

That satisfaction to customers, and the success of electric lighting, are dependent upon good, full, and clear light, which old, black, and dim lamps cannot give.

That to furnish a good, full, and clear light is as much a part of the Lighting Company's business as to supply current to light the lamps.

That a company should always endeavor to keep the average life of lamps within 600 hours.

That to renew dim lamps properly on the free renewal system, inspectors should examine the circuits regularly when the lamps are burning. If lamp renewals are charged to customers, induce them to exchange their dim lamps.

Faults in Incandescent Lamps.

Rapid Loss of Candle-Power.—Rapid loss of candle-power is one defect in incandescent lamps, and we have shown that all lamps suffer a gradual loss of candle-power as they are used. A very rapid loss in candle-power is, however, a real fault, due to inexperienced manufacture, or use at excessive voltage. The remedy is to purchase only lamps of standard reputation, produced by the experienced manufacturer, and to maintain pressure at normal on the lamps. The pressure should be carefully tested with accurate portable instruments at the lamp sockets; and if found high, the pressure should be regulated to accord with the voltage of lamps, or lamps supplied to accord with the pressure.

Blackening of Bulbs. — Another defect in incandescent lamps is the blackening of bulbs, although this is more often a supposed defect than a real one. A lamp may lose in candle-power and show but little blackening; and on the other hand, a lamp may get quite black and lose little in candle-power. Thus a 50-volt lamp which has a more stable filament than the 110-volt lamp, often shows considerable blackening with little loss of candle-power.

Blackening in good lamps results from either high pressure or excessive life. This is a supposed fault. The best of lamps, if burned too long, will always show a certain amount of blackening. The remedies are, of course, regulation of pressure and frequent renewals.

The above are the most important defects to be found in incandescent lamps.

General Illumination.

The subject of illumination has been divided by Mr. E. L. Elliott, to whom we are indebted for many suggestions, into the following sub-divisions: Intensity or Brilliancy, Distribution, Diffusion, and Quality.

Intensity or Brilliancy. — The average brilliancy of illumination required will depend on the use to which the light is put. "A dim light that would be very satisfactory for a church would be wholly inadequate for a library, and equally unsuitable for a ballroom."

The illumination given by one candle at a distance of one foot is called the "candle-foot," and is taken as a unit of intensity. In general, intensity of illumination should nowhere be less than one candle-foot, and the demand for light at the present time quite frequently raises the brilliancy to double this amount. As the intensity of light varies inversely with the square of the distance, a 16 candle-power lamp gives a candle-foot of light at a distance of four feet. A candle-foot of light is a good intensity for reading purposes.

Assuming the 16 candle-power lamp as the standard, it is generally found that two 16 candle-power lamps per 100 square feet of floor space give good illumination, three very bright, and four brilliant. These general figures will be modified by the height of ceiling, color of walls and ceiling, and other local conditions. The lighting effect is reduced, of course, by an increased height of ceiling. A room with dark walls requires nearly three times as many lights for the same illumination as a room with walls painted white. With the amount of intense light available in arc and incandescent lighting, there is danger of exceeding "the limits of effective illumination and producing a glaring intensity," which should be avoided as carefully as too little intensity of illumination.

Distribution of Light.—Distribution considers the arrangement of the various sources of light, and the determination of their candle-power. The object should be to "secure a uniform brilliancy on a certain plane, or within a given space. A room uniformly lighted, even though comparatively dim, gives an effect of much better illumination than where there is great brilliancy at some points and comparative darkness at others. The darker parts, even though actually light enough, appear dark by contrast, while the lighter parts are dazzling. For this reason naked lights of any kind are to be avoided, since they must appear as dazzling points, in contrast with the general illumination."

The arrangement of the lamps is dependent very largely upon existing conditions. In factories and shops, lamps should be placed over each machine or bench so as to give the necessary light for each workman. In the lighting of halls, public buildings, and large rooms, excellent effects are obtained by dividing the ceiling into squares and placing a lamp in the center of each square. The size of square depends on the height of ceiling and the intensity of illumination desired. Another excellent method consists in placing the lamps in a border along the wall near the ceiling.

For the illumination of show windows and display effects, care must be taken to illuminate by reflected light. The lamps should be so placed as to throw their rays upon the display without casting any direct rays on the observer.

The relative value of high candle-power lamps in case of an equivalent number of 16 candle-power lamps is worthy of notice. Large lamps can be efficiently used for lighting large areas, but in general, a given area will be much less effectively lighted by high candle-power lamps than by an equivalent number of 16 candle-power lamps. For instance, sixteen 64 candle-power lamps distributed over a large area will not give as good general illumination as sixty-four 16 candle-power lamps distributed over the same area. High candle-power lamps are chiefly useful when a brilliant light is needed at one point, or where space is limited and an increase in illuminating effect is desired.

Diffusion of Light.—"Diffusion refers to the number of rays that cross each point. The amount of diffusion is shown by the character of the shadow. Daylight on a cloudy day may be considered perfectly diffused; it produces no shadows whatever. The light from the electric arc is least diffused, since it emanates from a very small surface; the shadows cast by it have almost perfectly sharp outlines. It is largely due to its high state of diffusion that daylight, though vastly more intense than any artificial illumination, is the easiest of all lights on the eyes. It is a common and serious mistake, in case of weak or overstrained eyes, to reduce the intensity of the light, instead of increasing the diffusion."

Quality of Light.—"Aside from difference in intensity, light produces many different effects upon the optic nerves and their centers in the brain. These different impressions we ascribe to difference in the quality of the light. Thus, 'hard light,' 'cold light,' 'mellow light,' 'ambient light,' etc., designate various qualities. Quality in light is exactly analogous to timber or quality in sound, which is likewise independent of intensity. The most obvious differences in quality are plainly those called color. But color is by no means the element of quality. The proportion of invisible rays and the state of diffusion, are highly important factors, but on account of not being directly visible, they have been generally overlooked, and are but imperfectly understood."

Luminosity of Incandescent Lamps.

As showing the quality of incandescent light, we present here a curve showing the relative luminosity of an incandescent lamp at different regions of the visible spectrum.

On this subject Mr. E. L. Nichols states the following :

"The most important wave lengths, so far as light-giving power is concerned, are those which form the yellow of the spectrum, and the relative luminosity falls off rapidly both toward the red and the violet. The longer waves have, however, much more influence upon the candle-power than the more refrangible rays.

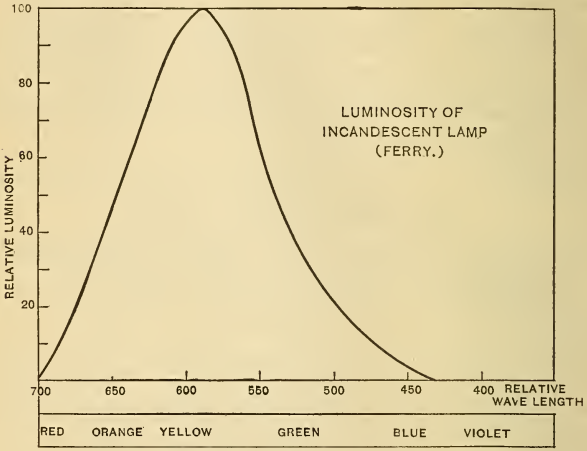


FIG. 6. Regions of Spectrum.

"Luminosity is the factor which we must take into account in seeking a complete expression for the efficiency of any source of illumination, and the method to be pursued in the determination of luminosity must depend upon the use to which the light is applied. If we estimate light by its power of bringing out the colors of natural objects, the value which we place upon the blue and violet rays must be very different from that which would be ascribed to them if we consider merely their power of illumination as applied to black and white. In a picture gallery, for instance, or upon the stage, the value of an illuminant increases with the temperature of the incandescent material out of all proportion to the candle-power, whereas, candle-power affords an excellent measure of the light to be used in a reading room."

Relative Value of Arc and Incandescent Lighting.

The relative value of the arc and incandescent systems of lighting is frequently difficult to determine. Incandescent lamps have the advantage that they can be distributed so as to avoid the shadows necessarily cast by one single source of light. Arc lamps used indoors with ground or opal globes cutting off half the light, have an efficiency not greater than two or three times that of an incandescent lamp. Nine 50 watt, 16 candle-power lamps consume the same power as one full 450 watt arc lamp. It has been found that unless an area is so large as to require 200 or 300 incandescent lights distributed over it, arc lamps requiring equal total power will not light the area with as uniform brilliancy.

The Correct Use of Light.

How to Avoid Harmful Effects on the Eyes.—An objection frequently urged against the incandescent lamp is that it is harmful to the eyes and ruins the sight. This is true only in so far as the lamp may be improperly used. Any form of light as frequently misused would produce the same harmful results. Few people think of attempting to read by an unshaded oil lamp, and yet many will sit in the glare of a clear glass incandescent lamp. Incandescent lamps are more generally complained of, because, unlike oil or gas, they can be used in any position. Bookkeepers and clerks are often seen with an incandescent lamp at the end of a drop hanging directly in front of their eyes—an impossible position of the light from gas or oil.

The first hygienic consideration in artificial lighting is to avoid the use of a single bright light in a poorly illuminated room. In working under such a light the eye is adapted to the surrounding darkness, and yet there is one spot in the middle of the eye that is kept constantly fixed on the very bright light. The brilliancy of the single light acting on the eye adjusted to darkness, works harm. There should be a general illumination of the room in addition to any necessary local light. If sufficient general illumination is provided, the eye is adjusted to the light, and the local light can be safely used. The ideal arrangement provides general illumination so strong that a pencil placed on the page of a book casts two shadows of nearly equal intensity—one coming from the general light and the other from the local light.

Care should also be taken to prevent direct rays from striking the eye. The light that reaches the eye by day is always reflected. In reading or writing, to avoid shadows, the light should come over the left shoulder. Only the reflected rays can then reach the eye.

Another point to be avoided is the careless, general use of clear glass, unshaded lamps. Frosted bulbs should be used in place of clear glass where soft light for reading is required. The intensity of light reflected from a small source is increased, and intense light injures the eye. With a clear glass globe the whole volume of light proceeds directly from the small surface of the lamp filament. With a frosted bulb the light is radiated from the whole surface of the bulb, and while the total illuminating effect is practically undiminished, the light is softened by diffusion, to the great comfort and relief of the eyes.

Finally, the use of old, dim, and blackened lamps, giving but a small fraction of their proper light, is very often a source of trouble in not supplying a sufficient quantity of light. Users of lamps are not otfen aware of the loss in candle-power a lamp undergoes, and so it happens that lamps are retained in use long after their efficient light-giving power has vanished. Proper attention to lamp renewals on the part of Central Stations is necessary to correct this evil.

The correct use of light requires:

That there should be general illumination in addition to the light near at hand.

That only reflected light should reach the eye. The light should be so placed as to throw the direct rays on the book or work, and not in the eye.

That the light should be placed so that shadows will not fall on the work in hand.

That shades and frosted bulbs should be used to soften the light.

That lamps be frequently renewed to keep the light up to full candle-power.

Life of Incandescent Lamps.

In the early days that lamp which had the longest life was said to be the best; the desideratum, however, as has been seen, is not long life, but constancy of candle-power (combined with high efficiency and low cost) during the period of use up to the smashing point. If an initial efficiency too high be adopted, the constancy is inferior; to prove this, Messrs. Siemens and Halske have made a number of tests, obtaining the following net results:

1½ initial watts rose to 4.46 watts after burning 55 hours.
2 initial watts rose to 3.99 watts after 90 hours.
2½ initial watts rose to 3.58 watts after 150 hours.

The table below contains the mean values of tests of more than 500 lamps of 49 different types, and taken from 28 different factories; The watts per candle-power and fall of candle-power are given.

Table of Average Candle-Power and Efficiency of Lamps at Different Periods of their Lives.

Hours after Start.	Initial Consumption in Watts.									
	2.0 to 2.5		2.5 to 3.0		3.0 to 3.5		3.5 to 4.0		4.0 upwards.	
	C. P. in %	Watts per c.p.	C.P. in %	Watts per c.p.	C.P. in %	Watts per c.p.	C.P. in %	Watts per c.p.	C.P. in %	Watts per c.p.
0	100	2.4	100	2.9	100	3.3	100	3.8	100	4.5
100	84	2.8	93	3.0	95	3.4	96	4.1	96	4.7
200	70	3.3	85	3.3	91	3.5	91	4.3	92	4.9
300	59	3.7	81	3.5	88	3.6	86	4.5	87	5.2
400	53	4.2	76	3.8	84	3.7	81	4.7	82	5.4
500	48	4.6	71	4.0	79	3.9	77	5.0	75	5.8
600	45	4.8	67	4.2	76	4.1	73	5.3	72	6.1
700	41	5.2	64	4.4	72	4.2	69	5.6	68	6.4
800	39	5.3	62	4.7	69	4.4	66	5.9	65	6.8
900	38	5.5	59	5.0	67	4.7	63	6.1	62	6.9
1000	37	5.7	56	5.3	64	5.0	60	6.3	60	7.0
1100	36	5.7	53	6.0	62	5.4	58	6.5	58	7.1
1200	35	5.8	50	6.3	59	5.6	46	6.7	56	7.1

Distribution of Light by Incandescent Lamps.

The best form of lighting interiors is to have single lamps uniformly distributed over the ceiling; unless the room has been especially designed with this in view, it is sometimes difficult to accomplish.

Another method giving most excellent results, but requiring more candle-power, is the arrangement of lamps around the sides of the room close to the ceiling. If the walls and ceiling are of a light color, this method is quite satisfactory, and easier to wire.

If the chandeliers, or more correctly in this case, electroliers, are used, it is best to have but one main or large one in the room, balancing the light by side brackets.

All such suspended lights should be above the line of vision as far as convenient.

The most economical distribution as far as candle-power necessary is the first mentioned, where lights are evenly distributed over the ceiling, to obtain the same luminosity by using clusters of lamps more widely distributed instead of single ones, will require much more candle-power.

The 16 candle-power lamp is the universal standard in the United States when rating lamps or illumination, and the following table gives the basis on which illumination of different classes of buildings is figured.

Ordinary illumination, 1 lamp, 8 feet from floor for 100 square feet, as in sheds, depots, walks, etc.

In waiting-rooms, ferry-houses, etc., 1 lamp for 75 square feet.

In stores, offices, etc., 1 lamp for 60 square feet.

Of course the above must be varied to suit the circumstances, such as dark walls or other surroundings requiring more light, as the walls reflect little of that furnished; and in rooms with dead white walls the reflection approaches 90 per cent and less lamps would be required than in interiors having worse reflecting surfaces.

A very ingenious and satisfactory method of illuminating high arched and vaulted interiors, developed first by Mr. I. R. Prentiss of the Brush Company, is to place a number of lamps around the lower edge of the arch or dome, with reflectors under them, and so located behind the cornice as to be invisible to the eye from the floor.

The dome or arch will reflect a large part of the light so placed, giving a very fine even illumination to the whole interior, without shadows, and very restful to the eye.

Of course the arch must be of good color for reflecting the light, or much of it will be wasted.

Equivalent Rates for Incandescent Lighting.

(Buckley.)

Gas per 1000 Cubic Feet.	Without Lamp Renewals.			Including Renewals.		
	Sixteen Candle-Power Lamp per Hour.	Sixteen Candle-Power Lamp, per Month.	1000 Watt Hours.	Sixteen Candle-Power Lamp, per Hour.	Sixteen Candle-Power Lamp, per Month.	1000 Watt Hours.
$1.00	$0.005	$0.42	$0.10	$0.0056	$0.47	$0.12
1.20	.006	.50	.12	.0066	.55	.14
1.40	.007	.58	.14	.0076	.63	.16
1.50	.0075	.63	.15	.0081	.68	.17
1.60	.008	.67	.16	.0086	.72	.18
1.80	.009	.75	.18	.0096	.80	.20
2.00	.01	.83	.20	.0106	.88	.22
2.20	.011	.92	.22	.0116	.97	.24
2.40	.012	1.00	.24	.0126	1.05	.26
2.50	.0125	1.04	.25	.0131	1.09	.27
2.60	.013	1.08	.26	.0136	1.13	.28
2.80	.014	1.17	.28	.0146	1.22	.30
3.00	.015	1.25	.30	.0156	1.27	.32
3.20	.016	1.34	.32	.0166	1.30	.34
3·40	.017	1.42	.34	.0176	1.39	.36
3.50	.0175	1.46	.35	.0181	1.47	.37
3.60	.018	1.50	.36	.0186	1.55	.38
3.80	.019	1.58	.38	.0196	1.63	.40
4.00	.02	1.67	.40	.0206	1.72	.42
4.50	.0225	1.88	.45	.0231	1.93	.47
5.00	.025	2.08	.50	.0256	2.14	.52

Cost of Producing Electric Light.

No very general investigation has yet been made on this subject in the United States, and few outside the Edison Companies have good facilities for determining the cost. Buckley gives the following:

"The profits on electric lighting depend primarily on the average number of hours the lamps burn. Under usual conditions (supplying incandescent current through meter including lamp renewals) the cost per lamp per hour averages as follows:

Average Cost of Arc and Incandescent Lamps per Hour.

(Buckley.)

Length Time Burning.	Cost 16 Candle-Power Lamp, per Hour.	Cost 2000 Candle-power Arc, per Hour.	Cost 1200 Candle-power Arc, per Hour,
½ Hour each day	$.02	$0.16	$0.14
1 Hour each day	.0112	.08½	.07¼
2 Hours each day . . .	.0062	.05	.04¼
3 Hours each day . . .	.0046	.04	.03½
4 Hours each day . . .	.0037	.03½	.03
5 Hours each day . . .	.0032	.03	.02½
6 Hours each day . . .	.0028	.02¾	.02¼
7 Hours each day . . .	.0026	.02½	.02⅛
8 Hours each day . . .	.0025	.02¼	.02
9 Hours each day . . .	.0024	.02⅛	.01⅞
10 Hours each day . . .	.0022	.02	.01¾

Notes: —

An incandescent lamp gives off from ⅕ to $\frac{1}{10}$ the heat of an equivalent gas-jet.

An arc lamp gives off from $\frac{1}{20}$ to $\frac{1}{40}$ as much heat as gas-jets producing an equal light.

A 5-foot (16 c.p.) gas-jet vitiates as much air as four men.

LIGHTING SCHEDULES.

General Rule for Construction of Schedules.

Moonlight Schedules. — Start lamps one half hour after sunset until fourth night of new moon; start lamps one hour before moonset.

Extinguish lamps one hour before sunrise, or one hour after moonrise.

No light the night before, the night of, and the night after full moon.

During summer months there will be found nights near that of full moon when, under the rule, the time of lighting would be very short. It may not be positively necessary to light up during such times.

If better service be desired, but not full every night and all-night service; lamps can be started at sunset and run to 12 or 1 o'clock on full-time schedule, and after 12 or 1 on the moonlight basis.

The above rules by Alex. C. Humphreys, M.E., have been modified by Frund as follows: Light every night from dusk to 12 o'clock; after 12 o'clock follow Humphrey's rule for moonlight schedule, excepting there will be no light after 12 o'clock during the three nights immediately preceding full moon.

All-Night, Every-Night Schedule. — Start lamps one half hour after sunset, and extinguish them one half hour before sunrise every day in the year. Full schedule commonly called 4000 hours for the year.

All the above rules serve to make schedules for any locality, and such schedules must be based on *sun time* for the locality, and not on *standard time.*

Permanent average schedules are used in New York City, but for other cities they are usually made up fresh every year.

Following will be found New York City time tables, also another set by Humphreys that is a good average for *sun time* in any locality.

Lighting Table for New York City.

Night of	JANUARY.			FEBRUARY.			MARCH.			APRIL.			MAY.			JUNE.		
	Light.	Extinguish.	Time Burning.	Light.	Extinguish.	Time Burning.	Light.	Extinguish.	Time Burning.	Light.	Extinguish.	Time Burning.	Light.	Extinguish.	Time Burning.	Light.	Extinguish.	Time Burning.
	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.
1	5.14	6.54	13.40	5.48	6.39	12.51	6.22	6.02	11.40	6.54	5.14	10.20	7.26	4.27	9.01	7.54	4.01	8.07
2	5.15	6.54	13.39	5.49	6.37	12.48	6.23	6.01	11.38	6.56	5.12	10.16	7.27	4.26	8.59	7.55	4.01	8.06
3	5.16	6.54	13.38	5.50	6.36	12.46	6.24	5.59	11.35	6.57	5.10	10.13	7.28	4.24	8.56	7.56	4.00	8.04
4	5.17	6.54	13.37	5.52	6.35	12.43	6.25	5.58	11.33	6.58	5.08	10.10	7.29	4.23	8.54	7.56	4.00	8.04
5	5.18	6.54	13.36	5.53	6.34	12.41	6.26	5.57	11.31	6.59	5.06	10.07	7.30	4.22	8.52	7.57	3.59	8.02
6	5.19	6.54	13.35	5.54	6.33	12.39	6.27	5.55	11.28	7.00	5.04	10.04	7.31	4.21	8.50	7.57	3.59	8.02
7	5.20	6.54	13.34	5.55	6.32	12.37	6.29	5.54	11.25	7.01	5.03	10.02	7.32	4.20	8.48	7.58	3.58	8.00
8	5.21	6.54	13.33	5.56	6.31	12.35	6.30	5.52	11.22	7.02	5.01	9.59	7.33	4.19	8.46	7.58	3.58	8.00
9	5.22	6.54	13.32	5.58	6.30	12.32	6.31	5.50	11.19	7.03	4.59	9.56	7.34	4.18	8.44	7.59	3.58	7.59
10	5.23	6.53	13.30	5.59	6.29	12.30	6.32	5.48	11.16	7.04	4.58	9.54	7.35	4.17	8.42	8.00	3.58	7.58
11	5.24	6.53	13.29	6.00	6.28	12.28	6.33	5.46	11.13	7.05	4.56	9.51	7.36	4.16	8.40	8.00	3.58	7.58
12	5.25	6.53	13.28	6.01	6.27	12.26	6.34	5.45	11.11	7.06	4.55	9.49	7.37	4.15	8.38	8.01	3.58	7.57
13	5.26	6.52	13.26	6.03	6.24	12.21	6.35	5.43	11.08	7.07	4.54	9.47	7.38	4.14	8.36	8.01	3.58	7.57
14	5.27	6.52	13.25	6.04	6.23	12.19	6.36	5.42	11.06	7.08	4.52	9.44	7.39	4.13	8.34	8.02	3.58	7.56
15	5.28	6.52	13.24	6.06	6.21	12.15	6.37	5.40	11.03	7.09	4.51	9.42	7.40	4.12	8.32	8.02	3.58	7.56
16	5.29	6.51	13.22	6.07	6.20	12.13	6.38	5.39	11.01	7.10	4.49	9.39	7.41	4.12	8.31	8.02	3.58	7.56
17	5.30	6.51	13.21	6.08	6.19	12.11	6.39	5.37	10.58	7.11	4.47	9.36	7.41	4.11	8.30	8.03	3.58	7.55
18	5.31	6.50	13.19	6.10	6.18	12.08	6.40	5.35	10.55	7.12	4.46	9.34	7.42	4.10	8.28	8.03	3.58	7.55
19	5.33	6.49	13.16	6.11	6.16	12.05	6.41	5.33	10.52	7.13	4.44	9.31	7.43	4.10	8.27	8.03	3.58	7.55
20	5.34	6.48	13.14	6.13	6.15	12.02	6.42	5.32	10.50	7.14	4.43	9.29	7.44	4.09	8.25	8.03	3.58	7.55
21	5.35	6.48	13.13	6.14	6.12	11.58	6.43	5.31	10.48	7.15	4.42	9.27	7.45	4.08	8.23	8.04	3 58	7.54
22	5.36	6.47	13.11	6.15	6.11	11.56	6.44	5.30	10.46	7.16	4.40	9.24	7.46	4.07	8.21	8.04	3.58	7.54
23	5.37	6.46	13.09	6.17	6.09	11.52	6.45	5.28	10.43	7.17	4.39	9.22	7.47	4.06	8.19	8.04	3.58	7.54
24	5.39	6.45	13.06	6.18	6.08	11.50	6.46	5.26	10.40	7.18	4.37	9.19	7.48	4.05	8.17	8.04	3.59	7.55
25	5.40	6.45	13.05	6.19	0.07	11.48	6.47	5.24	10.37	7.19	4.36	9.17	7.49	4.05	8.16	8.04	3.59	7.55
26	5.41	6.44	13.03	6.20	6.06	11.46	6.48	5.23	10.35	7.20	4.35	9.15	7.49	4.04	8.15	8.05	4.00	7.55
27	5.42	6.43	13.01	6.21	6.05	11.44	6.49	5.22	10.33	7.22	4.33	9.11	7.50	4.04	8.14	8.05	4.00	7.55
28	5.43	6.42	12.59	6.22	6.04	11.42	6.50	5.20	10.30	7.23	4.32	9.09	7.51	4.03	8.12	8.05	4.00	7.55
29	5.45	6.42	12.57	6.22	6.03	11.41	6.51	5.18	10.27	7.24	4.30	9.06	7.52	4.03	8.11	8.05	4.01	7.56
30	5.46	6.41	12.55	. . .	. . .	. . .	6.52	5.16	10.24	7.25	4.29	9.04	7.53	4.02	8.09	8.05	4.01	7.56
31	5.47	6.40	12.53	. . .	. . .	. . .	6.53	5.15	10.22	. . .	. . .	. . .	7.53	4.02	8.09	. . .	. . .	. . .
			413.10			355.27			341.29			290.17			264.39			238.51

Lighting Table for New York City — *Continued.*

Night of	JULY.			AUGUST.			SEPTEMBER.			OCTOBER.			NOVEMBER.			DECEMBER.		
	Light.	Extinguish.	Time Burning.	Light.	Extinguish.	Time Burning.	Light.	Extinguish.	Time Burning.	Light	Extinguish.	Time Burning.	Light.	Extinguish.	Time Burning.	Light.	Extinguish.	Time Burning.
	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.
1	8.04	4.02	7.58	7.46	4.26	8.40	7.03	4.58	9.55	6.13	5.27	11.14	5.27	6.01	12.34	5.04	6.36	13.32
2	8.04	4.03	7.59	7.45	4.27	8.42	7.01	4.59	9.58	6.11	5.28	11.17	5.26	6.02	12.36	5.04	6.37	13.33
3	8.04	4.03	7.59	7.44	4.28	8.44	7.00	5.00	10.00	6.10	5.30	11.20	5.25	6.03	12.38	5.04	6.38	13.34
4	8.03	4.04	8.01	7.43	4.29	8.46	6.58	5.01	10.03	6.08	5.31	11.23	5.24	6.05	12.41	5.03	6.39	13.36
5	8.03	4.05	8.02	7.41	4.30	8.49	6.56	5.02	10.06	6.07	5.32	11.25	5.23	6.06	12.43	5.03	6.40	13.37
6	8.03	4.05	8.02	7.40	4.31	8.51	6.54	5.03	10.09	6.05	5.33	11.28	5.21	6.08	12.47	5.03	6.41	13.38
7	8.03	4.06	8.03	7.39	4.32	8.53	6.53	5.04	10.11	6.03	5.34	11.31	5.20	6.09	12.49	5.03	6.42	13.39
8	8.02	4.07	8.05	7.37	4.33	8.56	6.51	5.05	10.14	6.02	5.35	11.33	5.19	6.10	12.51	5.03	6.43	13.40
9	8.02	4.07	8.05	7.36	4.34	8.58	6.49	5.06	10.17	6.00	5.36	11.36	5.18	6.12	12.54	5.03	6.44	13.41
10	8.02	4.08	8.06	7.35	4.35	9.00	6.47	5.07	10.20	5.58	5.37	11.39	5.17	6.13	12.56	5.03	6.45	13.42
11	8.01	4.09	8.08	7.34	4.36	9.02	6.46	5.08	10.22	5.57	5.38	11.41	5.16	6.14	12.58	5.03	6.46	13.43
12	8.01	4.10	8.09	7.33	4.37	9.04	6.44	5.09	10.25	5.55	5.39	11.44	5.15	6.16	13.01	5.03	6.47	13.44
13	8.00	4.10	8.10	7.31	4.38	9.07	6.43	5.10	10.27	5.54	5.40	11.46	5.14	6.17	13.03	5.03	6.48	13.45
14	8.00	4.11	8.11	7.30	4.39	9.09	6.41	5.11	10.30	5.52	5.41	11.49	5.13	6.18	13.05	5.03	6.48	13.45
15	7.59	4.12	8.13	7.28	4.40	9.12	6.39	5.12	10.33	5.51	5.42	11.51	5.12	6.19	13.07	5.04	6.49	13.45
16	7.59	4.13	8.14	7.27	4.41	9.14	6.37	5.13	10.36	5.49	5.43	11.54	5.11	6.20	13.09	5.04	6.49	13.45
17	7.58	4.14	8.16	7.26	4.42	9.16	6.35	5.14	10.39	5.47	5.45	11.58	5.10	6.21	13.11	5.04	6.50	13.46
18	7.58	4.15	8.17	7.25	4.43	9.18	6.34	5.14	10.40	5.46	5.46	12.00	5.10	6.22	13.12	5.04	6.50	13.46
19	7.57	4.15	8.18	7.24	4.44	9.20	6.32	5.15	10.43	5.44	5.47	12.03	5.09	6.23	13.14	5.05	6.51	13.46
20	7.56	4.16	8.20	7.23	4.45	9.22	6.31	5.16	10.45	5.43	5.48	12.05	5.08	6.24	13.16	5.05	6.51	13.46
21	7.56	4.17	8.21	7.21	4.46	9.25	6.30	5.17	10.47	5.42	5.49	12.07	5.08	6.25	13.17	5.06	6.52	13.46
22	7.55	4.18	8.23	7.20	4.47	9.27	6.28	5.18	10.50	5.41	5.50	12.09	5.07	6.28	13.21	5.66	6.52	13.46
23	7.54	4.19	8.25	7.18	4.48	9.30	6.26	5.19	10.53	5.39	5.51	12.12	5.06	6.29	13.23	5.07	6.52	13.45
24	7.53	4.20	8.27	7.16	4.49	9.33	6.24	5.20	10.56	5.38	5.52	12.14	5.06	6.30	13.24	5.07	6.52	13.45
25	7.52	4.21	8.29	7.13	4.50	9.37	6.23	5.21	10.58	5.36	5.53	12.17	5.05	6.31	13.26	5.08	6.53	13.45
26	7.51	4.22	8.31	7.12	4.51	9.39	6.21	5.22	11.01	5.35	5.54	12.19	5.05	6.32	13.27	5.08	6.53	13.45
27	7.50	4.23	8.33	7.11	4.52	9.41	6.19	5.23	11.04	5.33	5.55	12.22	5.05	6.32	13.27	5.09	6.53	13.44
28	7.49	4.24	8.35	7.09	4.53	9.44	6.18	5.24	11.06	5.32	5.56	12.24	5.05	6.33	13.28	5.09	6.53	13.44
29	7.48	4.24	8.36	7.08	4.54	9.46	6.16	5.25	11.09	5.30	5.57	12.27	5 04	6.34	13.30	5.10	6.54	13.44
30	7.48	4.25	8.37	7.06	4.55	9.49	6.15	5.26	11.11	5.29	5.59	12.30	5.04	6.35	13.31	5.11	6.54	13.43
31	7.47	4.26	8.39	7.05	4.57	9.52	. . .	. . .	. . .	5.28	6.00	12.32	. . .	. . .	. . .	5.12	6.54	13.42
			256.12			286.26			316.48			368.50			392.59			424.52

Summary of New York City Lighting Table.

	Hours for the Month.	Average.	Average Day.
	h.m.	h.m.	
January	413.10	13.19	18th
February	355.27	12.15	15th
March	341.29	11.01	16th
April	290.17	9.40	16th
May	264.39	8.32	15th
June	238.51	7.57	12th
July	256.12	8.16	17th
August	286.26	9.14	16th
September	316.48	10.33	15th
October	368.50	11.54	16th
November	392.59	13.05	14th
December	424.52	13.42	10th
Total hours	3950		
		h.m.	
Shortest	June 21	7.54	
Longest	Dec. 21	13.46	
Average	Mar. 21 & Sept. 21	10.47	

NOTE.—*Lights started 30 minutes after sunset. Lights stopped 30 minutes before sunrise.*

For commercial lighting: add 1 hour for part night lights, add 2 hours for all night lights to above schedule.

Table Showing Hours of Lighting Throughout a Year of 8760 Hours.

Daily Lighting.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total per Annum.
From sundown to 8 p.m.	125	89	67	36	6	...	...	21	54	87	117	140	742
" " " 9 "	156	117	98	66	37	20	25	52	84	118	147	171	1091
" " " 10 "	187	145	129	96	68	50	56	83	114	149	177	202	1456
" " " 11 "	218	173	160	126	99	80	87	114	144	180	207	233	1821
" " " midnight	249	201	191	156	130	110	118	145	174	211	237	264	2186
" " " 2 a.m.	311	257	253	216	192	170	180	207	234	273	297	326	2916
" " " 4 "	373	313	315	276	254	230	242	269	294	335	357	388	3646
From 4 a.m. to sunrise	125	92	69	32	3	...	..	24	51	75	103	154	728
" 5 " " "	94	64	38	2	...	...	...	...	21	44	73	123	459
" 6 " " "	63	36	7	...	...	...	...	...	...	13	43	63	254

Humphreys' Lighting Tables.

(All Night, Every Night Schedule.)

JANUARY.

Day of Month.	Light.	Extinguish.	Number of Hours.
	h.m.	h.m.	h.m.
1	4.40	6.30	13.50
2	4.40	6.30	13.50
3	4.40	6.30	13.50
4	4.50	6.30	13.40
5	4.50	6.30	13.40
6	4.50	6.20	13.30
7	4.50	6.20	13.30
8	4.50	6.20	13.30
9	4.50	6.20	13.30
10	4.50	6.20	13.30
11	4.50	6.20	13.30
12	4.50	6.20	13.30
13	4.50	6.20	13.30
14	5.00	6.20	13.20
15	5.00	6.20	13.20
16	5.00	6.20	13.20
17	5.00	6.20	13.20
18	5.00	6.20	13.20
19	5.00	6.20	13.20
20	5.00	6.20	13.20
21	5.00	6.20	13.20
22	5.10	6.20	13.10
23	5.10	6.20	13.10
24	5.10	6.20	13.10
25	5.10	6.20	13.10
26	5.10	6.20	13.10
27	5.10	6.10	13.00
28	5.10	6.10	13.00
29	5.10	6.10	13.00
30	5.10	6.10	13.00
31	5.20	6.10	12.50
Total number of hours .			414.10

FEBRUARY.

Day of Month.	Light.	Extinguish.	Number of Hours.
	h.m.	h.m.	h.m.
1	5.20	6.10	12.50
2	5.20	6.10	12.50
3	5.20	6.10	12.50
4	5.20	6.10	12.50
5	5.20	6.10	12.50
6	5.20	6.00	12.40
7	5.20	6.00	12.40
8	5.30	6.00	12.30
9	5.30	6.00	12.30
10	5.30	6.00	12.30
11	5.30	6.00	12.30
12	5.30	6.00	12.30
13	5.30	6.00	12.30
14	5.30	5.50	12.20
15	5.30	5.50	12.20
16	5.40	5.50	12.10
17	5.40	5.50	12.10
18	5.40	5.50	12.10
19	5.40	5.50	12.10
20	5.40	5.50	12.10
21	5.40	5.40	12.00
22	5.40	5.40	12.00
23	5.40	5.40	12.00
24	5.40	5.40	12.00
25	5.50	5.40	11.50
26	5.50	5.40	11.50
27	5.50	5.40	11.50
28	5.50	5.30	11.40
Total number of hours . . .			345.10

MARCH.

Day of Month.	Light.	Extinguish.	Number of Hours.
	h.m.	h.m.	h.m.
1	5.50	5.30	11.40
2	5.50	5.30	11.40
3	5.50	5.30	11.40
4	5.50	5.30	11.40
5	6.00	5.30	11.30
6	6.00	5.20	11.20
7	6.00	5.20	11.20
8	6.00	5.20	11.20
9	6.00	5.20	11.20
10	6.00	5.20	11.20
11	6.00	5.20	11.20
12	6.00	5.20	11.20
13	6.00	5.10	11.10
14	6.10	5.10	11.00
15	6.10	5.10	11.00
16	6.10	5.10	11.00
17	6.10	5.10	11.00
18	6.10	5.10	11.00
19	6.10	5.00	10.50
20	6.10	5.00	10.50
21	6.10	5.00	10.50
22	6.10	5.00	10.50
23	6.10	5.00	10.50
24	6.20	5.00	10.40
25	6.20	4.50	10.30
26	6.20	4.50	10.30
27	6.20	4.50	10.30
28	6.20	4.50	10.30
29	6.20	4.50	10.50
30	6.20	4.50	10.30
31	6.20	4.40	10.20
Total number of hours . .			341.50

Humphreys' Lighting Tables — *Continued.*

(*All Night, Every Night Schedule.*)

APRIL.				MAY.				JUNE.			
Day of Month.	Light.	Extinguish.	Number of Hours.	Day of Month.	Light.	Extinguish.	Number of Hours.	Day of Month.	Light.	Extinguish.	Number of Hours.
	h.m.	h.m.	h.m.		h.m.	h.m.	h.m.		h.m.	h.m.	h.m.
1	6.20	4.40	10.20	1	7.00	4.00	9.00	1	7.20	3.30	8.10
2	6.30	4.40	10.10	2	7.00	4.00	9.00	2	7.20	3.30	8.10
3	6.30	4.40	10.10	3	7.00	3.50	8.50	3	7.30	3.30	8.00
4	6.30	4.40	10.10	4	7.00	3.50	8.50	4	7.30	3.30	8.00
5	6.30	4.40	10.10	5	7.00	3.50	8.50	5	7.30	3.30	8.00
6	6.30	4.30	10.00	6	7.00	3.50	8.50	6	7.30	3.30	8.00
7	6.30	4.30	10.00	7	7.00	3.50	8.50	7	7.30	3.30	8.00
8	6.30	4.30	10.00	8	7.00	3.50	8.50	8	7.30	3.30	8.00
9	6.30	4.30	10.00	9	7.00	3.50	8.50	9	7.30	3.30	8.00
10	6.30	4.30	10.00	10	7.00	3.50	8.50	10	7.30	3.30	8.00
11	6.30	4.30	10.00	11	7.10	3.50	8.40	11	7.30	3.30	8.00
12	6 40	4.20	9.40	12	7.10	3.50	8.40	12	7.30	3.30	8.00
13	6.40	4.20	9.40	13	7.10	3.40	8.30	13	7.30	3.30	8.00
14	6.40	4.20	9.40	14	7.10	3.40	8.30	14	7.30	3.30	8.00
15	6.40	4.20	9.40	15	7.10	3.40	8.30	15	7.30	3.30	8.00
16	6.40	4.20	9.40	16	7.10	3.40	8.30	16	7.30	3.30	8.00
17	6.40	4.20	9.40	17	7.10	3.40	8.30	17	7.30	3.30	8.00
18	6.40	4.20	9.40	18	7.10	3.40	8.30	18	7.30	3.30	8.00
19	6.40	4.10	9.30	19	7.10	3.40	8.30	19	7.30	3.30	8.00
20	6.40	4.10	9.30	20	7.10	3.40	8.30	20	7.30	3.30	8.00
21	6.40	4.10	9.30	21	7.20	3.40	8.20	21	7.30	3.30	8.00
22	6.50	4.10	9.20	22	7.20	3.40	8.26	22	7.30	3.30	8.00
23	6.50	4.10	9.20	23	7.20	3.40	8.20	23	7.30	3.30	8.00
24	6.50	4.10	9.20	24	7.20	3.40	8.20	24	7.30	3.30	8.00
25	6.50	4.10	9.20	25	7.20	3.30	8.10	25	7.30	3.30	8.00
26	6.50	4.00	9.10	26	7.20	3.30	8.10	26	7.30	3.30	8.00
27	6.50	4.00	9.10	27	7.20	3.30	8.10	27	7.30	3.30	8.00
28	6.50	4.00	9.10	28	7.20	3.30	8.10	28	7.30	3.30	8.00
29	6.50	4.00	9·10	29	7.20	3.30	8.10	29	7.30	3.30	8.00
30	6.50	4.00	9.10	30	7.20	3.30	8.10	30	7.30	3.30	8.00
				31	7.20	3.30	8.10				
Total number of hours .			290.20	Total number of hours . . .			264.30	Total number of hours . .			240.20

Humphreys' Lighting Tables — *Continued.*

(All Night, Every Night Schedule.)

July.				August.				September.			
Day of Month.	Light.	Extinguish.	Number of Hours.	Day of Month.	Light.	Extinguish.	Number of Hours.	Day of Month.	Light.	Extinguish.	Number of Hours.
	h.m.	h.m.	h.m.		h.m.	h.m.	h.m.		h.m.	h.m.	h.m.
1	7.30	3.30	8.00	1	7.10	4.00	8.50	1	6.30	4.30	10.00
2	7.30	3.30	8.00	2	7.10	4.00	8.50	2	6.30	4.30	10.00
3	7.30	3.30	8.00	3	7.10	4.00	8.50	3	6.30	4.30	10.00
4	7.30	3.40	8.10	4	7.10	4.00	8.50	4	6.30	4.30	10.00
5	7.30	3.40	8.10	5	7.10	4.00	8.50	5	6.30	4.30	10.00
6	7.30	3.40	8.10	6	7.10	4.00	8.50	6	6.20	4.30	10.10
7	7.30	3.40	8.10	7	7.10	4.00	8.50	7	6.20	4.30	10.10
8	7.30	3.40	8.10	8	7.10	4.00	8.50	8	6.20	4.40	10.20
9	7.30	3.40	8.10	9	7.10	4.10	9.00	9	6.20	4.40	10.20
10	7.30	3.40	8.10	10	7.00	4.10	9.10	10	6.20	4.40	10.20
11	7.30	3.40	8.10	11	7.00	4.10	9.10	11	6.20	4.40	10.20
12	7.30	3.40	8.10	12	7.00	4.10	9.10	12	6.10	4.40	10.30
13	7.30	3.40	8.10	13	7.00	4.10	9.10	13	6.10	4.40	10.30
14	7.30	3.40	8.10	14	7.00	4.10	9.10	14	6.10	4.40	10.30
15	7.30	3.40	8.10	15	7.00	4.10	9.10	15	6.10	4.40	10.30
16	7.30	3.40	8.10	16	7.00	4.10	9.10	16	6.10	4.40	10.30
17	7.30	3.40	8.10	17	6.50	4.10	9.20	17	6.10	4.40	10.30
18	7.30	3.50	8.20	18	6.50	4.10	9.20	18	6.00	4.50	10.50
19	7.30	3.50	8.20	19	6.50	4.20	9.30	19	6.00	4.50	10.50
20	7.30	3.50	8.20	20	6.50	4.20	9.30	20	6.00	4.50	10.50
21	7.30	3.50	8.20	21	6.50	4.20	9.30	21	6.00	4.50	10.50
22	7.20	3.50	8.30	22	6.50	4.20	9.30	22	6.00	4.50	10.50
23	7.20	3.50	8.30	23	6.50	4.20	9.30	23	6.00	4.50	10.50
24	7.20	3.50	8.30	24	6.40	4.20	9.40	24	5.50	4.50	11.00
25	7.20	3.50	8.30	25	6.40	4.20	9.40	25	5.50	4.50	11.00
26	7.20	3.50	8.30	26	6.40	4.20	9.40	26	5.50	4.50	11.00
27	7.20	3.50	8.30	27	6.40	4.20	9.40	27	5.50	4.50	11.00
28	7.20	3.50	8.30	28	6.40	4.20	9.40	28	5.50	5.00	11.10
29	7.20	3.50	8.30	29	6.40	4.30	9.50	29	5.50	5.00	11.10
30	7.20	4.00	8.40	30	6.40	4.30	9.50	30	5.40	5.00	11.20
31	7.20	4.00	8.40	31	6.30	4.30	10.00				
Total number of hours			257.00	Total number of hours . . .			288.00	Total number of hours .			317.20

Humphreys' Lighting Tables — *Continued.*

(*All Night, Every Night Schedule.*)

OCTOBER.				NOVEMBER.				DECEMBER.			
Day of Month.	Light.	Extinguish.	Number of Hours.	Day of Month.	Light.	Extinguish.	Number of Hours.	Day of Month.	Light.	Extinguish.	Number of Hours.
	h.m.	h.m.	h.m.		h.m.	h.m.	h.m.		h.m.	h.m.	h.m.
1	5.40	5.00	11.20	1	5.00	5.30	12.30	1	4.30	6.10	13.40
2	5.40	5.00	11.20	2	5.00	5.30	12.30	2	4.30	6.10	13.40
3	5.40	5.00	11.20	3	4.50	5.30	12.40	3	4.30	6.10	13.40
4	5.40	5.00	11.20	4	4.50	5.40	12.50	4	4.30	6.10	13.40
5	5.40	5.00	11.20	5	4.50	5.40	12.50	5	4.30	6.10	13.40
6	5.30	5.00	11.30	6	4.50	5.40	12.50	6	4.30	6.10	13.40
7	5.30	5.00	11.30	7	4.50	5.40	12.50	7	4.30	6.10	13.40
8	5.30	5.10	11.40	8	4.50	5.40	12.50	8	4.30	6.10	13.40
9	5.30	5.10	11.40	9	4.50	5.40	12.50	9	4.30	6.10	13.40
10	5.30	5.10	11.40	10	4.50	5.40	12.50	10	4.30	6.10	13.40
11	5.30	5.10	11.40	11	4.50	5.40	12.50	11	4.30	6.20	13.50
12	5.20	5.10	11.50	12	4.40	5.50	13.10	12	4.30	6.20	13.50
13	5.20	5.10	11.50	13	4.40	5.50	13.10	13	4.30	6.20	13.50
14	5.20	5.10	11.50	14	4.40	5.50	13.10	14	4·30	6.20	13.50
15	5.20	5.10	11.50	15	4.40	5.50	13.10	15	4.30	6.20	13.50
16	5.20	5.10	11.50	16	4.40	5.50	13.10	16	4.30	6.20	13.50
17	5.20	5.20	12.00	17	4.40	5.50	13.10	17	4.30	6.20	13.50
18	5.20	5.20	12.00	18	4.40	5.50	13.10	18	4.30	6.20	13.50
19	5.10	5.20	12.10	19	4.40	5.50	13.10	19	4.30	6.20	13.50
20	5.10	5.20	12.10	20	4.40	5.50	13.10	20	4.40	6.20	13.40
21	5.10	5.20	12.10	21	4.40	6.00	13.20	21	4.40	6.20	13.40
22	5.10	5.20	12.10	22	4.40	6.00	13.20	22	4.40	6.20	13.40
23	5.10	5.20	12.10	23	4.40	6.00	13.20	23	4.40	6.20	13.40
24	5.10	5.20	12.10	24	4.40	6.00	13.20	24	4.40	6.20	13.40
25	5.10	5.20	12.10	25	4.40	6.00	13.20	25	4.40	6.20	13.40
26	5.00	5.30	12.30	26	4.30	6.00	13.30	26	4.40	6.20	13.40
27	5.00	5.30	12.30	27	4.30	6.00	13.30	27	4.40	6.20	13.40
28	5.00	5.30	12.30	28	4.30	6.00	13.30	28	4.40	6.20	13.40
29	5.00	5.30	12.30	29	4.30	6.00	13.30	29	4.40	6.20	13.40
30	5.00	5.30	12.30	30	4.30	6.10	13.40	30	4.40	6.20	13.40
31	5.00	5.30	12.30					31	4.40	6.20	13.40
Total number of hours .			369.40	Total number of hours . . .			393.10	Total number of hours .			425.10
								Total for year			3946.40

Hours of Lighting per Annum by Different Schedules.

Regular all-night schedule	4000 hours
New York City schedule	3950 hours
Philadelphia schedule	4288 hours
Providence schedule	4012 hours
Philadelphia moonlight schedule	2190 hours
Frund schedule	3000 hours

Hours of Burning Commercial Lights.

Time of Sunrise and Sunsets.

	Sun Sets.	Lights Start.	Used to 8 p.m.	Used to 9 p.m.	Used to 9.30 p.m.	Used to 10.00p.m.	Used to 11.00p.m.	Used to 12.00 m.	Sun Rises.	All night lights. L'ts go out.	All night lights. Us'd all n'gt.
	h.m	h.m	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.
Jan. 15	4.55	4.30	3.30	4.30	5.00	5.30	6.30	7.30	7.25	8.00	15.30
Feb. 15	5.31	5.00	3.00	4.00	4.30	5.00	6.00	7.00	6.56	7.30	14.30
Mar. 15	6.06	5.30	2.30	3.30	4.00	4.30	5.30	6.30	6.12	6.45	13.15
April 15	6.41	6.15	1.45	2.45	3.15	3.45	4.45	5.45	5.16	5.45	11.30
May 15	7.13	6.45	1.15	2.15	2.45	3.15	4.15	5.15	4.39	5.15	10.30
June 15	7.37	7.00	1.00	2.00	2.30	3.00	4.00	5.00	4.24	5.00	10.00
July 15	7.32	7.00	1.00	2.00	2.30	3.00	4.00	5.00	4.39	5.15	10.45
Aug. 15	7.00	6.30	1.30	2.30	3.00	3.30	4.30	5.30	5.08	5.45	11.45
Sept. 15	6.09	5.30	2.30	3.30	4.00	4.30	5.30	6.30	5.40	6.15	12.45
Oct. 15	5.19	4.45	3.15	4.15	4.45	5.15	6.15	7.15	6.13	6.45	14.00
Nov. 15	4.39	4.00	4.00	5.00	5.30	6.00	7.00	8.00	6.52	7.15	15.45
Dec. 15	4.31	4.00	4.00	5.00	5.30	6.00	7.00	8.00	7.20	7.45	15.45
Aver'ge for y'r	6.06	5.30	2.30	3.30	4.00	4.30	5.30	6.30	5.54	6.26	13.00

Graphic Lighting Schedule for London, England.

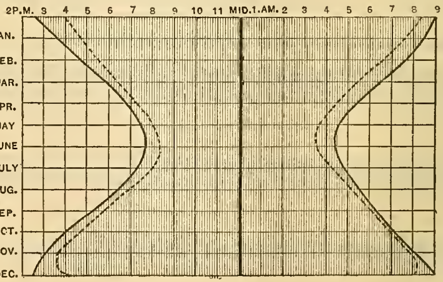


Fig. 7.—The shaded area represents the time during which light is required. The horizontal lines show the months of the year. The vertical lines show the hours of the day and night. The inner dotted lines show the time of sunset and sunrise. The outer lines show the time of lighting up and extinguishing. Each square is an hour month, *i.e.*, 30.4 hours.

ELECTRIC STREET RAILWAYS.

CARS, MOTORS, AND GRADES.

(From Pamphlet by S. H. Short, issued by Walker Company.)

Grades and sharp curves should of course be avoided as much as possible, but when unavoidable, the ascent of a 10 per cent or even a 12 per cent grade is possible to a car fitted with a double 15 h. p. or 20 h. p. equipment, and pulling no trailer. The grip of the wheels on the rails may be depended upon, with the aid of sand, to give from 250 to 300 pounds pull for each ton of weight upon them, in even the worst weather. On nearly level roads (having nothing steeper than a 2 per cent grade), a single 25 h. p. equipment will handle a car, and in a pinch pull a trailer. Ordinarily, however, it is not advisable to use a trail car with a single 20 h. p. equipment, as it makes a slow start and a slow maximum speed. A single 30 h. p. equipment should be able to handle a short car and trailer satisfactorily on roads with nothing greater than 2 per cent grades. While the power of a 30 h. p. motor could be depended upon to climb steeper grades, the adhesion of the wheels in bad weather cannot be. Single 20 or 30 h. p. equipments will handle 20 ft. or 22 ft. cars nicely, when no trailer is used, on as high as 4 per cent grades, and even steeper in good weather, the failure being, as previously explained, not in the power of the motor, but in the adhesion of the wheels to the rails. The 30 h. p. motor has the advantage of the 20 h. p. in giving a quicker start and higher speed on grades. Single motor equipments are, however, not advisable, on account of the liability of a single pair of drivers to slip in bad weather. They will prove especially annoying where snowstorms are of frequent occurrence, or where the track is liable to become icy. All long double-truck cars should have double equipments, as their greater weight requires greater power to bring them up to speed quickly, even on a level. On roads with over 4 per cent grades, whether it is proposed to haul trail cars or not, double equipments should be installed. A double 25 or 30 h. p. equipment will handle a trail car on a 6 per cent or 7 per cent grade, the advantage of the 30 h. p. motors again being the higher speed on grades and quicker start. On roads where the traffic is sufficient to warrant the use of trailers with short cars, but the grades exceed 7 per cent, long cars on double trucks, or radial trucks, with double-motor equipments should be substituted. These will climb nearly as steep grades as the smaller cars, without trailers. Long cars are not advisable except in the case just named, and on long runs where the stops are few, as the time required for the letting off and taking on of passengers is excessive.

Finally, on roads where traffic, such as fairs, base-ball games, etc., has to be handled, giving light loads most of the time, but few exceedingly heavy ones, the most economical arrangement is that of 30 h. p. double equipments, hauling two trailers, when the heavy traffic is to be handled. This combination can be depended upon for grades not exceeding 3 per cent in bad and 4 per cent in good weather.

CURVES.

A 30 ft. radius curve on grade adds about as much to the resistance of a car as 4 per cent additional grade. It will consequently be frequently found impossible to start on such a curve on grade in bad weather without sand. Sand boxes should, then, be a part of every car's equipment. Sharp curves on grade should always be avoided if possible, as they are the cause of great annoyance on wet or icy days.

STATION.

A station should never contain less than two dynamos. It is desirable also for the steam plant to be composed of two or more units if possible; but on very small roads, say under five cars, this is of course impracticable. The general plan of a station should be such that the disabling of one dynamo or engine could not cause a shut-down on the road. For roads of 15 cars or less, where the fluctuations of load are exceedingly violent, simple high-speed engines are undoubtedly to be preferred. As the road grows larger and the load more steady, simple Corliss engines will give a somewhat better steam consumption. On a road of 40 cars or more, compound condensing engines, of either the Corliss or high-speed type, in units of such size that at least one can be kept fairly loaded at all times, will be economical. Always condense either simple or compound engines when water for that purpose can be had plenty and cheap. Never use compound engines non-condensing. Considering the increased expense and complication, together with the difficulty in regulating under widely and suddenly varying loads, the economy of triple-expansion engines in railway work is doubtful.

The size of the engine should be always such as to give the maximum average efficiency with the variations of load in question. It should be noted here that this is not the same size engine which will give the maximum efficiency at the average load.

Where it is possible, belt directly from fly-wheels of engines to generator pulleys. Counter shafts give flexibility and make possible the use of larger steam units, but they consume a very appreciable amount of power, and are liable to give trouble otherwise.

Concerning the amount of power per car in generators and engines, no general rule can be laid down, as three variables, viz., grade resistances, curve resistances, and traffic, must be considered in this connection. 25 h. p. (rated at $\frac{1}{4}$–$\frac{1}{3}$ cut off), and 30 amperes per car for roads of 5 to 10 cars, and 20 h. p. with 25 amperes per car for larger roads, would probably cover the demands. This, however, should be considered only as a rough estimate. The question of the amount, character, and location of power should be settled for each road separately by a thoroughly competent engineer, as a small variation from correct principles and design in this respect is liable to considerably increase the running expenses. The whole design should be based on Sir Wm. Thomson's principle, namely, that "The interest on the investment and the cost of such losses as could have been avoided by larger investment should be equal."

SPECIFICATIONS vs. STANDARD TYPES.

The series motor can easily be designed to fill two conditions as to speed and power in the same machine, provided always that the condition for the lesser power calls also for the greater speed, and that these two requirements are not too near alike in speed when the powers called for vary widely or *vice versa* — too near alike in power when the speed varies widely.

Standard motors for street-railway work are now designed to give a 20-ft. loaded car a speed of from 20 to 22 miles per hour on a level, and to develop

NOTE. — In the selection of engines for electrical railway work, the best practice of to-day is to choose the engines in the same manner as for any other commercial manufacturing plant. For large installations, or where storage batteries are used for regulating the load, and so retaining fairly constant power requirements, the size and arrangement of the plant will determine whether the engines should be simple, compound, or triple expansion, and whether they should be run condensing or not, if water is available.

Engines should be designed with all shafts, pins, wearing surface, etc., heavy enough for the maximum loads or over loads, but their cylinders should be so proportioned that the average loads be secured at the most economical point of cut-off. This gives strength for heavy load and economy for average conditions.

Countershafts with friction clutches and pulleys are seldom installed to-day. Either direct-belted or direct-connected engines and dynamos are better, requiring less engine-room area, expense for real estate, building, etc., and reduce friction losses and cost of repairs. *J. S. G.*

their full rated capacity (of 20 h.p., 25 h.p., etc.), at a speed of 10 miles per hour, when mounted upon wheels of a specified diameter (generally 33 inch).

The voltage being kept the same, each speed corresponds to a certain horizontal effort or thrust at the circumference of the wheel, this horizontal effort increasing as the speed decreases. Therefore, for each different tractive resistance, be it due tc the condition of the track, to grade or curve, or to whatever cause, has for a given weight of car and load, a given speed which cannot be altered without altering at the same time the two speeds which the motor was originally designed to give. These speeds are most easily altered by changing the diameter of the wheel to a larger or smaller size than the standard, according as it is desired to increase or decrease the speed, or in S. R motors by changing the ratio of the gearing.

In asking for designs for special motors, the weight of the maximum train and the maximum speed on level, together with the weight of the maximum train and the highest speed on the maximum grade, should be given. As before stated, within limits, any conditions as to speed on level and on grade can be approximated by special design.

DESIRABLE POINTS IN MOTORS AND CAR EQUIPMENT.

It is desirable that motors should be electrically sound, i.e., that their insulation should be high, mechanically strong, and waterproof. It is of great advantage in this connection if the entire frame of the motor can be insulated from the car truck and consequently from the ground, thus relieving the insulation of the armature and fields of half the strain. The mechanical difficulties in the way of accomplishing this, however, go a great way towards counterbalancing the advantage gained.

A high average efficiency between 3-quarters and full load should be obtained if possible, but mechanical points should not be neglected to obtain this.

A motor should run practically sparkless up to $\frac{3}{4}$ of its rated capacity. A low starting current is especially desirable, and for obtaining this nothing can equal a multiple series controlling device, which cuts the starting current actually in half. This device also enables cars to run at a slow speed with far greater efficiency than any other method.

Mechanically, the motor should be simple. The fewer the parts, and especially the wearing parts, the better, It should be well encased in a covering strong enough not only to keep out water, pebbles, bits of wire, etc., encountered on the track, but to shove aside or slide over an obstruction too high to be cleared. At the same time, the case should be hinged so that by the removal of a few bolts access can be had to the whole interior of the motor. The brush holders and commutator should be easily accessible through the traps in the car floor at all times. As much of the weight of the motor as possible should be carried by the truck on springs ; if practicable, all of it. This arrangement saves much of the wear and tear on the tracks.

A switch in addition to the controlling stand should always be provided, by which the motorman himself can cut off the trolley current, in case of accident to the controlling apparatus.

Roads having long, steep grades should have their cars provided with a device for using the motors as a brake in case the wheel brake gives out. There are several methods of accomplishing this, but limited space prohibits any description of them.

Last, but by no means least, all wearing parts should be capable of being *easily* and *cheaply* replaced.

NOTE.—Double brakes or track brakes should be used on roads with steep grades. Power brakes are seldom used on ordinary cars. With the increase in the length and weight of cars they will probably come into more general use, and orders have been issued by the Railroad Commission of the State of New York that all street cars must be equipped with power brakes.

J. S. G.

WEIGHTS OF RAILS.

Pounds per Yard.	Weight per Mile. Long Tons.		Weight per 1000′. Long Tons.	
25	$39\frac{640}{2240}$	39.286	$7\frac{986.7}{2240}$	7.441
30	$47\frac{320}{2240}$	47.143	$8\frac{2080}{2240}$	8.929
35	55	55	$10\frac{933.3}{2240}$	10.417
40	$62\frac{1920}{2240}$	62.857	$11\frac{2026.6}{2240}$	11.905
45	$70\frac{1600}{2240}$	70.714	$13\frac{880}{2240}$	13.393
48	$74\frac{960}{2240}$	74.428	$14\frac{635.5}{2240}$	14.284
50	$78\frac{1280}{2240}$	78.571	$14\frac{1973.3}{2240}$	14.881
52	$81\frac{1600}{2240}$	81.714	$15\frac{1066.7}{2240}$	15.477
55	$86\frac{960}{2240}$	86.428	$16\frac{826.6}{2240}$	16.369
56	88	88	$16\frac{1604.4}{2240}$	16.667
58	$91\frac{320}{2240}$	91.143	$17\frac{586.7}{2240}$	17.262
58½	$91\frac{2080}{2240}$	91.928	$17\frac{1920}{2240}$	17.411
60	$94\frac{640}{2240}$	94.286	$17\frac{920}{2240}$	17.857
62	$97\frac{960}{2240}$	97.428	$18\frac{1013.3}{2240}$	18.452
63	99	99	$18\frac{1680}{2240}$	18.75
63½	$99\frac{1760}{2240}$	99.785	$18\frac{2013.3}{2240}$	18.899
65	$102\frac{320}{2240}$	102.143	$19\frac{773.3}{2240}$	19.345
66	$103\frac{1600}{2240}$	103.714	$19\frac{1440}{2240}$	19.643
66½	$104\frac{1120}{2240}$	104.5	$19\frac{1773.3}{2240}$	19.792
67	$105\frac{640}{2240}$	105.286	$19\frac{2106}{2240}$	19.940
68	$106\frac{1920}{2240}$	106.857	$20\frac{533.3}{2240}$	20.238
70	110	110	$20\frac{2000}{2240}$	20.833
71	$111\frac{280}{2240}$	111.125	$21\frac{293.3}{2240}$	21.131

WEIGHTS OF RAILS — *Continued.*

Pounds per Yard.	Weight per Mile. Long Tons.		Weight per 1000′. Long Tons.	
72	$113\frac{320}{2240}$	113.143	$21\frac{960}{2240}$	21.429
75	$117\frac{1920}{2240}$	117.857	$22\frac{720.2}{2240}$	22.322
77	121	121	$22\frac{2053.3}{2240}$	22.917
78	$122\frac{320}{2240}$	122.143	$23\frac{480}{2240}$	23.214
80	$125\frac{1600}{2240}$	125.714	$23\frac{1813.3}{2240}$	23.810
82	$129\frac{1920}{2240}$	129.857	$24\frac{906.6}{2240}$	24.405
85	$133\frac{1280}{2240}$	133.571	$25\frac{666.6}{2240}$	25.298
90	$141\frac{960}{2249}$	141.428	$26\frac{1760}{2240}$	26.786
91	143	143	$27\frac{186.6}{2240}$	27.083
98	154	154	$29\frac{373.3}{2240}$	29.167
100	$157\frac{320}{2240}$	157.143	$29\frac{1706.7}{2240}$	29.762

For iron or steel weighing 480 lbs. per cubic foot: Cross-section in square inches = weight in lbs. per yard ÷ 10.

For iron or steel having $\frac{1}{7}$ conductivity of copper: Weight in lbs. per yard ÷ 11.6333 = number of 0000 B. & S. copper wires with combined equivalent carrying capacity. Also, weight in lbs. per yard × 18189.1 = C. M. of equivalent copper wire.

RADIUS OF CURVES FOR DIFFERENT DEGREES OF CURVATURE.

Degrees.	Feet Radius.	Degrees.	Feet Radius.	Degrees.	Feet Radius.	Degrees.	Feet Radius	Degrees.	Feet Radius.
1	5730	11	521	21	273	31	185	41	139
2	2865	12	477	22	260	32	179	42	136
3	1910	13	441	23	249	33	174	43	133
4	1432	14	409	24	238	34	169	44	130
5	1146	15	382	25	229	35	163	45	127
6	955	16	358	26	220	36	159	46	125
7	818	17	337	27	212	37	155	47	122
8	716	18	318	28	206	38	150	48	119
9	636	19	301	29	197	39	147	49	117
10	573	20	286	30	191	40	143	50	114

NOTE No. 1.—A 1° curve has a radius of 5730 feet; 2° curve, $\frac{1}{2}$ this; 3° curve, $\frac{1}{3}$ this, etc.

GRADES IN PER CENT AND RISE IN FEET.

Per Cent Grade.	Rise in Feet at Given Distances.		
	500 Feet.	1000 Feet.	5,280 Feet (1 Mile).
$\frac{1}{2}$	2.5	5	26.4
1	5	10	52.8
1.5	7.5	15	79.2
2	10	20	105.6
2.5	12.5	25	132
3	15	30	158.4
3.5	17.5	35	184.8
4	20	40	211.2
4.5	22.5	45	237.6
5	25	50	264
5.5	27.5	55	290.4
6	30	60	316.8
6.5	32.5	65	343.2
7	35	70	369.6
7.5	37.5	75	396
8	40	80	422.4
8.5	42.5	85	448.8
9	45	90	475.2
9.5	47.5	95	501.6
10	50	100	528
11	55	110	580.8
12	60	120	633.6
13	65	130	686.4
14	70	140	739.2
15	75	150	792

NOTE No. 1. — For other distances interpolate the table by direct multiplication or division.

ELEVATION OF OUTER RAIL ON CURVES.

Degree of Curve.	Radius of Curve.	Speed in Miles per Hour.									
		10	15	20	25	30	35	40	45	50	60
		Elevation of Outer Rail in Inches.									
1	5730	$\frac{1}{16}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{7}{16}$	$\frac{5}{8}$	$\frac{13}{16}$	$1\frac{1}{16}$	$1\frac{3}{8}$	$1\frac{11}{16}$	$2\frac{1}{2}$
2	2865	$\frac{1}{8}$	$\frac{5}{16}$	$\frac{9}{16}$	$\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{11}{16}$	$2\frac{3}{16}$	$2\frac{3}{4}$	$2\frac{7}{16}$	$4\frac{15}{16}$
3	1910	$\frac{3}{16}$	$\frac{1}{2}$	$\frac{13}{16}$	$1\frac{5}{16}$	$1\frac{7}{8}$	$2\frac{1}{2}$	$3\frac{5}{16}$	$4\frac{1}{8}$	$5\frac{1}{8}$	$7\frac{3}{8}$
4	1432	$\frac{1}{4}$	$\frac{5}{8}$	$1\frac{1}{16}$	$1\frac{11}{16}$	$2\frac{1}{2}$	$3\frac{3}{8}$	$4\frac{3}{8}$	$4\frac{9}{16}$	$6\frac{13}{16}$	$9\frac{3}{4}$
5	1146	$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{3}{8}$	$2\frac{3}{8}$	$3\frac{1}{16}$	$4\frac{3}{16}$	$5\frac{7}{16}$	$6\frac{7}{8}$	$8\frac{1}{2}$	$12\frac{1}{16}$
6	955	$\frac{7}{16}$	$\frac{15}{16}$	$1\frac{5}{8}$	$2\frac{9}{16}$	$3\frac{11}{16}$	5	$6\frac{9}{16}$	$8\frac{1}{4}$	$10\frac{1}{8}$	
7	818	$\frac{1}{2}$	$1\frac{1}{16}$	$1\frac{15}{16}$	3	$4\frac{5}{16}$	$5\frac{7}{8}$	$7\frac{5}{8}$	$9\frac{9}{16}$	$11\frac{3}{4}$	
8	716	$\frac{9}{16}$	$1\frac{1}{4}$	$2\frac{3}{16}$	$3\frac{7}{16}$	$4\frac{15}{16}$	$6\frac{11}{16}$	$8\frac{11}{16}$	$10\frac{7}{8}$		
9	636	$\frac{5}{8}$	$1\frac{3}{8}$	$2\frac{1}{2}$	$3\frac{13}{16}$	$5\frac{1}{2}$	$7\frac{1}{2}$	$9\frac{3}{4}$	$12\frac{13}{16}$		
10	573	$\frac{11}{16}$	$1\frac{7}{16}$	$2\frac{3}{4}$	$4\frac{1}{4}$	$6\frac{1}{8}$	$8\frac{5}{16}$	$10\frac{3}{4}$			
11	521	$\frac{3}{4}$	$1\frac{11}{16}$	3	$4\frac{11}{16}$	$6\frac{3}{4}$	$9\frac{1}{8}$	$11\frac{13}{16}$			
12	477	$\frac{13}{16}$	$1\frac{7}{8}$	$3\frac{5}{16}$	$5\frac{1}{8}$	$7\frac{5}{16}$	$9\frac{15}{16}$	$12\frac{13}{16}$			
14	409	$\frac{15}{16}$	$2\frac{3}{16}$	$3\frac{13}{16}$	$5\frac{15}{16}$	$8\frac{9}{16}$	$11\frac{1}{2}$				
16	358	$1\frac{1}{16}$	$2\frac{1}{2}$	$4\frac{3}{8}$	$6\frac{13}{16}$	$9\frac{11}{16}$					
18	318	$1\frac{1}{4}$	$2\frac{3}{4}$	$4\frac{15}{16}$	$7\frac{5}{8}$	$10\frac{7}{8}$					
20	286	$1\frac{3}{8}$	$3\frac{1}{16}$	$5\frac{7}{16}$	$8\frac{1}{2}$	12					

NOTE No. 1. — When $E =$ elevation in inches of outer rail above the horizontal plane:

$V =$ velocity of car in feet per second;
$R =$ radius of curve in feet;

Therefore $E = 1.7879 \frac{V^2}{R}$ when gauge of track is 4′–8½″.

SPIKES.

Size.	No. per Keg of 200 Lbs.	Lbs. per Spike.	Spikes per Lb.
$4\frac{1}{2} \times \frac{1}{2}$	533	.3752	2.66
$5 \times \frac{7}{16}$	650	.3077	3.25
$5 \times \frac{1}{2}$	520	.3846	2.6
$5 \times \frac{9}{16}$	393	.5089	1.96
$5\frac{1}{2} \times \frac{1}{2}$	466	.4292	2.33
$5\frac{1}{2} \times \frac{9}{16}$	384	.5208	1.92
$6 \times \frac{9}{16}$	350	.5714	1.75
$6 \times \frac{5}{8}$	260	.7692	1.3

SPIKES PER 1000′ AND PER MILE SINGLE TRACK, WITH FOUR SPIKES PER TIE.

Spacing of Ties.	Per 1000′.	Per Mile.
10 ties to 30′ rail	$1333\frac{1}{3}$	7040
11 " " " "	$1466\frac{2}{3}$	7744
12 " " " "	1600	8448
13 " " " "	$1733\frac{1}{3}$	9152
14 " " " "	$1866\frac{2}{3}$	9856
15 " " " "	2000	10560
16 " " " "	$2133\frac{1}{3}$	11264

JOINTS PER MILE OF SINGLE TRACK.

	Per 1000′.	Per Mile.
Joints — 30′ rails	$66\frac{2}{3}$	352
Angle bars	$133\frac{1}{3}$	704
Bolts — 4 hole bars	$266\frac{2}{3}$	1408
" 6 " "	400	2112
" 8 " "	$533\frac{1}{3}$	2816
" 12 " "	800	4224

TIES PER 1000′ AND PER MILE.

Spacing.	Per 1000′.	Per Mile.
10 ties to 30′ rail	$333\frac{1}{3}$	1760
11 " " " "	$366\frac{2}{3}$	1936
12 " " " "	400	2112
13 " " " "	$433\frac{1}{3}$	2288
14 " " " "	$466\frac{2}{3}$	2464
15 " " " "	500	2640
16 " " " "	$533\frac{1}{3}$	2816

BOARD FEET, CUBIC FEET, AND SQUARE FEET OF BEARING SURFACE PER TIE.

Size.	Board Feet.	Cubic Feet.	Bearing Surface
5″ × 5″ × 7′	14.56	1.213	2.91
5″ × 6″ × 7′	17.5	1.458	3.5
5″ × 7″ × 7′	20.41	1.7	4.08
5″ × 8″ × 7′	23.33	1.944	4.66
6″ × 6″ × 7′	21	1.75	3.5
6″ × 7″ × 7′	24.5	2.041	4.08
6″ × 8″ × 7′	28	2.333	4.66
6″ × 9″ × 7′	31.5	2.625	5.25
6″ × 10″ × 7′	35	2.916	5.83
6″ × 8″ × 8′	32	2.666	5.33
6″ × 9″ × 8′	36	3	6
6″ × 10″ × 8′	40	3.333	6.66

REPORT OF U. S. DEPARTMENT OF AGRICULTURE ON DURABILITY OF RAILROAD TIES.

White oak	8 years.
Chestnut	8 "
Black locust	10 "
Cherry, black walnut, locust	7 "
Elm	6 to 7 "
Red and black oaks	4 to 5 "
Ash, beech, and maple	4 "
Redwood	12 "
Cypress and red cedar	10 "
Tamarack	7 to 8 "
Longleaf pine	6 "
Hemlock	4 to 6 "
Spruce	5 "

PAVING.

Paving prices vary so that it is difficult to state even an approximate cost that will not be dangerous to use. Prices are not at all alike for asphalt, even in cities in the same localities; other styles vary according to proximity of material, cost of labor, and amount of competition.

Square yards of paving between rails, 4′ 8½″ gauge, less 4″ for width of carriage tread:

Per 1000′ run = 485.89 sq. yards.
Per mile run = 2565.5 "

Square yards paving for 18″ outside both rails:

Per 1000′ run = 333⅓ sq. yards.
Per mile run = 1760 "

Approximate Cost of Paving. (Davis.)

PAVEMENT.	Cost of all Material and Labor.			Cost of Tearing up Existing Pavement and Replacing as Found.	
	Per Sq. Yd.	Per ft. of Single Track.	Per Mile of Single Track.	Per ft. Single Track.	Per Mile of Single Track.
	$	$	$	$	$
Granite blocks on gravel foundation	2.80	2.24	12000	.35	1900
Gravel blocks on concrete foundation	3.60	2.88	15500	.45	2400
Asphalt on concrete foundation	3.80	3.04	16000		
Vitrified brick on broken stone	2.15	1.72	9000	.45	2400
Wood without concrete	1.50	1.20	8000		
Cobble without concrete	2.00	1.60	8500	.30	1600
Macadam	1.00	.80	4500	.50	2700

ESTIMATE OF TRACK LAYING FORCE.

One engineer, 1 rodman, 1 foreman of diggers, 1 foreman of track-layers, 4 spikers, 20 laborers, 2 general helpers. Such a gang can lay from 400 to 900 feet of single track per day.

In case it is desired to proceed more rapidly, the above number of men should be increased proportionately, omitting the engineer and rodman, as these two will be able to handle any ordinary number of gangs, no matter how widely scattered, if a horse and buggy is placed at their disposal.

Tools For Track Gang as Above.

One portable tool-box padlocked, 1 small flat car, 1 portable forge, 4 cold chisels, 2 ball pein hammers, 6 lbs.; 1 sledge, 12 lbs.; 2 axes, 2 adzes, 1 crosscut saw, 1 large double-handled saw, 6 track wrenches, 2 monkey wrenches, 1 complete ratchet track drill with bits, 1 track "Jimmy" for bending rails, 1 reel line cord, braided: 30 picks, 15 extra pick-handles, 25 long-handled, roundnose shovels, 6 short handled, square-nose shovels, 10 tampers, 5 wheelbarrows, 2 track gauges, 1 level, 1 straight-edge, 4 pair rail tongs, 6 spiking hammers, 3 crow-bars, one end sharp, the other end chisel-pointed, 2 spike claw-bars, 1 engineer's transit, 1 leveling-rod, 10 surveyor's marking-pins, 1 steel tape, 10 red lanterns, 1 box lump chalk, 1 squirt oil-can, 1 quart black oil, 5 gals. kerosene, 1 flag-rod, 1 paper of tacks, 1 broad blade hatchet.

RAILWAY TURNOUTS.

By W. E. Harrington, B. S.

For example, assume a railway to operate 4 cars, the distance between terminals four miles, the time of round trips 60 minutes, and the headway 15 minutes, with a lay over at each end of five minutes. Take a piece of cross-section paper, and make the vertical lines represent distance, and the horizontal lines represent time.

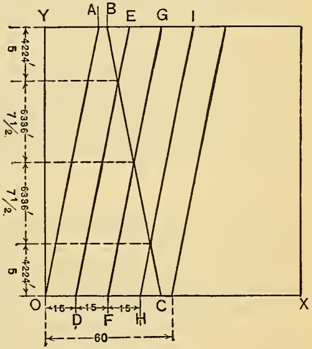


FIG. 1. Location of Street Railway Turnouts.

The time necessary to run from terminus to terminus is half of 60 minutes, less ½ of ten minutes (the layover time), or 25 minutes. Let each division on the ordinate axis represent the distance traversed by a car in one minute, which in the above case is 844.8 feet per minute, assuming that the car is to run at the average speed of 9.6 miles per hour. Let each division on the axis of abscissas represent five minutes. The first car will travel from terminus to terminus as represented by the diagonal line OA. This line shows the car's position at any instant of time, assuming, of course, that the car is running at a uniform rate of speed. The car upon its arrival at the other terminus will have a lay-over of five minutes as represented by the horizontal space AB. Upon the expiration of the time of lay-over the car starts upon its return run. This determines the locus of the several turnouts, as the car has to pass each of the remaining cars. The line of the return run is represented by the line BC. Upon the arrival of the car at the original terminus and a lay-over of five minutes, the cycle of trips will be repeated. During the time the first car is running its round trip the other cars are leaving at intervals of 15 minutes, as represented by the lines DE, FG, and HI. Where these three lines intersect the line BC turnouts must be located, as the cars meet and pass at these points. The distance apart of the turnouts, as well as their distance from the starting terminus O, may be readily determined by projecting the intersections on the axis of ordinates OY.

1. The number of turnouts for a given number of cars is one less than the number of cars running.

2. The time consumed running between turnouts must be the same between all the turnouts. For instance, if it is found necessary to irregularly locate turnouts for any reason, then the time consumed by a car running between these two turnouts farthest apart determines the time the cars must run between the remaining turnouts, even though two or more of the turnouts be only a slight fraction of the distance apart of the two greater ones.

3. The time consumed running between two consecutive turnouts is one-half the running time between cars.

For determining the distance apart of turnouts without the aid of graphical methods :

RULE. — To the length of the railway from terminus to terminus add the distance a car would travel running at the same rate of speed as running on the main line, for the time of lay-over at one terminus. Divide the above result by the number of cars desired to be run, the result is the distance between turnouts. Multiply this latter result by two less than the number of cars, and deduct the result obtained from the length of the line from terminus to terminus, and divide by two. The result is the distance from either terminus and the first adjacent turnout.

To operate more or less cars on a railway than it is designed for is a question most frequently met in railway practice.

Rule 1 tells us that we must have one turnout less than the number of cars running. In Fig. 1 we have four cars and three turnouts. If we propose running three cars we would use two turnouts, by omitting the middle turnout. The result is at once apparent ; for according to Rule 2, the time to run between turnouts is determined by the time consumed in running between those two turnouts farthest apart. Since the distance is doubled, the time consumed is doubled. Where with four cars, with fifteen minutes between cars, and sixty minutes for the round trip, with three cars the time between cars as by Rule 2 is thirty minutes, and the time of round trip is ninety minutes, making at once a very pronounced loss.

The better plan, and the one usually pursued by railway managers, is to run the lesser number of cars on the same trip time as the railway was designed for. In our example above, the three cars would be run as if the four cars were running, with the exception that the space which the car should be running in will be omitted, leaving an interval between two of the cars of thirty minutes, giving only the loss occasioned by the omission of one car.

Another method to pursue, especially so where additional cars will be run at times, such as holidays, excursions, and other times of travel requiring more than the regular number of cars to accommodate the travel, is to provide and locate more turnouts. The expense of doubling the number of turnouts, while they would be a great convenience, would not be warranted without the railway were doing a large and growing business, with a fluctuating number of cars in service. Two cases should be considered.

First — If a certain fixed number of cars are to be operated for the greater portion of time and the extra cars for odd and infrequent intervals, locate the turnouts to suit the regular business.

Second — In the case of a railway running an irregular number of cars — for instance, a railway running a heavy business at certain times of the day — as the lesser number of cars are subordinate to the greater number, locate the turnouts to run the greater number of cars the most efficiently.

In conclusion, we might state that the grades, the running through crowded business streets, stoppages occasioned by grade railroad crossings, and varying business, all enter in and must be considered while designing.

Block Signal for Single-Track Roads or for Bridges, etc.

M. S. Wightman has designed a system which is operated automatically by the passage of the trolley wheel along the wire, as follows :

Suppose a car passing south from the north siding, its trolley makes contact at "make hanger a′," current passes through magnet A′, white lamps W′, plunger contacts RS — WSR — red lamps R′ to ground. Plunger is then raised connecting contacts TM. Current then flows from trolley through contacts TM, magnet A′, white lamps W′, contacts WSM — L, — line, contacts in box at south switch, L — WSM, contacts WSB — RS, through the red lights to ground. This condition remains until the car passes "break hanger" contact a²; the trolley while striking the "break hanger a²" momentarily excites magnet B, raising the plunger and breaking the signal

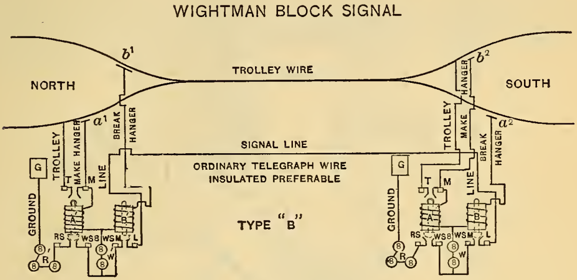


FIG. 2.

circuit at WSM — L, this in turn de-energizes magnet A′, its plunger drops to its normal position, breaking the circuit at TM, and the signal is "off." The same action in a reverse direction takes place when a car passes out of the south siding going north.

Another method, a manual one, is in use by the Lehigh Valley Traction Co. on all the street railways in and about Allentown and Bethlehem, Penn. One advantage claimed for this system over an automatic method is, that the conductor is responsible for maintaining his own right of way.

The system is operated as follows: A conductor before entering a section between switches pushes a switch-rod, which sets a signal at the turnout ahead, a magnet operating a red semaphore and incandescent lamps behind a red glass disk. This makes the signal visible both night and day. This semaphore stays set until he reaches the switch ahead; then the conductor opens the circuit which sets the track behind him to safety. If on reaching the switch he finds the semaphore is set to danger, he has to wait

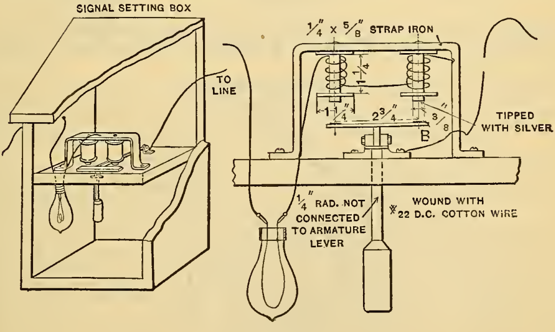


FIG. 3.

on switch until car passes. Conductors only set semaphores ahead of them and release those behind; the car is controlled by semaphores operated by the conductors of cars passing it at the switches, and the signal systems for cars operating in opposite direction are entirely independent. In each signal box there is also a pilot lamp which is extinguished when the section of track is opened, and illuminated when the section is closed; this gives

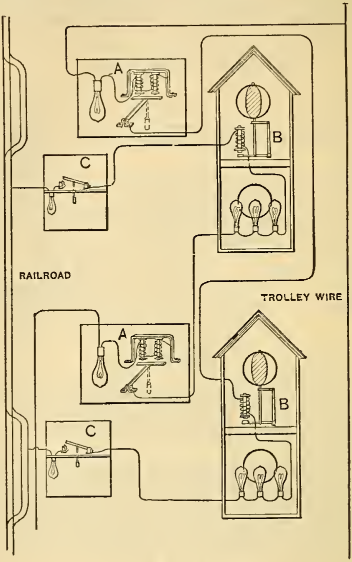


FIG. 4.

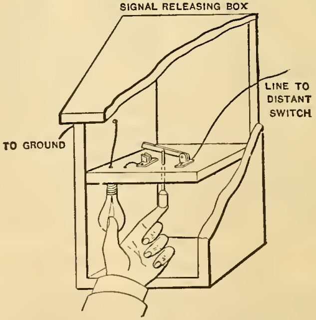


FIG. 5.

the conductor knowledge that his signals have operated properly at the distant switch. As the first signal set gives the right of way, there is no meeting between switches. The detailed description is given below.

There are three separate operating parts, — a signal setting-box, a signal releasing-box, and the semaphore box.

The signal setting-box is shown with details in Fig. 3. The magnets are 1⅕ in. x 1¼ in. winding-space with fiber heads, and ⅛ in. core; the end of the iron cores exposed to the armature are tipped with platinum or silver, and the armature B is also faced as these surfaces come together and complete the circuit and are held in contact by this current also passing through the magnets. The armature B normally rests out of the influence of its magnet. A rod entering from the bottom of this box shoves the armature up into contact with the ends of the magnet, and is held in this position until the circuit is broken.

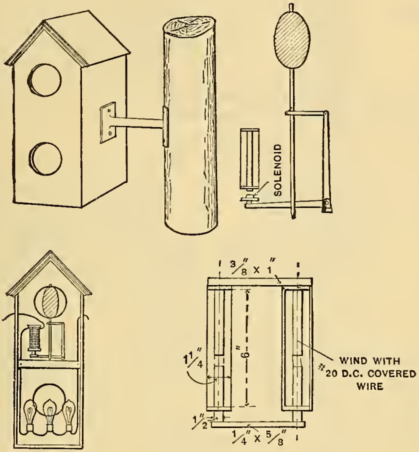


FIG. 6.

The current from the trolley enters first through a lamp, then through the magnet-winding to the frame. When the armature is up the current passes down the arm holding the armature, and then through the signal line to the distant semaphore box.

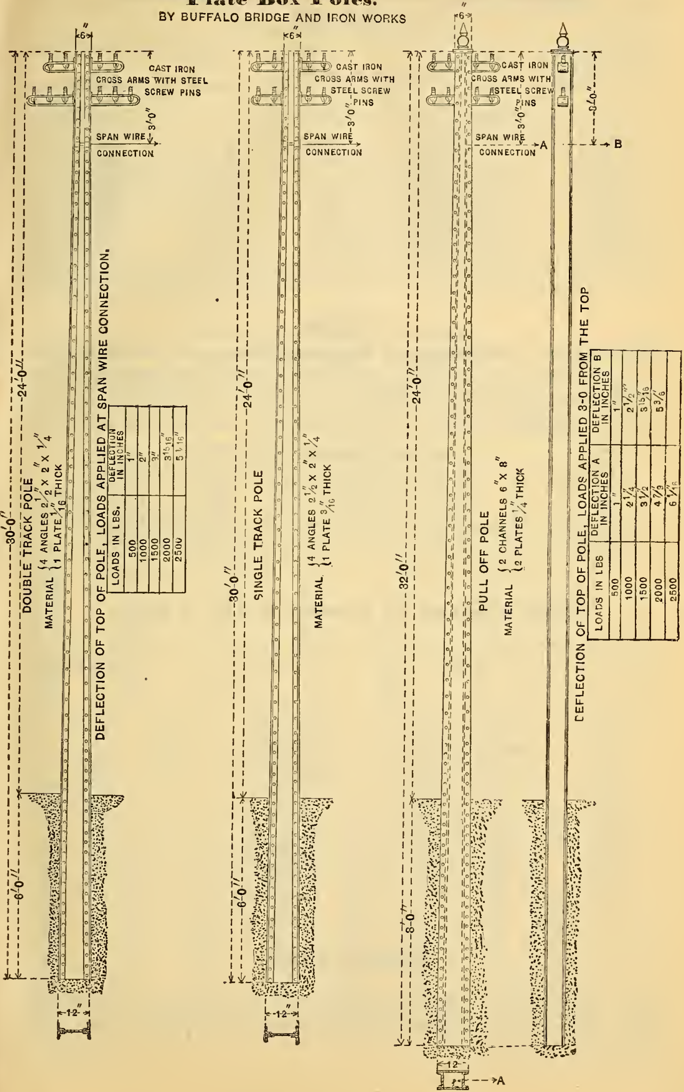
The semaphore box contains a pair of solenoid magnets, which set the semaphore disk and light the lamps. These lamps are arranged behind a red glass disk inserted in the semaphore box. The disk is set by means of a solenoid operating a bell crank and link, which turns the semaphore rod and displays the red disk. The dimensions and methods of general construction employed are shown in Fig. 6. The circuit first passes through three lamps, then through the solenoid, and out to the signal releasing-box. The construction of this box is shown in Fig. 5, and consists of a switch and a lamp in circuit with this switch. It is operated by pushing up the rod, and when the rod is released the blade falls back into position, but it will not close the circuit now; for on opening the circuit, the magnet in the circuit-making box dropped its armature, and opened the current at the distant switch, which can now only be closed by the conductor on the car following. The diagram of connections is given in Fig. 4. Covered No. 10 iron wire can be used. Robert Doumblaser developed all the details.

LIST OF MATERIAL REQUIRED FOR ONE MILE OF OVERHEAD LINE FOR ELECTRIC STREET RAILWAY.

Material for Railway Construction.			1 Mile Overhead.				Curve Overhead Material.					Anchorage.	
			Cross Suspension.		Bracket Suspension.		Main Line.		Branch Line.		Turnout, 200 ft.		
			Single Tr.	Double Tr.	Single Tr.	Double Tr.	Single Tr.	Double Tr.	Single Tr.	Double Tr.		Single Tr.	Double Tr.
Copper.	No. 0 B. & S. H. D. Trolley	Ft.	5280	10560	5280	10560					250		
		Lb.	1685	3369	1685	3369					80		
	No. 0 B. & S. S.D. F'd'r T'ps	Ft.	400	500	90	180							
		Lb.	154	192	35	69							
Galv. Iron	7 strand No. 12 span	Ft.	3600	3600			800	800	800	800	200	400	600
		Lb.	756	756			168	168	168	168	42	84	122
	7 strand No. 15 guy	Ft.	3000	4500	1500	2000	100	100	100	100			
		Lb.	300	450	150	200	10	10	10	10			
Plain ears			45	90	45	90	5	10	5	15	4		
Strain ears							2	4	1	2			
Splicing ears			1	2	1	2							
Feeder ears			10	20	10	20							
Insulating caps . .			45	90	45	90	7	4	6	17	4		
Insulating cones . .			45	90	45	90	7	4	6	17	4		
Ins. Holders	Straight line . .		45	90									
	Single curve . .						3	3	3	5			
	Double curve .						4	11	3	12	4		
	Bracket . . .				45	90							
Strain insulators . .			90	90			4	4	2	2		1	2
Turnbuckles . . .			90	90			4	4	2	2		2	2
Section insulators .			2	4	2	4							
Frogs									1	2	2		
Frog crossings . . .										1			
Hardwood pins . .			45	45									
Eye bolts			90	90			2	2	2	2	2	2	2
Cast-iron brackets .					45	90							
Gas-pipe arms . . .					45	90					2		
Cross arms (1¼″–18) .			45	45	48	48							
Cross-arm braces (½″×8″)			90	90									
Bolts for brackets (½″×4″)					45	90							
Lag screws for brackets (½″×7″) . . .					45	90							
Lag screws for cross arms (⅜″×3″) . .			45	45									
Lag screws for braces			144	144									
Poles, 125 ft. apart .			90	90	45	45	2	2	2	2		2	2
Channel pins . . .			800	1600	800	1600							
Bonds			400	800	400	800							
Lightning arresters .			3	3	3	3							
Section switch boxes			2	2	2	2							

Plate Box Poles.

BY BUFFALO BRIDGE AND IRON WORKS



DEFLECTION OF TOP OF POLE, LOADS APPLIED AT SPAN WIRE CONNECTION.

LOADS IN LBS.	DEFLECTION IN INCHES
500	1"
1000	2"
1500	3"
2000	$3\frac{15}{16}''$
2500	$5\frac{1}{16}''$

DEFLECTION OF TOP OF POLE, LOADS APPLIED 3-0 FROM THE TOP

LOADS IN LBS	DEFLECTION A IN INCHES	DEFLECTION B IN INCHES
500	1"	1"
1000	$2\frac{1}{4}''$	$2\frac{1}{2}''$
1500	$3\frac{1}{2}$	$3\frac{15}{16}''$
2000	$4\frac{7}{9}''$	$5\frac{3}{6}''$
2500	$6\frac{1}{16}''$	

FIG. 7.

TUBULAR IRON OR STEEL POLES.

By Morris, Tasker, & Co. (Inc.).

Size.	Wrought Iron or Steel.	Length.	Weight.
No. 1, light	5 in., 4 in., 3 in.	27 ft.	350 lbs.
No. 1, heavy . . .	5 in., 4 in., 3 in.	27 ft	500 lbs.
No. 2, light	6 in., 5 in., 4 in.	28 ft.	475 lbs.
No. 2, heavy . . .	6 in., 5 in., 4 in.	28 ft.	700 lbs.
No. 3, light	7 in., 6 in., 5 in.	30 ft.	600 lbs.
No. 3, heavy . . .	7 in., 6 in., 5 in.	30 ft.	1000 lbs.
No. 4, light	8 in., 7 in., 6 in.	30 ft.	825 lbs.
No. 4, heavy . . .	8 in., 7 in., 6 in.	30 ft.	1300 lbs.

POLES.

Dimensions and Weights Wrought-Iron and Steel Poles.

Length.	Diameter.	Weights.
27 ft.	5 in., 4 in., 3 in.	350 lbs. to 515 lbs.
28 ft.	6 in., 5 in., 4 in.	475 lbs. to 725 lbs.
30 ft.	6 in., 5 in., 4 in.	510 lbs. to 775 lbs.
30 ft.	7 in., 6 in., 5 in.	600 lbs. to 1000 lbs.
28 ft.	8 in., 7 in., 6 in.	775 lbs. to 1260 lbs.
30 ft.	8 in., 7 in., 6 in.	825 lbs. to 1350 lbs.

Cubic Contents of Wooden Poles, in Feet.

Length.	Diameter.	Section.	Cubic Feet.
27 ft.	6 in. × 8 in.	Circular	7.36
27 ft.	7 in. × 9 in.	Circular	9.56
27 ft.	7 in. × 9 in.	Octagonal	10.1
28 ft.	7 in. × 9 in.	Circular	9.92
28 ft.	7 in. × 9 in.	Octagonal	10.46
28 ft.	8 in. × 10 in.	Circular	12.52
28 ft.	8 in. × 10 in.	Octagonal	13.2
30 ft.	7 in. × 9 in.	Circular	10.63
30 ft.	7 in. × 9 in.	Octagonal	11.21
30 ft.	8 in. × 10 in.	Circular	13.41
30 ft.	8 in. × 10 in.	Octagonal	14.15
30 ft.	9 in. × 12 in.	Octagonal	19.06

Rake of Poles.

Wooden poles should be given a rake of 9 to 18 inches away from the street. Iron or steel poles set in concrete need be given but 6 to 9 inches rake. Corner poles, and those supporting curves, should be given additional rake or be securely guyed.

AVERAGE WEIGHTS OF VARIOUS WOODS, IN POUNDS.

Kind.	Condition.	Weight per Cubic Foot.
Live oak	Perfectly dry	59
White oak	Perfectly dry	48
Red oak	Perfectly dry	35
Chestnut	Perfectly dry	41
Southern yellow pine	Perfectly dry	45
Northern yellow pine	Perfectly dry	34
Long-leaf yellow pine	Unseasoned	65
Norway pine	Perfectly dry	46
Spruce	Perfectly dry	25
Hemlock	Perfectly dry	25

The weight of green woods may be from one-fifth to one-half greater than the weight when perfectly dry.

DIP IN SPAN WIRE.

(Merrill.)

The following tables give the dip of the span wire in inches under the combined weight of span wire and trolley wire, for various spans and strains. Length of trolley wire between supports, 125 feet. Weight of trolley wire, 319 lbs. per 1000 feet. Weight of span wire, 210 lbs. per 1000 feet.

Single Trolley Wire.

Spans in Feet.	Strain on Poles, in Pounds.						
	500	800	1000	1500	2000	2500	3000
30	7.8	4.9	3.9	2.6	1.9		
40	10.6	6.5	5.3	3.5	2.7		
50	13.6	8.5	6.8	4.5	3.4	2.7	
60	16.7	10.4	8.3	5.6	4.2	3.3	2.8
70	19.9	12.4	9.9	6.6	4.9	4	3.3
80	23.2	14.5	11.6	7.7	5.6	4.6	3.9
90	26.7	16.7	13.4	8.9	6.6	5.3	4.5
100	30.3	18.9	15.2	10.1	7.6	6.1	5.1
110	34	21.3	17	11.3	8.5	6.8	5.7
120	37.9	23.7	18.9	12.6	9.5	7.6	6.3

Two Trolley Wires, 10 Feet Apart.

Span in Feet.	Strain on Poles, in Pounds.							
	500	800	1000	1500	2000	2500	3000	3500
40	15.4	9.6	7.7	5.1	3.9	3.1		
50	20.8	13.	10.4	6.9	5.2	4.2		
60	26.3	16.4	13.1	8.8	6.6	5.3	4.4	
70	31.9	19.9	15.9	10.6	8.	6.4	5.3	
80	37.6	23.5	18.8	12.5	9.4	7.5	6.3	5.4
90	43.5	27.2	21.8	14.5	10.9	8.7	7.3	6.2
100	49.5	30.9	24.8	16.5	12.4	9.9	8.3	7.1
110	55.6	34.7	27.8	18.5	13.9	11.1	9.3	7.9
120	61.9	38.7	30.9	20.6	15.5	12.4	10.3	8.7

NOTE. — See also chapter on *Conductors*.

For table of stranded wire for spans and guys see page 158, Properties of Conductors.

Span wires should be stranded galvanized iron or steel, sizes $\frac{1}{4}$ inch diameter $\frac{5}{16}$, $\frac{1}{2}$, or $\frac{5}{8}$ inch according to the weight of trolley wire, etc., to be supported. Where wooden poles are used it is not necessary to provide other insulation for the span wire, and the wire can be secured to the loop

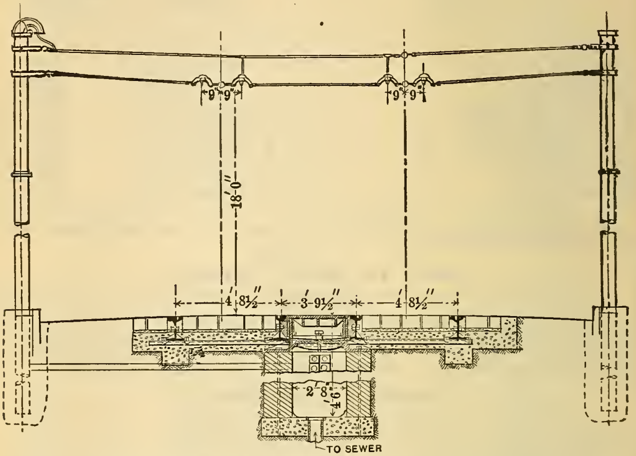


FIG. 8. Section of Track and Overhead Construction in Broad Streets, showing Double Overhead Wires and Underground Feeder Conduits.

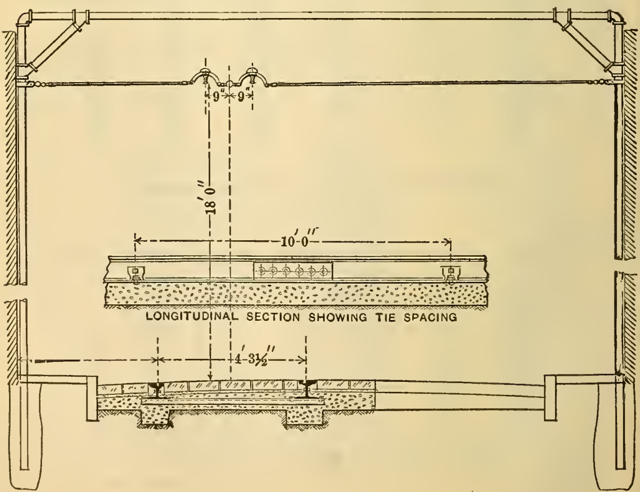


FIG. 9. Section of Track and Overhead Construction in Narrow Streets, showing Overhead Pipe Brace.

TROLLEY SUSPENSION FOR HAVANA STREETS, AS DEVELOPED BY F. S. PEARSON.

of an eye-bolt that is long enough to pass through the pole at a point from twelve to eighteen inches below the top, and that has a long thread to allow taking up slack. On many roads in the country the span wire is simply wrapped around the pole top, using a number of feet more wire, making it difficult to take up slack, and presenting a slovenly appearance. Where metal poles are used it is necessary to insulate the span wire from the pole This has been done in some cases by inserting a long wooden plug in the top of tubular poles, capping it with iron, the wooden plug then being provided with the regular eye-bolt. The most modern way is to provide a good anchor bolt or clasp on the pole, then insert between the span wire and this bolt one of the numerous forms of line or circuit-breaking insulators devised for the purpose. If the anchor bolt is not made for taking up slack, the insulating device can be so designed as to be used as a turnbuckle. Of course insulation must be provided for both ends of the span wire.

Span wire must be pulled very taut when erected so that the sag under load will be a minimum. Height above rail surface should be at least 18 feet after the trolley-wires are in place. This height is regulated by statute in some States, and runs all the way from 18 to 21 feet.

Figures 8, 9, and 10 illustrate one of the most modern installations, that at Havana, Cuba, as designed by Mr. F. S. Pearson for double trolley.

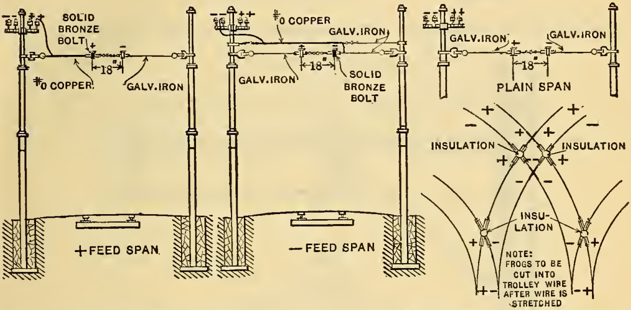


FIG. 10. Views of Trolley Spans with Plus and Minus Feeder connections and Plan of Double Track Y, showing Location of Insulators.

SIDE BRACKETS.

Along country roads and in such places as the track is along the side of the roadway or street, it is customary to use single poles with side brackets to support the trolley wire.

Where side brackets are used it is not safe to place the pole less than four feet away from the nearest rail, and to give flexibility to the stranded supporting wire, now always provided for the trolley wire, the bracket should be long enough to reach the distant rail, thus giving a little more than two feet of cable for flexibility. A common length of bracket is 9 feet.

Figures 11 and 13 show the simple form of side bracket in most general use, and Figs. 12 and 14 show variations of the same. It is obvious that this method of support may be made as elaborate and ornamental as may be desired.

On double-track roads *center-pole* construction is sometimes used, in which poles are placed along the center line between the two tracks, and brackets are erected on each side of the poles overhanging the tracks. Where wooden poles are used a good form of construction is to bore the pole at the proper height and run through it the tube for the arms, this long tube being properly stayed on both sides of the pole by irons from the pole-top to the bracket ends, or by braces against the pole. The trolley supporting wire can extend from end to end of the brackets *through* the pole, or can be cut at the pole, and eye-bolts be used, as in the side-bracket construction shown by Fig. 11.

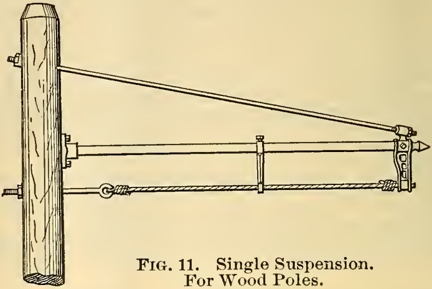


FIG. 11. Single Suspension.
For Wood Poles.

Figures 15 and 16 illustrate simple forms of center-pole brackets.

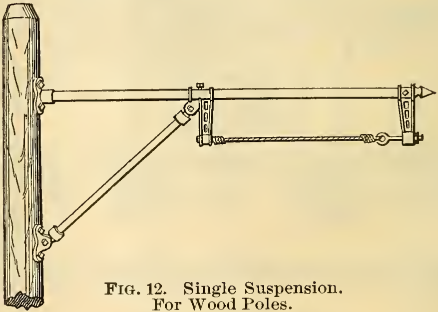


FIG. 12. Single Suspension.
For Wood Poles.

Center-pole construction is quite often used on boulevards in cities, where the brackets and poles can be made quite ornamental.

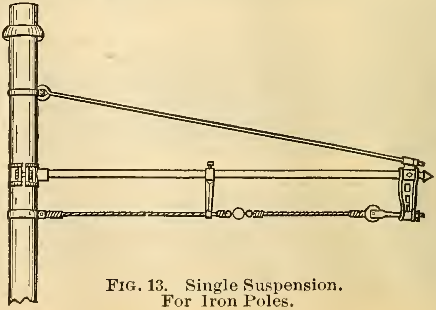


FIG. 13. Single Suspension.
For Iron Poles.

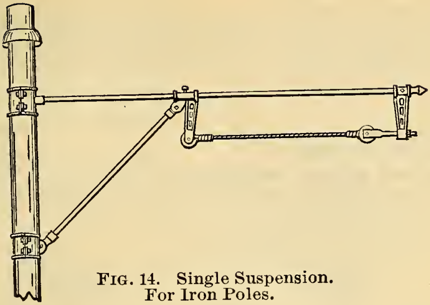


FIG. 14. Single Suspension.
For Iron Poles.

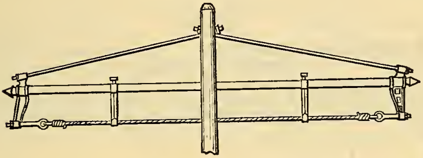


FIG. 15. Double Suspension. For Wood Poles.

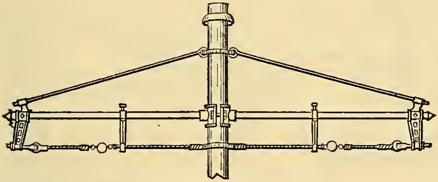


FIG. 16. Double Suspension. For Iron Poles.

TROLLEY WIRE SUSPENSION.

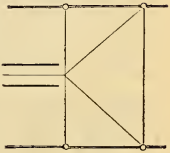


FIG. 17.

The support of the trolley wire along straight lines is a simple matter and needs no explanation; at curves and ends there have been some simple forms developed in practice that are handy to have at hand. Following are some of the points:

Terminal anchorage.—Single track. See Fig. 17.

Line anchorage.—See Figs. 18 and 19. To be placed at the foot of all grades, at the top of hills, and at tangents, three (3) per mile is good practice; where curves are frequent they will afford all the anchorage necessary.

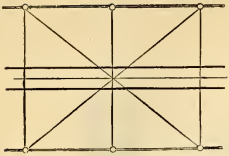


FIG. 18. Single Track.

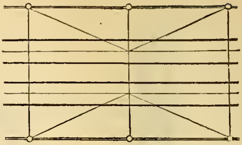


FIG. 19. Double Track.

Turnout and Siding Suspension.—Following is a sketch of a very simple arrangement of suspension and guys for a single-track turn-out.

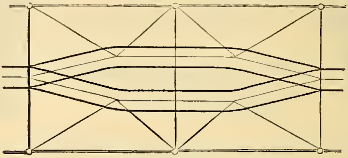


FIG. 20.

Curves, Suspension, and Guys.—The suspension of the trolley wire at curves is complicated or simple, according as the track may be single or double, or the curve may be at a crossing or a simple curve. Below are sketches of several types of suspension for different forms of curves, for single and double track, for cross suspension, and for center-pole construction.

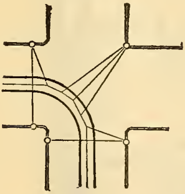


FIG. 21. Simple Right-angle Curve, Single Track.

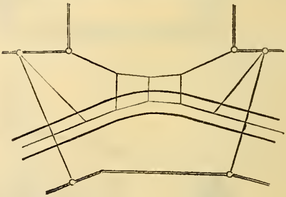


FIG. 22. Single Track, Obtuse Angle.

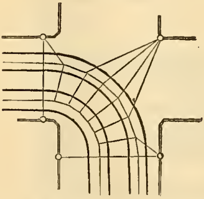


FIG. 23. Double Track, Right-angle Turn, Cross Suspension.

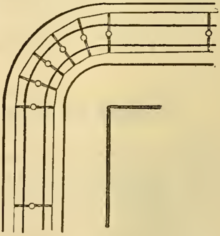


FIG. 24. Double Track, Right-angle Turn, Center Pole.

Crossings, Suspension, and Guys.—Simple crossings of tracks make no complication in the suspension of the trolley wires. When curves are added to connect one track with the other, complications begin, and where double tracks cross double tracks, and each is connected to the other by curves each way, the network of trolley wires becomes very complicated. Following are sketches of a couple of simple crossings which will clearly enough illustrate the methods of suspension commonly used.

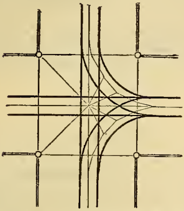


FIG. 25. Single-Track Crossing, Cross Suspension.

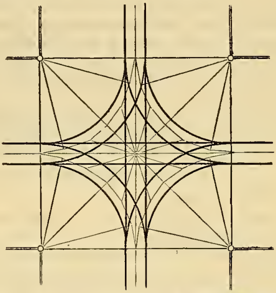


FIG. 26. Single-Track Crossing, Cross Suspension.

GUARD WIRES.

Where trolley wires are used in cities or in any location where there are other overhead conductors liable to fall across the trolley wire, it is customary to place guard wires parallel with but above the trolley wire, as shown in the following sketch. A piece of No. 6 B. & S. galvanized iron or steel

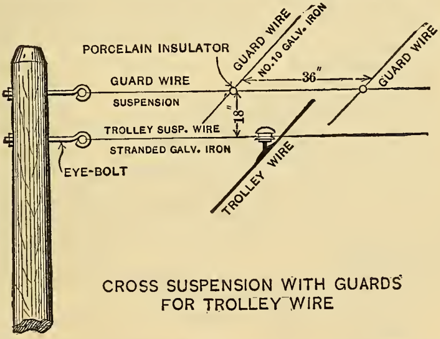


FIG. 27.

wire is drawn taut above the regular suspension wire; porcelain insulators are secured to the same at a point about a foot or 18 inches either side of the trolley wire, and through these insulators is threaded and tied a No. 10 galvanized iron wire. This guard should be broken at least every half-mile where it is in any great length, as it is not advisable to have it a continuous conductor for any great distance, and it is advisable to avoid its use wherever possible.

DETERMINATION OF MOST ECONOMICAL DENSITY OF CURRENT IN STREET RAILWAY CONDUCTORS.

(See Chapter on "Conductors," also paper by Mr. H. M. Sayers.*)

Wherever there is danger of interference with other properties from electrolysis it is desirable to have the drop in rails quite low, the B.T. regula-

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* *See Trans I. E. E. for July, 1900.*

tions being 7 volts between points on rails. This of course means track return feeders, and in some cases "negative boosters," or boosters on the track feeders.

The formula was developed by Professor Perry from Kelvin's law, and following is Mr. Sayers's application of it to tramway work: —

Formula for Determining the Most Economical Current Density and Drop in Conductors for Tramway Lines.

$R =$ percentage or rate to be charged on complete cost of cables laid ready for use, representing interest and depreciation and maintenance, say 7 per cent.

Hours run per year, at 15 hours per day, for 365 days $= 5475$.

$w =$ number of watts continuously wasted in distributing system, that would cost one dollar per annum at a rate of 1.5 cents per k.w. hour.

$$= \frac{100 \text{ cents}}{5475 \times \frac{1.5}{1000}} = 12.18 \text{ watts for one dollar.}$$

$p =$ cost of copper per ton of 2000 lbs. @ 30 c. per lb. laid complete ready for use $= \$600$.

$m =$ tons (2000 lbs.) copper per mile for 1 square inch cross-section $= 10.2$ tons.

$r =$ resistance per mile of copper of 1 square inch cross-section $= .0455$ ohms.

$t =$ most economical drop per mile in volts.

then
$$t = \sqrt{\frac{R.w.p.m.r}{100}} = \sqrt{\frac{7 \times 12.15 \times 600 \times 10.2 \times .0155}{100}}.$$

$$t = \sqrt{236.8} = 15.39 \text{ volts per mile.}$$

$$\frac{t}{.0455} = \frac{15.39}{.0455} = 338 \text{ amperes per square inch.}$$

It is obvious that the distance that the current can be transmitted at the economical density is limited by the permissible drop in the distributing system. The total drop is usually divided somewhat as follows, and is varied to suit conditions.

Drop in feeders	50 volts.
Drop in trolley	5 "
Drop in track return	5 "
Drop in return feeders (boosted)	booster.

Thus the distance over which an unboosted feeder will carry current without exceeding the drop is determined as follows:

$$\frac{50 \text{ volts drop in feeder}}{t = 15.37 \text{ volts drop per mile}} = 3.25 \text{ miles, in this case.}$$

Where feeders are "boosted" it is necessary to introduce in the formula, the factors of the cost of the booster and its losses, changing the value of "w" and therefore that of "t," let

$a =$ cost per annum per k.w. for interest and depreciation on cost of booster, say \$7.50.

$b =$ cost per annum for supplies and maintenance of booster, say \$2.50, say the efficiency of the booster is 75 per cent,

then,
$$\frac{a + b}{365 \times 15} = \frac{\$10.00}{5475} = \$.001827 \text{ per k.w. hour.}$$

and
$$w = \frac{100}{\left(.1827 + \frac{1.5 \times 100}{75}\right) \times \frac{5475}{1000}} = 8.37 \text{ watts for 1 dollar per annum.}$$

Using the same values as in the first equation,

$$t = \sqrt{\frac{7 \times 8.37 \times 600 \times 10.2 \times .0455}{100}} = \sqrt{163} = 12.76 \text{ volts per mile.}$$

and $\frac{t}{.0455} = \frac{12.76}{.0455} = 281$ amperes per square inch as the most economical current density for boosted feeders.

Determination of the most economical drop, or limiting distance on the track may be made by the above formulæ, but calculations may be expedited by use of a constant, as follows. Let

c = constant for ampere miles.
n = resistance of track per mile, say .03 ohms.
d = limit of drop permitted in rails, say 5 volts. Then

$$c = \frac{d}{n} = \frac{5}{.03} = 166 \text{ ampere miles.}$$

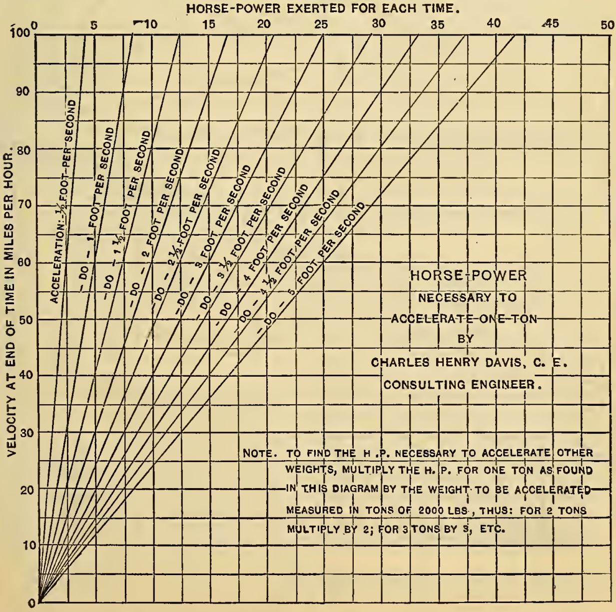
Thus, if each car requires an average of 20 amperes the limit in miles of track for a drop of 5 volts would be for the above values, 166 ÷ (20 × no. of cars, say 5) = 1.66 miles, provided all the cars were bunched at the end, or that one or two cars were ascending a heavy grade, requiring the same amount of current. To determine the greatest length of track that can be economically used without feeders, where cars are scattered along a line, the distances intervening between the power-house, or other power or feeding center, and each car, are multiplied by the amperes required per car, and the sum of these products must not exceed the value of "*C*," as follows:

1 car	.5 miles	from power-house,	20	amperes	c = 10
1 "	1.5 "	" " "	20	"	c = 30
1 "	3. "	" " "	20	"	c = 60
1 "	5. "	" " "	20	"	c = 100
				Total	c = 200

In this case c = 200, or more than the limit of 166; therefore the feeder point must be between the third and fourth cars, and the distance will be governed much by the grade between these points, for it is obvious that each of the above cars will take a much larger current than stated when ascending grades, and the value of this extra current must be carefully determined before making the calculations.

HORSE-POWER OF ACCELERATION.

The following diagram shows the power required to accelerate one ton, when running at any speed, to the next higher speed in miles per hour.



HORSE-POWER NECESSARY TO ACCELERATE ONE TON BY CHARLES HENRY DAVIS, C. E. CONSULTING ENGINEER.

NOTE. TO FIND THE H.P. NECESSARY TO ACCELERATE OTHER WEIGHTS, MULTIPLY THE H. P. FOR ONE TON AS FOUND IN THIS DIAGRAM BY THE WEIGHT TO BE ACCELERATED MEASURED IN TONS OF 2000 LBS., THUS: FOR 2 TONS MULTIPLY BY 2; FOR 3 TONS BY 3, ETC.

FIG. 28. *Copyrighted, 1901, by Charles Henry Davis. All rights reserved.*

Power Curves. — For convenience in quickly ascertaining the horsepower required to propel a car of known weight under known conditions of speed and grade, the curves shown below have been calculated.

The quantities which the various lines represent are clearly marked in the cut, but for the benefit of those who may be unfamiliar with such diagrams, the following explanation is inserted: The left-hand portion of the lower horizontal line represents the speed in miles per hour; the right-hand portion of same line, the h. p. per car; the oblique lines in left-hand side of cut, the per cent grade as marked on each line; the oblique lines on right-hand side of cut, the weight of car as marked; while the vertical line in centre of cut represents the h. p. per ton.

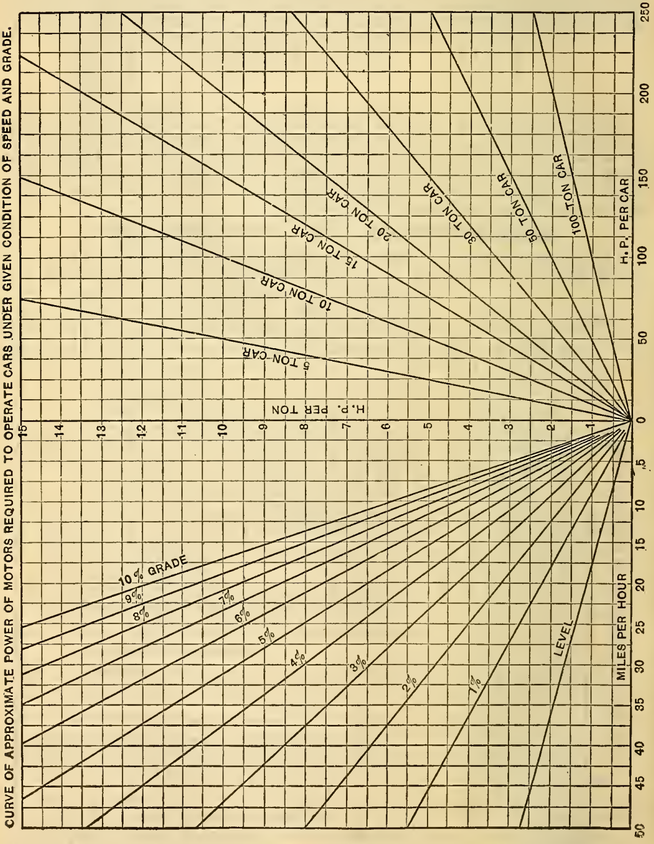


FIG. 29.

TABULATED CONSTANTS FOR DETERMINING THE HORSE-POWER OF TRACTION.

(Computed by W. F. D. Crane, M.E.)

Miles per Hour.	*H* on Levels. *K*=10	H′ on Grades — To be Added to Horse-Power on Levels.												
		1%	1½%	2%	2½%	3%	3½%	4%	4½%	5%	6%	7%	8%	9%
¼	.00666	.01333	.0200	.0266	.0333	.0400	.0466	.0533	.0600	.0666	.0800	.0933	.1166	.1200
½	.01333	.0266	.0400	.0533	.0666	.0800	.0933	.1066	.1200	.1333	.1600	.1866	.2133	.2400
¾	.0200	.0400	.0600	.0800	.1000	.1200	.1400	.1600	.1800	.2000	.2400	.2800	.3200	.3600
1	.0266	.0533	.0800	.1066	.1333	.1600	.1866	.2133	.2400	.2666	.3200	.3733	.4266	.4800
1½	.0400	.0800	.1200	.1600	.2000	.2400	.2800	.3200	.3600	.4000	.4800	.5600	.6400	.7200
2	.0533	.1066	.1600	.2133	.2666	.3200	.3733	.4266	.4800	.5333	.6400	.7466	.8533	.9600
2½	.0666	.1333	.2000	.2666	.3333	.4000	.4866	.5333	.6000	.6666	.8000	9.333	1.066	1.200
3	.0800	.1600	.2400	.3200	.4000	.4800	.5600	.6400	.7200	.8000	.9600	1.120	1.280	1.440
3½	.0933	.1866	.2800	.3733	.4666	.5600	.6533	.7466	.8400	.9333	1.120	1.306	1.493	1.680
4	.1066	.2133	.3200	.4266	.5333	.6400	.7466	.8533	.9600	1.066	1.280	1.493	1.706	1.920
4½	.1200	.2400	.3600	.4800	.6000	.7200	.8400	.9600	1.080	1.200	1.440	1.680	1.920	2.160
5	.1333	.2666	.4000	.5333	.6666	.8000	.9333	1.066	1.200	1.333	1.600	1.866	2.133	2.400
5½	.1466	.2933	.4400	.5866	.7333	.8800	1.026	1.173	1.320	1.466	1.760	2.053	2.346	2.640
6	.1600	.3200	.4800	.6400	.8000	.9600	1.120	1.280	1.440	1.600	1.920	2.240	2.560	2.88
6½	.1733	.3466	.5200	.6933	.8666	1.040	1.213	1.386	1.560	1.733	2.080	2.426	2.773	3.120
7	.1866	.3733	.5600	.7466	.9333	1.120	1.3066	1.413	1.680	1.866	2.240	2.613	2.986	3.360
7½	.2000	.4000	.6000	.8000	1.000	1.200	1.400	1.600	1.800	2.000	2.400	2.800	3.200	3.600
8	.2133	.4266	.6400	.8533	1.066	1.280	1.493	1.706	1.920	2.133	2.560	2.986	3.413	3.840
8½	.2266	.4533	.6800	.9066	1.133	1.360	1.586	1.813	2.040	2.266	2.720	3.173	3.626	4.080
9	.2400	.4800	.7200	.9600	1.200	1.440	1.680	1.920	2.160	2.400	2.880	3.360	3.840	4.320
10	.2666	.5333	.8000	1.066	1.333	1.600	1.866	2.133	2.400	2.666	3.200	3.733	4.266	4.800
11	.2933	.5866	.8800	1.173	1.466	1.760	2.053	2.346	2.640	2.933	3.520	4.106	4.693	5.280
12	.3200	.6400	.9600	1.280	1.600	1.920	2.240	2.560	2.880	3.200	3.840	4.480	5.120	5.700
13	.3466	.6933	1.040	1.3866	1.733	2.080	2.426	2.773	3.120	3.466	4.160	4.853	6.346	6.240
14	.3733	.7466	1.120	1.493	1.866	2.240	2.663	2.986	3.360	3.733	4.480	5.226	5.973	6.72
15	.4000	.8000	1.200	1.600	2.000	2.400	2.800	3.200	3.600	4.000	4.800	5.600	6.400	7.200

H. P. $= \frac{Wn}{375} (K \pm 2000 \sin \theta)$. W = Load in tons. n = Speed in miles per hour,

$\doteq Wn \times .0026\frac{2}{3} (K \pm 2000 \sin \theta)$. K = Resistance in lbs. per ton. $K' = \frac{K}{10}$

H = Constants of power required to move ONE TON ON LEVEL at speeds in table with $K = 10$.

H' = Constants of ADDITIONAL POWER required to raise ONE TON ON GRADES and at speeds given.

$H \times WK'$ = H. P. required on LEVELS alone for speeds given.

$H' \times W$ = H. P. additional on GRADES alone for speeds and % given.

$W(K'H \pm H')$ = total H. P. required.

Example: Given a motor car, total weight 9 tons, to ascend a 7 per cent grade at a speed of six miles per hour. What is the estimated horse-power required, with $K = 30$ lbs.?

H for 6 miles per hour is .16, which, multiplied by $9 \times \frac{30}{10}, = 4.32$ h. p., in overcoming the track resistances alone.

$H' = 2.240$, which, multiplied by 9, = 20.16. The sum of the two will give the total theoretical, *i.e.*, 24.48 h.p. required. Allowing 50 per cent as the combined efficiency of motors and gearing, to operate this car would require a draft of 48.96 h. p. upon the line.

HORSE-POWER OF TRACTION. (Davis.)

Per Cent Grade.	Speed in Miles per Hour.												
	4	6	8	10	12	15	20	25	30	35	40	50	60
	Horse-Power Required to Propel One Ton at Various Speeds up Various Grades.												
0	.32	.48	.64	.80	.96	1.20	1.60	2.00	2.40	2.80	3.20	4.00	4.80
1	.53	.80	1.07	1.33	1.60	2.00	2.66	3.33	4.00	4.66			
2	.74	1.12	1.49	1.87	2.24	2.80	3.63	4.66	5.60				
3	.93	1.44	1.92	2.40	2.88	3.60	4.80	6.00					
4	1.17	1.76	2.34	2.93	3.52	4.40	5.47						
5	1.39	2.08	2.77	3.46	4.16	5.20							
6	1.60	2.40	3.20	4.00	4.80								
7	1.88	2.72	3.62	4.53									
8	2.02	3.04	4.05										
9	2.24	3.36	4.48										
10	2.47	3.68	4.90										
11	2.67	4.00											
12	2.88	4.32											
13	3.09												
14	3.29												
15	3.52												

NOTE No. 1. — The h. p. required to propel a car equals the total weight of car plus its load (in tons) multiplied by the h. p. in table corresponding to assumed grade and speed.

STREET RAILWAY.

Tractive Force.

F. E. Idell, M. E.

On Good Track. —	To start car	116 lbs. per ton.
	To keep in motion at 6 miles per hr.	15.6 " " "
On Bad Track. —	To start car	135 " " "
	To keep in motion	32 " " "
On Curves. —	To start car from 0 to 6 miles per hour average, 264 feet per minute. .	284 " " "

APPROXIMATE INDICATED HORSE-POWER PER CAR. (Dawson.)

Number Cars.	I. H. P.
1 to 5	35
5 " 10	30
10 " 15	25
15 " 25	20
25 " 50	15

I. H. P. per car in large city systems varies from 18 to 23.

TRACTION.

(Davis.)

Per cent Grade.	Tractive Force in Pounds per Ton.	Load of Trailer Cars in Tons which a Motor Car of one Ton will Haul.		
		Snowy Rail.	Wet Rail.	Dry Rail.
0	30	8.50	12.33	16.00
1	50	4.70	7.00	9.00
2	70	3.07	4.21	6.14
3	90	2.17	3.44	4.55
4	110	1.60	2.63	3.54
5	130	1.19	2.07	2.84
6	150	0.90	1.66	2.33
7	170	0.70	1.35	2.00
8	190	0.50	1.10	1.63
9	210	0.35	0.90	1.38
10	230	0.24	0.74	1.17
11	250	0.14	0.60	1.00
12	270	0.05	0.48	0.85
13	290	Wheels slip.	0.38	0.77
14	310	. . .	0.30	0.61
15	330	. . .	0.21	0.51
16	350	. . .	0.14	0.43
17	370	. . .	0.08	0.35
18	390	. . .	0.02	0.28
19	410	. . .	Wheels slip.	0.22
20	430	. . .	. . .	0.16
21	450	. . .	. . .	0.11
22	470	. . .	. . .	0.06
23	490	. . .	. . .	Wheels slip.

NOTE No. 1.—Multiply figures in table by weight of motor car (in tons) to get weight of trailer (in tons) that said motor car will haul up corresponding grades.

REVOLUTIONS PER MINUTE OF VARIOUS SIZED WHEELS TO MAKE VARIOUS SPEEDS.

Diameter of Wheel.	Miles per Hour.									
	2	4	6	8	10	15	20	25	30	40
	Feet per Minute.									
	176	352	528	704	880	1320	1760	2200	2640	3520
24 in.	28	56	84	112	140	210	280	350	420	560
26 in.	26	52	78	103	129	194	258	323	388	517
28 in.	24	48	72	96	120	180	240	300	360	480
30 in.	22	45	67	90	112	168	224	280	336	448
33 in.	20	41	61	82	102	153	204	255	306	408
36 in.	19	37	56	75	93	140	187	234	280	374
42 in.	16	32	48	64	80	120	160	200	240	320

TRACTION.

Theoretical Horse-Power per Ton of 2000 Lbs. and per Mile per Hour with Various Grades and Coefficients of Traction.

(Merrill.)

% Grade.	Coefficient of Traction.										
	12	13.5	15	18	20	25	30	35	40	50	60
0	.032	.036	.04	.048	.05⅓	.06⅔	.08	.09⅓	.10⅔	.13⅓	.16
1	.085⅓	.089⅓	.09⅓	.101⅓	.10⅔	.12	.13⅓	.14⅔	.16	.18⅔	.21⅓
2	.138⅔	.142⅔	.14⅔	.154⅔	.16	.17⅓	.18⅔	.20	.21⅓	.24	.26⅔
3	.192	.196	.20	.208	.21⅓	.22⅔	.24	.25⅓	.26⅔	.29⅓	.32
4	.245⅓	.249⅓	.25⅓	.261⅓	.26⅔	.28	.29⅓	.30⅔	.32	.34⅔	.37⅓
5	.298⅔	.302⅔	.30⅔	.314⅔	.32	.33⅓	.34⅔	.36	.37⅓	.40	.42⅔
6	.352	.356	.36	.368	.37⅓	.38⅔	.40	.41⅓	.42⅔	.45⅓	48
7	.405⅓	.409⅓	.41⅓	.421⅓	.42⅔	.44	.45⅓	.46⅔	.48	.50⅔	.53⅓
8	.458⅔	.462⅔	.46⅔	.474⅔	.48	.49⅓	.50⅔	.52	.53⅓	.56	.58⅔
9	.512	.516	.52	.528	.53⅓	.54⅔	.56	.57⅓	.58⅔	.61⅓	.64
10	.565⅓	.569⅓	.57⅓	.581⅓	.58⅔	.60	.61⅓	.62⅔	.64	.66⅔	.69⅓
11	.618⅔	.622⅔	.62⅔	.634⅔	.64	.65⅓	.66⅔	.68	.69⅓	.72	.74⅔
12	.672	.676	.68	.688	.69⅓	.70⅔	.72	.73⅓	.74⅔	.77⅓	.80
13	.725⅓	.729⅓	.73⅓	.741⅓	.74⅔	.76	.77⅓	.78⅔	.80	.82⅔	.85⅓
14	.778⅔	.782⅔	.78⅔	.794⅔	.80	.81⅓	.82⅔	.84	.85⅓	.88	.90⅔
15	.832	.836	.84	.848	.85⅓	.86⅔	.88	.89⅓	.90⅔	.93⅓	.96

$$H.P. = .002\tfrac{2}{3}\,[K + (20 \times \%\ \text{grade})].$$

HORSE-POWER, SPEED, AND HORIZONTAL EFFORT IN POUNDS.

Mech. H. P.	Miles Per Hour.									
	2	4	6	8	10	15	20	25	30	40
	Feet Per Minute.									
	176	352	528	704	880	1320	1760	2200	2640	3520
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
2	375.0	187.0	125.0	93.7	75.0	50.0	37.5	30.0	25.0	18.7
4	750.0	375.0	250.0	187.5	150.0	100.0	75.0	60.0	50.0	37.5
6	1125.0	562.0	375.0	281.2	225.0	150.0	112.5	90.0	75.0	56.2
8	1500.0	750.0	500.0	375.0	300.0	200.0	150.0	120.0	100.0	75.0
10	1875.0	937.0	625.0	468.7	375.0	250.0	187.5	150.0	125.0	93.7
15	2812.0	1406.0	937.0	703.1	562.5	375.0	281.2	225.0	187.5	140.6
20	3750.0	1870.0	1250.0	937.2	750.0	500.0	375.0	300.0	250.0	187.5
25	4687.0	2343.0	1562.0	1172.0	937.5	625.0	468.7	375.0	312.5	234.3
30	5625.0	2812.0	1875.0	1406.0	1125.0	750.0	562.5	450.0	375.0	281.2
40	7500.0	3750.0	2500.0	1875.0	1500.0	1000.0	750.0	600.0	500.0	375.0
50	9372.0	4687.0	3125.0	2344.0	1875.0	1250.0	937.5	750.0	625.0	468.7

POWER REQUIRED FOR DOUBLE AND SINGLE TRUCK CARS.

Wattmeter placed on car. (McCulloch.)

	Average Watts.	Average Watt-hours per Car-mile.	Average Speed. Miles per Hour.	Average Watts, per Seat Capacity.	Average Watts per Ton (car empty).	Average Watt-hours per Car Mile per 1000 Passengers.
Double-truck car. Seats 36; weight, 11.75, tons; average for entire day	12040	1334	9.03	335	1025	5.9
Same as above. Average for heaviest trip . . .	13080	1412	9.25	335	1025	——
Single-truck car, no trailer. Seats 28; weight, 8 tons	8471	921	9.20	303	1060	——
Single-truck car. Trailers operated 26% of the time. Average for the entire day	9400	1110	8.42	254	1088	7.9
Single-truck motor and open trailer. Seats, 63; weight, 10.5 tons. Average for heaviest trip	12680	1440	8.84	201	1208	——

HORIZONTAL EFFORT EXERTED ON CURVES.

Pounds Per Ton.

Length of Wheel Base, Feet.	Radius of Curvature — Feet.							
	25	30	40	50	60	70	80	100
3.5	88.6	73.9	55.4	44.3	36.9	31.7	27.7	22.2
4	94.0	78.4	58.8	47.0	39.2	33.6	29.4	23.5
4.5	99.4	82.9	62.2	49.7	41.4	35.5	31.1	24.9
6	115.6	96.4	72.3	57.8	48.2	41.3	36.1	28.9
6.5	121.0	100.9	75.7	60.5	50.4	43.2	37.9	30.3
7	126.4	105.4	79.0	63.2	52.7	45.2	39.5	31.6

Assumed — 3 miles per hour speed on curve, 4 ft. 8½ in. gauge.

Formula from Molesworth :

Let

W = weight on wheels in lbs.
K = coefficient, in this case .27.
G = gauge of track = 4.′ — 8½″ = feet.
B = rigid wheel base in feet.
R = radius of curves in feet.

Then

$$\text{Tractive force or resistance per ton} = \frac{W \times K \times (G + B)}{2\,R}$$

HORIZONTAL EFFORT ON GRADES.

Pounds per Ton.

Grade. Per Ct.	Speed — Miles per Hour.									
	2	4	6	8	10	12	14	16	18	20
0	15.03	15.11	15.24	15.42	15.66	15.95	16.29	16.69	17.14	17.64
1	35.03	35.11	35.24	35.42	35.66	35.95	36.29	36.69	37.14	37.64
1½	45.03	45.11	45.24	45.42	45.66	45.95	46.29	46.69	47.14	47.64
2	55.03	55.11	55.24	55.42	55.66	55.95	56.29	56.69	57.14	57.64
2½	65.03	65.11	65.24	65.42	65.66	65.95	66.26	66.69	67.14	67.64
3	75.03	75.11	75.24	75.42	75.66	75.95	76.29	76.69	77.14	77.64
3½	85.03	85.11	85.24	85.42	85.66	85.95	86.29	86.69	87.14	87.64
4	95.03	95.11	95.24	95.42	95.66	95.95	96.29	96.69	97.14	97.64
5	115.03	115.11	115.24	115.42	115.66	115.95	116.29	116.69	117.14	117.64
6	135.03	135.11	135.24	135.42	135.66	135.95	136.29	136.69	137.14	137.64
7	155.03	155.11	155.24	155.42	155.66	155.95	156.29	156.69	157.14	157.64
8	175.02	175.11	175.24	175.42	175.66	175.95	176.29	176.69	177.14	177.64
9	195.03	195.11	195.24	195.42	195.66	195.95	196.29	196.69	197.14	197.64
10	215.03	215.11	215.24	215.42	215.66	215.95	216.29	216.69	217.14	217.64

APPROXIMATE CURRENT CONSUMPTION PER CAR.

Two 25-H.P., S. R. G. Motors.

Diameter Wheels. Inches.	Horizontal Effort — Pounds.									
	100	200	400	600	800	1000	1200	1400		
30	25.8	32.8	44.6	54.6	63.8	72.6	82.6	92.0		
33	26.6	34.0	47.0	57.6	67.4	77.6	88.4	98.2		

Two 30-H.P., S. R. G. Motors.

Diameter Wheels. Inches.	Horizontal Effort — Pounds.									
	100	250	500	750	1000	1250	1500	2000	2500	3000
30	28.6	38.8	51.4	63.0	73.2	84.2	93.4	111.8	130.0	147.6
33	29.4	40.0	54.0	65.8	77.0	88.8	98.8	119.2	138.4	158.0

AXLE SPEED PER CAR WITH DOUBLE MOTOR EQUIPMENT—REVS. PER MINUTE.

Average of Several Types 25-H.P. Motors.

Diameter Wheels. Inches.	Horizontal Effort — Pounds.									
	100	200	400	600	800	1000	1200	1400		
30	308	253	195	170	153	141	131	122		
33	300	248	189	165	149	136	126	119		

Average of Several Types of 30 H. P. Motors.

liameter Wheels. nches.	Horizontal Effort — Pounds.									
	100	250	500	750	1000	1250	1500	2000	2500	3000
30	282	260	202	173	153	139	130	117	107	100
33	272	252	194	166	148	134	125	113	103	95

Formula for close approximation of current required to propel a given car.

No. tons in train × [((% grade + 1) 20) + (curve resistance per ton)] = Pounds Horizontal Effort.

NO. OF CARS ON TEN MILES OF TRACK, VARIOUS SPEEDS AND HEADWAYS.

Minutes Apart or Hdway.	Average Speed in Miles per Hour.									
	6	7	8	9	10	12	15	20	25	30
1	100	86	75	67	60	50	40	30	24	20
2	50	44	38	33	30	25	20	15	12	10
3	33	29	25	22	20	17	13	10	8	7
4	25	22	19	14	15	13	10	8	6	5
5	20	17	15	13	12	10	8	6	5	4
6	17	14	13	11	10	8	7	5	4	3
7	14	12	11	10	9	7	6	4	3	3
8	13	11	9	8	8	6	5	4	3	3
10	10	9	8	7	6	5	4	3	2	2
15	7	6	5	4	4	3	3	2	2	1
20	5	4	4	3	3	3	2	2	1	1
30	3	3	3	2	2	2	1	1	1	1

Note.—Fractions above one-half are considered whole numbers, and fractions below one-half are neglected.

To obtain the number of cars required to operate any length road, divie the number found in the table under the desired average speed and headway by ten, and multiply by the length of the road in question. Shouldt

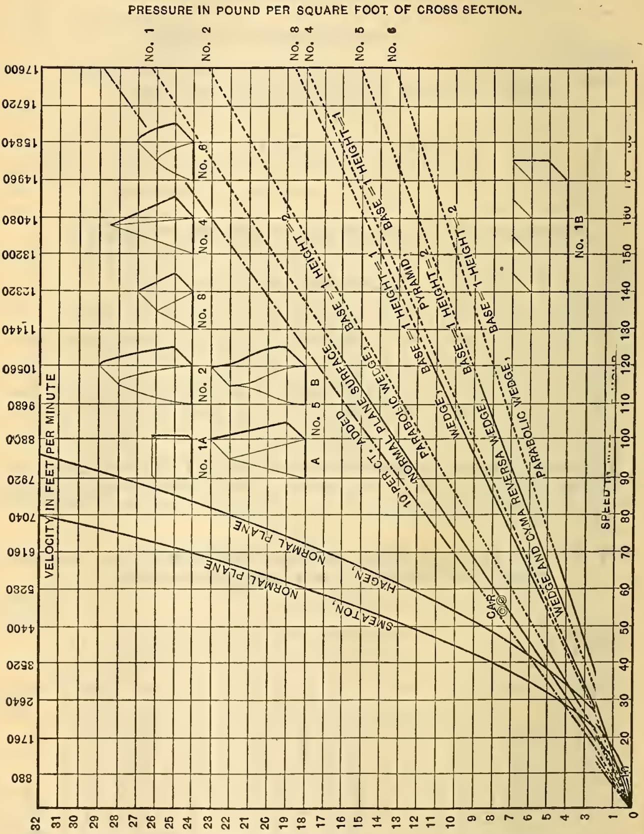


Fig. 30. "Effect of Shape of Moving Body on Air Resistance," Crosby's Experiments.

be desired to run at different average speeds on various portions of the road, treat each portion as a separate road, and add the results together. To the number of cars thus obtained should be added 20 per cent for reserve for roads under 20 cars. For roads over 20 cars, 10 per cent reserve will be enough

Formula :—

Let n = number of cars required.
m = miles of track.
S = average speeds in miles per hour.
I = interval or headway in minutes.

Then,

$$n = \frac{m \times 60}{S \times I}.$$

HEADWAY, SPEED, AND TOTAL NUMBER OF CARS.

Total number of cars on a given length of street on which cars are running both ways = (length of street × 120) ÷ (headway in minutes × speed in miles per hour).

MILES PER HOUR IN FEET PER MINUTE AND PER SECOND.

(Merrill.)

Miles per Hour.	Feet per Minute.	Feet per Second.	Miles per Hour.	Feet per Minute.	Feet per Second.
1	88	1.46	16	1408	23.47
2	176	2.94	17	1496	24.93
3	264	4.4	18	1584	26.4
4	352	5.87	19	1672	27.86
5	440	7.33	20	1760	29.33
6	548	8.8	21	1848	30.8
7	616	10.26	22	1936	32.26
8	704	11.73	23	2024	33.72
9	792	13.2	24	2112	35.2
10	880	14.67	25	2200	36.67
11	968	16.13	26	2288	38.14
12	1056	17.6	27	2376	39.6
13	1144	19.07	28	2464	41.04
14	1232	20.52	29	2552	42.50
15	1320	22	30	2640	44

RATING STREET-RAILWAY MOTORS.

(Condensed from W. B. Potter in Street Railway Journal.)

Rise of temperature after one hour's run under rated full load not to exceed 75° C. ; room being assumed at 25° C. Average load for a day's run should not exceed 30 per cent of its rated full load, which will give a rise of temperature of about 60° C.

The above ratings are based on a line potential of 500 volts, but the average performance can generally be increased in proportion to the increase in line voltage ; that is, a motor will do approximately 10 per cent heavier service for the same temperature rise when operated at 550 volts.

With electric brakes, motors must have increased capacity, as heating increases 20 to 25 per cent. The 20 per cent increase is on roads having few grades and stops, while the 25 per cent is on hilly roads with frequent stops.

Approximate rated horse-power of motors =

(total weight of car in tons) × (max. speed in miles per hour on level).

For equipments with electric brakes, divide by 4 instead of 5. When maximum speed is not known, it may be assumed as twice the schedule speed.

Example 1:

$$\frac{\text{20 ton car (loaded)} \times \text{50 m. p. h.}}{5} = \text{200 h. p., or four 50 h. p. motors.}$$

In this case, if the line pressure were raised to 600 volts, electric brakes could be used on the equipment by changing the gear ratio so as to have the same maximum speed.

Example 2:

$$\frac{\text{11 ton car (loaded)} \times \text{25 m. p. h.}}{5} = \text{55 h. p., or two 30 h. p. motors,}$$

These rules indicate minimum capacity under ordinary conditions.

Tractive Effort.

Tractive effort is dependent on the rate of acceleration, grade, car friction, and air resistance, which latter is ordinarily included in friction. Acceleration is expressed in miles an hour per sec. 1 mile per hour per sec. = 1.466 feet per sec. Excluding car friction, a tractive effort of 92⅓ lbs. per ton (2000) will produce an acceleration of 1 mile per hour per sec. on a level track, and the rate of acceleration will vary in direct proportion to the amount of tractive effort. On ordinary street cars, tractive effort during acceleration often rises to 200 or 300 lbs. per ton.

On elevated or suburban roads the maximum tractive effort is generally 100 to 150 lbs. per ton. For heavy freight work with slow speeds, the tractive effort seldom exceeds 30 to 40 lbs. per ton.

Grades are commonly expressed in percentage of feet rise in 100 feet of distance, and tractive effort for a grade is the same percentage of the weight to be drawn as the rise is of the length of 100 feet. For instance, the tractive effort for a weight of one ton (2000 lbs.) up a grade of 3 per cent would be 3 per cent of 2000 lbs., or 60 lbs. For the total tractive effort there must be added to this, the effort for overcoming the car, wind, and rolling friction on a level.

Maximum tractive efforts from numerous tests are shown in the following table:

	Tractive effort in lbs. per ton.
15 ton car, up to 25 m. p. h.	25
" " " " " 50 " " "	50
25 " " " " 25 " " "	20
" " " " " 50 " " "	25
100 " train " " 25 " " "	15
Heavy freight train up to 25 m. p. h.	6 to 10.

The above figures have to be increased for snow and ice on the track

Tractive Coefficient.

This coefficient is usually expressed as the ratio between the weight on the driving-wheels and the tractive effort, and varies largely with the condition of the rails.

In train work, the weight on drivers should be six times the tractive effort.

Example:—Required the weight of a locomotive to draw a 100-ton train up a 2 per cent grade.

For train.

100 tons × 15 lbs. for friction = 1500 lbs.
" " × 40 " " grade = 4000 "
5500 lbs.

Assume a 20-ton locomotive.

20 tons × 15 lbs. for friction = 300 lbs.
20 " × 40 " " grade = 800 "

Total tractive effort, 6600 lbs.

6600 lbs. equals 16.5 per cent of 20 tons, or a tractive coefficient of 16.5 per cent. Starting the train on a 2 per cent grade with acceleration of ⅓ m. p. h. per sec. would mean additional tractive effort equivalent to $\frac{92.3}{3} = 30.8$ lbs. per ton.

This would add to the requirements as follows:

Train 100 tons, for friction and grade as above . . .	5500 lbs.
" " " at 30.8 lbs. for acceleration	3080 "
Total for train	8580 lbs.

Assume 35-ton locomotive with motors on all axles.

35 tons at 15 lbs. for friction	525 lbs.
" " " 40 " " grade	1400 "
" " " 30.8 for acceleration	1078 "
Total tractive effort . . .	11583 lbs.

or a tractive coefficient of 16.5 per cent for the 35-ton locomotive.

Tests show the following tractive coefficients:

	per cent.	Sanded per cent.
Dry rail	28	30
Thoroughly wet rail	20	25
Greasy moist rail .	15	25

With ice and snow on the track, the coefficient is lower, and the rolling-friction higher.

Average energy.—Approximate capacity of a power station may be assumed as about 100 watt-hours per ton mile of schedule speed for ordinary conditions of city and suburban service.

Example:—15-ton car, 12 miles per hour schedule,

k.w. at station = 100 × 15 × 12 = 18 k.w.

If stops are a mile or more apart, only 60 to 70 watt-hours may be necessary.

Frequent stops and high schedule speeds take 120 or more watt-hours.

The following table of efficiencies will be found convenient in estimating the power required for operation of motor cars, using three-phase transmission and direct current motors. The efficiencies would vary somewhat with the load factor, but can be taken as generally applicable.

Considering the I.H.P. of the engine as a basis, for the

Average efficiency of engine	90 per cent.
" " " generator	94 " "
" " " high potential lines	95 " "
" " " substations	90 " "
" " " direct current lines	92 " "
" " " motors, including losses of control	72 " "
Combined efficiency of the motors and series parallel control during period of cutting out the controller may be taken as	63 " "
Efficiency of motors after cutting out the controller, depending on size of motors	80 to 85 per cent.

DIMENSIONS, WEIGHTS, ETC., OF PRINCIPAL TYPES OF RAILWAY MOTORS.

(Geo. F. Hanchett in *Street Railway Journal.*)

Designation.		General Data.													
No.	Name of Motor.	Service.	H.P.	Maker.	Speed at Full Load.	Reduction Ratio.	Gearing.		No. of Poles.	No. of Field Coils.	Total Field Turns.	Slots in Armature.	Conductors per Slot.	Commutator Bars.	No of Bands.
							Pin.	Gear.							
1	S. R. G. 30	St. Railway	15	Thomson-Houston	. . .	4.78	14	67	2	2	206	64	32	64	. . .
2	W. P. 30	St. Railway	15	Thomson-Houston	. . .	4.78	14	67	2	1	139	64	16	64	None
3	W. P. 50	St. Railway	25	Thomson-Houston	. . .	4.78	14	67	2	1	102	64	9, 12 or 13	64	None
4	S. R. F. 30	St. Railway	15	Thomson-Houston	. . .	4.78	14	67	2	2	320	Smooth body	10	64	. . .
5	G. E. 800	St. Railway	25	General Electric Co.	. . .	4.78	14	67	4	2	203	105	6 + 8	105	. . .
6	G. E. 1000	St. Railway	35	General Electric Co.	500	3.94	17	67	4	4	143.5	93	8	93	. . .
7	G. E. 1200	Interurban	38	General Electric Co.	. . .	3.53	17	60	4	2	198	105	8	105	. . .
8	G. E. 2000	Interurban	138	General Electric Co.	. . .	3.18	17	54	4	2	84	141	2	141	. . .
9	G. E. 51	Interurban	82	General Electric Co.	. . .	1.74	31	54	4	4	56	37	12	111	. . .
10	G. E. 52	St. Railway	27	General Electric Co.	. . .	4.78	14	67	4	4	155.5	29	24	87	. . .
11	G. E. 57	Traction He'vy	52	General Electric Co.	. . .	3.72	18	67	4	4	110	33	18	99	. . .
12	No. 3	St. Railway	20-25-30	Westinghouse Elec. & Mfg. Co.	300	3.45	18	62	4	4	. . .	95	. . .	95	22

13	No. 12	St. Railway	25-30	Westinghouse Elec. & Mfg. Co.	525-715	4.86	14	68	4	4	. . .	47	. . .	93	13
14	No. 12 A	St. Railway	25-30	Westinghouse Elec. & Mfg. Co.	510-550 685	4.86	14	68	4	4	. . .	47	. . .	93	14
15	No. 38 B	Interurban	50	Westinghouse Elec. & Mfg. Co.	520	2.42 3.56 4.86	24 18 14	50 64 68	4	4	. . .	45	. . .	135	6
16	First Walker Motor	St. Railway	25	Walker Mfg. Co.	375	3.65	. . .	. . .	4	4	167	101	6	101	. . .
17	No. 3 N	Narrow Gage	25	Walker Co.	600	4.78	14	67	4	4	144	55	16	109	3
18	No. 2 Special	Narrow Gage	20	Walker Co.	400	5.41	17	92	4	4	125	48	30	143	. . .
19	3 S	St. Railway	25	Walker Co.	600	4.78	14	67	4	4	154	95	8	95	4
20	4 A	St. Railway	30	Walker Co.	550	4.78	14	67	4	4	161	95	8	95	5
21	No. 10	Suburban	50	Walker Co.	525	3.90	19	74	4	4	109½	95	6	95	5
22	No. 15	Interurban	75	Walker Co.	580	3.29	17	56	4	2	135	57	8	227	3
23	No. 20	Interurban	125	Walker Co.	660	3.375	16	54	4	2	90	63	4	125	. . .
24	No. 25	Interurban	200	Walker Co.	750	4.4	15	66	4	4	65	73	6	218	10
25	Gearless	St. Railway	20	Short Elec. Ry. Co.	110	. . .	. . .	. . .	6	3	264	48	16	184	. . .
26	Short S. R. G.	St. Railway	20	Short Elec. Ry. Co.	550	5	. . .	. . .	4	8	. . .	48	30	144	. . .
27	Oerlikon	St. Railway	20	Oerlikon Mac. Wks.	400	4.2	. . .	. . .	4	4	. . .	. . .	. . .	. . .	. . .
28	Oerlikon	St. Railway	15	Oerlikon Mac. Wks.	. . .	5	. . .	. . .	4	4	. . .	. . .	. . .	. . .	. . .
29	Oerlikon	St. Railway	10	Oerlikon Mac. Wks.	450	5	. . .	. . .	4	4	. . .	. . .	. . .	. . .	. . .
30	S. R. G.	St. Railway	30	Edison Gen. El. Co.	. . .	4.78	14	67	4	2	. . .	. . .	. . .	. . .	. . .
31	S. R. G.	St. Railway	15	Edison Gen. El. Co.	. . .	4.78	14	67	4	2	. . .	. . .	. . .	. . .	. . .

DIMENSIONS. WEIGHTS, ETC., OF PRINCIPAL TYPES OF RAILWAY MOTORS—(*Continued*).

(Georg e F. Hanchett, in *Street Railway Journal.*)

Number.	Weight, Lbs.			Dimensions, Inches.								Remarks.
	Complete with Gears.	Armature Complete.	Gears and Casing	Commutator Bearing.		Pinion Bearing.		Diameter of Armature.	Length of Armature.	Field wire. B. & S.	Armature wire. B. & S.	
					×		×					
1	2275	484	300	2	$2\frac{3}{4}$	$3\frac{3}{8}$	$5\frac{1}{2}$	$14\frac{1}{2}$	$8\frac{5}{8}$	. . .	. . .	Ring armature, 16 turns per section.
2	1975	665	325	. . .	. . .	. . .	. . .	$19\frac{5}{8}$	$7\frac{7}{16}$	. . .	. . .	Ring armature, toothed armature retained in lower half of frame.
3	3280	925	347	$2\frac{3}{4}$	$3\frac{1}{32}$	$2\frac{3}{4}$	$6\frac{1}{16}$	$19\frac{5}{8}$	$11\frac{1}{16}$	No. 4	.34 × .04	Ring armature, toothed, wound with flat ribbon.
4	2260	335	360	$3\frac{33}{64}$	$3\frac{1}{32}$	$3\frac{33}{64}$	$6\frac{1}{16}$	$9\frac{3}{4}$	9	. . .	. . .	Smooth body drum.
5	1800	635	235	$2\frac{1}{2}$	$4\frac{1}{2}$	$2\frac{1}{2}$	6	16	8	. . .	. . .	Eickmeyer drum, armature retained in lower half of frame.
6	2185	578	285	$2\frac{5}{8}$	$6\frac{3}{8}$	3	8	14	$13\frac{1}{8}$	. . .	. . .	Eickmeyer drum, armature retained in upper half of frame.
7	2975	963	294	$3\frac{1}{4}$	6	$3\frac{1}{4}$	8	16	13	. . .	. . .	Eickmeyer drum, armature retained in lower half of frame.
8	4650	1450	355	$3\frac{1}{4}$	6	$3\frac{1}{4}$	8	$18\frac{1}{2}$	$13\frac{1}{4}$	. . .	. . .	Eickmeyer drum, armature retained in lower half of frame.
9	3875	953	338	3	$5\frac{3}{4}$	$3\frac{1}{4}$	$8\frac{1}{4}$	16	10.5	. . .	. . .	Straight out winding, armature retained in upper half of frame.
10	1725	357	265	$2\frac{1}{2}$	$6\frac{3}{8}$	$2\frac{3}{4}$	$7\frac{3}{4}$	11	9	. . .	. . .	Straight out winding, armature retained in upper half of frame.
11	2972	704	340	$2\frac{7}{8}$	$6\frac{3}{8}$	$3\frac{1}{4}$	$8\frac{3}{4}$	14	12	. . .	. . .	Straight out winding, armature retained in upper half of frame.
12	2800	. . .	. . .	$1\frac{3}{4}$	$4\frac{11}{16}$	$2\frac{1}{2}$	$5\frac{1}{2}$	$11\frac{5}{8}$	15	. . .	No. 11.	Rectangular formed coils.

13	. . .	. . .	. . .	2	5¾	2½	6	. . .	. . .	. . .	. . .	
14	2270	360	350	2½	6	2½	6	11⅝	8⅛	. . .	. . .	One coil cut out.
15	2340	525	325	2¾	6	2¾	6	13⅞	. . .	. . .	. . .	Three coils per slot, no dead coil.
16	. . .	. . .	. . .	. . .	. . .	. . .	. . .	15	13	No. 8 B. W. G.	No. 10	Rectangular formed coils.
17	2079	405	292	. . .	. . .	. . .	. . .	12¾	14⅝	.180″ diam.	.09″ diam.	Eickmeyer winding.
18	1800	. . .	. . .	. . .	. . .	. . .	. . .	15	13¾	.180″ diam.	.08″ diam.	Eickmeyer winding.
19	2165	410	308	2½	5½	2½	5½	12¾	9¼	.165″ diam.	.102″ diam.	Straight out winding.
20	2250	. . .	. . .	2½	5½	2½	5½	12¾	9¼	.180″ diam.	.102″ diam.	Straight out winding.
21	3040	750	414	2¾	6	2¾	6	15	10	No. 2	No. 7	Straight out winding.
22	4450	1050	490	3	6	3	8½	18	8⅝	No. 0	.042 × .6	Straight out winding.
23	4700	. . .	. . .	3¼	6¼	3¼	8	18	13	No. 000 B. W. G.	.072 × .7	Straight out winding.
24	5530	1395	495	3½	6½	3½	9	19	13½	No. 0000	.045 × .6	Straight out winding.
25	2300	. . .	. . .	. . .	. . .	. . .	. . .	21	14⅜	.165″ diam.	.09 × .13	Hand wound ring.
26	2220	. . .	. . .	. . .	. . .	. . .	. . .	21¾	5⅜	. . .	.063 × .100	Hand wound ring.
27	2424	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	
28	2050	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	
29	1764	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	
30	2270	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	
31	1600	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	

WEIGHT OF MOTOR TRUCKS.

(Dawson.)

	Wgt. of Wheel. Lbs.	Diam. of Wheel Inches.	Gauge Standard.	Wgt. of Truck (bare) Lbs.	Weight of Truck Equipped with							
					S. R. G. 30.		W. P. 30.		W. P. 50		G. E. 800.	
					One Motor. Lbs.	Two Motors. Lbs.	One Motor. Lbs.	Two Motors. Lbs.	One Motor. Lbs.	Two Motors. Lbs.	One Motor. Lbs.	Two Motors. Lbs.
Bemis, 4 wheel . . .	250	30	4′ — 8½″	3123	5500	7800	5100	7000	5700	8200	5000	6800
Brill, " " . . .	300	30		3500	5800	8100	5400	7300	6000	8500	5300	7100
McGuire, 4 wheel . .	300	30		3000	5300	7600	4900	6800	5500	8000	4800	6600
Tripp, " " . .	280	30		3600	5900	8200	5500	7400	6100	8600	5400	6900
Bemis, 8 wheel . . .	300	30		3120 each	5420	. . .	5020	. . .	5620	. . .	4900	. . .
Brill, maximum traction	300 200	30 22		2700 each	5000	. . .	4600	. . .	5200	. . .	4500	. . .
Tripp, 8 wheel . . .	280	30		3200 each	5500	. . .	5100	. . .	5700	. . .	5000	. . .
Robinson, radial . . .	300 200	30 24		5000	7300	7600	6900	8800	7500	10000	6800	8000
Pecham, 4 wheel . .	300	30		4000	6700	6000	6300	8200	6900	9400	6200	8000
" 8 " . .	300	30		. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

APPROXIMATE WEIGHTS OF TRUCKS.

Kind.	Weight.
Single truck for motor car	3500 lbs.
Maximum traction	2600 "
Pivotal, motor car	3900 "
" trail car	1500 "
Radial	3700 "
Running gear	1500 "

TORQUE AND HORSE-POWER.

H. P. per Lb. Applied at Periphery at 100 Rev. per Min.

Diameter Wheel.	26″	28″	30″	33″	36″
H. P.	.02062	.02221	.0238	.02618	.02856

Pounds at Periphery per H. P. at 100 Rev. per Min.

Diameter Wheel.	26″	28″	30″	33″	36″
Lbs.	48.481	45.018	42.017	38.197	35.014

$$\text{Lbs.} = \frac{126050.9 \times \text{H. P.}}{\text{Diam.} \times \text{Rev.}}$$

H. P. = .00000793 × diam. wheel × rev. × lbs. at periphery.

H. P. per lb. at periphery at one mile per hour = .002867.

Lbs. at periphery per H. P. at one mile per hour = 374.9.

Note on Emergency Braking of Cars.

In case of emergency, motormen often reverse the motors, which brings the car up with a severe jerk, and is quite apt to strip gears. This is not necessary, and should never be done unless the canopy switch is first thrown off, then when the motors are reversed and the controller handle thrown around to *parallel*, the motors will act as generators and will bring the car to an easy stop with no harm to the apparatus. In case circuit breakers are used in place of the plain canopy switches, the reversal of the motors will draw so much current from the line that the circuit breakers, if properly adjusted, will open the circuit and the controller can then be used as suggested above.

COPPER WIRE FUSES FOR RAILWAY CIRCUITS.

B. & S. Gauges.	17	16	15	14	13	12	11	10	9	8	7
Fuse Point in Amperes.	100	120	140	166	200	235	280	335	390	450	520

DIMENSIONS OF BRILL CARS.

(*Corrected to Nov. 1, 1900.*)

Size of Car.	Lengths.			Widths.		Seating Capacity, @ 17 in. per Person.	Approximate Weight.			Remarks.
	Body.	Over All. (Bumpers.)	Platforms.	Over Sills.	At Belt Rails.		Body, Lbs.	Trucks, Lbs.	Running Gear, Lbs.	
16 foot closed	15 ft. 10 in.	25 ft. 6 in.	4′	6 ft. 2 in.	7 ft. 6 in.	22	4500	4800	—	
16 " trailer . . .	15 " 10 "	25 " 6 "	4′	—	7 " 6 "	22	4000	—	1400	
16 " storage battery	15 " 10 "	25 " 6 "	4′	6 " 6 "	7 " 6 "	22	5000	4800	—	
Convertible summer and winter trailer .	16 " 7 "	26 " 3 "	4′	—	7 " 6 "	24	4600	—	1400	
do. do.	17 " 6 "	27 " 2 "	4′	—	7 " 7 "	28	4300	—	1400	
17 foot closed . . .	17 " 0 "	26 " 8 "	4′	—	8 " 0 "	24	4800	4800	—	8 feet high in Center
18 " " . . .	18 " 0 "	27 " 8 "	4′	6 " 2 "	7 " 6 "	24	4800	4800	—	Vestibules.
18 " " . . .	18 " 0 "	27 " 8 "	4′	6 " 2 "	7 " 6 "	24	5100	4800	—	Vestibules.
21 " " . . .	21 " 0 "	29 " 8 "	3′6″	6 " 2 "	7 " 6 "	28	5250	4800	—	
Convertible winter and summer trailer . .	22 " 0 "	30 " 8 "	3′6″	—	8 "	36	7400	—		
22 foot closed trailer .	22 " 0 "	30 " 8 "	3′6″		7 " 6 "	30	6000	3000	—	
24 " closed . . .	24 " 0 "	33 " 8 "	4′	6 " 6 "	7 " 6 "	32	6000	3200	—	
25 " " . . .	25 " 0 "	34 " 8 "	4′	6 " 6 "	7 " 6 "	34	5850	3200	—	
25 " " . . .	25 " 0 "	34 " 8 "	4′	6 " 6 "	7 " 6 "	34	6050	3200	—	Vestibules.
Convertible summer and winter	25 " 6 "	35 " 2 "	4′	7 " 0 "	7 " 10 "	40	6200	5200	—	Vestibules.
do. do.	27 " 6 "	37 " 2 "	4′	—	8 " 0 "	44	6200	5200	—	
Akron, Bedford & Cl.	31 " 10 "	42 " 0 "	—	—	—	44	—	—	—	Total Weight, 27860
Buffalo & Niagara Falls	29 " 0 "	38 " 8 "	—	7 " 5½"	8 " 0 "	40	—	—	—	" " 23750

DIMENSIONS OF BRILL CARS—(*Continued*).

Size of Car.	Lengths.			Widths.		Seating Capacity, Persons.	Approximate Weights.			Remarks.
	Body.	Over All. (Bumpers)	Platforms.	Over Sills.	At Belt Rails.		Body, Lbs.	Truck, Lbs.	Running Gear, Lbs.	
7 seat open	—	22 ft. 4 in.	4 ft.	6 ft. 2 in.	6 ft. 10 in.	35	3500	4800		
7 " " trailer . .	—	22 " 3 "	4 "	—	6 " 10 "	35	3400	1400		
8 " open	—	25 " 0 "	4 "	6 " 2 "	6 " 10 "	40	4000	4800		
8 " "	—	25 " 0 "	4 "	6 " 0 "	6 " 10 "	40	4400	4800		Closed ends.
9 " "	—	27 " 8 "	4 "	6 " 2 "	7 " 0½ "	45	6200	4800		
8 " "	—	25 " 0 "	4 "	—	6 " 10 "	40	4250	4800		Vestibules.
8 " "	—	25 " 0 "	4 "	6 " 2 "	7 " 0½ "	40	7200	4800		Vestibules.
10 " "	—	30 " 4 "	4 "	—	7 " 6 "	50	4000		1400	
18 foot trailer . . .	18 ft. 0 in.	25 " 0 "	3′6″	—	7 " 6 "	24	4000	—	1400	
10 seat open	—	30 " 4 "	—	6 " 2 "	7 " 2 "	50	5000	5800		
12 " "	—	35 " 8 "	—	6 " 2 "	7 " 2 "	60	6000	5800		
Open trailer	23 ft. 6 in.	27 " 6 "	4 ft.	—	7 " 6 "	32	5100	3000		Width at steps 8 ft. 4 in.
14 seat open trailer .		41 " 0 "	—	—	7 " 6 "	70	6500	3200		
15 " " " . .	37 " 4 "	42 " 8 "	—	—	8 " 0 "	75	9000	6000		
Combined baggage and passenger car . .	26 " 0 "	32 " 0 "	3 ft.	6 " 10 "	7 " 6 "	24	5850	5200		Pass. compt. 17 ft. 4 in. Bag. compt. 8 " 8 "
Heavy 12 bench . .	—	34 " 0 "	4 ft.	6 " 9 "	7 " 7½ "	60				Total weight, 16000 lbs.

APPROXIMATE DIMENSIONS VARIOUS STYLES OF ELECTRIC CARS.

Motor Cars.

(Merrill.)

Kind.	Length over Platforms.	Length over Posts.	Length of Platforms.	Height over All.	Size of Wheels.	Height Inside.	Width.	Number of Seats.	Kind of Seats.	Seating Capacity.	Weight of Body, Lbs.
Closed	24′	16′	4′	10′ 6″ to 11″	33″ to 36″	7′ 8″ to 8′	7′ 6″	2	Length of car	22	4500 to 5000
Closed	26′	18	4′	“	“	“	“	2	“ “	26	4800 to 5100
Closed	32′	24′	4′	“	“	“	“	2	“ “	34	6000
Convertible Summer and winter . .	33′ 6″	25′ 6″	4′	“	“	“	7′ 10″	2	“ “	40	6200
Combination open and closed . . .	29′	11′ 8″	. . .	“	“	“	7′ 6″	. . .	. . . . . .	open part 24 closed part 16	5500
Open, but closed ends .	26′	20′ 8″	2′ 8″	“	“	“	6′ 10″	8	Reversible	40	4400
Open, and open ends .	22′ 6″	. . .	. . .	“	“	“	“	7	“	35	3500
Open, and open ends .	30′ 9″	. . .	. . .	“	“	“	7′ 2″	10	“	50	5000
Double decked, open body	24′ 9″	. . .	. . .	15′ 3″	. . .	. . .	6′ 10″	7	“	below 35 top 24	4400
Double decked, closed body . . .	35′	25′ 6″	4′ 9″	15′	. . .	. . .	7′ 6″	. . .	“	below 36 top 36	7500

Funeral car, motor or trail	20′	13′ 10″	3′ 1″	. . .	. . .	8′ 2″	7′	. . .	. . . . . .	. . .	3900
Open	24′	19′	2′ 6″	10′ 6″ to 11′ 6″	33″	7′ 8″ to 8′ 6″	7′	18	10 reversible ½ seats, 8 stationary ½ seats, center aisle.	36	3800
Open	25′	. . .	. . .	“	“	“	7′ 6″	10	vis-à-vis stationary back	50	4000
Open	29′ 6″	25′	2′ 3″	“	“	“	. . .	10	8 reversible 2 stationary	50	4400
Open	44′	37′ 6″	3′ 3″	“	“	“	8′	15	13 reversible 2 stationary	90	9000
Convertible summer and winter	23′	16′ 7″	3′ 3½″	“	“	“	7′ 8″	12	6½ seats each side of aisle	24	4600
Double decked, open body	24′ 9″	. . .	. . .	15′ 3″	“	. . .	6′ 10″	7	reversible	below 35 top 24	4400
Double decked, closed body	26′	15′ 10″	5′ 5″	. . .	. . .	. . .	7′ 6″	. . .	. . . . . .	below 22 top 22	4000
Double decked, closed body	34′	28′	3′	16′	33″	8′ 6″	8′	. . .	. . . . . .	below 48 top 40	12000
4-wheel gondola	13′ 10″	. . .	. . .	. . .	. . .	. . .	7′ 10″	. . .	. . . . . .	10000 lbs.	3250
4-wheel box-car	15′ 3″	12′ 3″	1′ 6″	. . .	. . .	6′ 3″	6′ 6″	. . .	. . . . . .	11000 lbs.	3800
Express and baggage	21′	. . .	. . .	. . .	. . .	. . .	7′ 3″	. . .	. . . . . .	. . .	5000

WEIGHTS OF CARS, MOTORS, TRUCKS, ETC.

(Davis.)

Kind of Cars.	Cars.		Passenger Capacity.		Approximate Weight in Pounds.												
						Wheels (300 lbs. each).		Trucks (without Wheels or Motors).		Motor Equipments.		Complete Motor Car.			Complete Trailer Car.		
	Total Width.	Total Length.	Seating.	Excursion.	Car Body.	Rigid Truck (1 truck, 4 wheels.	Pivotal Truck (2 trucks, 8 wheels).	Rigid (1 truck).	Pivotal (2 trucks).	Double, 15 H.P.	Double, 30 H.P.	Without Passengers.	Ordinary Load.	Excursion Load.	Without Passengers.	Ordinary Load.	Excursion Load.
Closed, 16 ft. Body.	7 ft., 4 in.	24′	22	75	4500	1200		2500		4400		12600	15680	23100	8200	11280	18700
Open, 8 seated . .	6 " 10 "	25′	40	80	4000	1200		2500		4400		12100	17700	23300	7700	13300	18900
Closed, 25 ft. Body.	7 " 10 "	33′	40	125	7000		2400		3800		5600	18800	24400	36300	13200	18800	30700
Open, 12 seated . .	6 " 10 "	34′	60	125	6500		2400		3800		5600	18300	26700	35800	12700	21100	30200

DIMENSIONS OF STANDARD—PECKHAM TRUCKS.

Style.	Lengths.			Height of Truck.	Weight Complete Pounds.
	Top Frame.	Spring base.	Wheel Base.	30 in. Wheels.	
8 Standard, for open cars	14 ft. 9 in.	13 ft. 2 in.	7 in.	27½ in.	
8 A “ “ “ “	14 “ 9 “	13 “ 2 “	7 “	27½ “	4500
9 A Extra long, for open cars	16 “ 6 “	14 “ 6 “	7 “	27½ “	5000
7 D Excelsior	16 “ 6 “	16 “ 0 “	7 “	26 “	4500
7 B “	13 “ 6 “	13 “ 0 “	7 “	26 “	4000
7 A “	13 “ 6 “	13 “ 0 “	7 “	26 “	
7 Excelsior trailer truck	13 “ 0 “	12 “ 6 “	6 ft. 6 in.	26 “	
Extra strong storage battery	16 “ 6 “	14 “ 6 “	7 ft.	27½ “	5000
Extra long, with regular and emergency brake	16 “ 6 “	14 “ 6 “	7 “	27½ “	5000
Extra long, with track brake	16 “ 6 “	14 “ 6 “	7 “	27½ “	5000
Electric mining truck .	18 “ 0 “	—	6 ft. 6 in.	27½ “	4500

Note on Motors.

It had been the author's intention to include in this chapter cuts and dimensions of the standard motors and generators; but it was found that the standards changed so rapidly, and practice demanded so many and diversified forms of motor and equipment, that it was impracticable to include such cuts without danger of misleading the engineer.

ELEVATED RAILWAY TRAIN PERFORMANCE.

(S. H. Short.)

Data Sheet of Train No. 1.

Elevated Railway Service

Number of cars in train	3
Full speed of train on level track (miles per hour) . .	31
Average speed, stops one-third mile apart (miles per hour)	16.5

Motor Car.

Weight of motor car body	10	Tons.
Weight of both trucks	10	“
Weight of two motors	7	“
Weight of seventy-five passengers	5	“
Total weight of loaded motor car	32	“
Number of motors on motor car	2	“
*Commercial rated power of each	200	H.P.
Safe constant load for each	100	“
Safe temporary tractive effort of equipment	10,000	Lbs.
Safe constant tractive effort of equipment	3,500	“
Weight on drivers	19.5	Tons.
Ratio of weight on drivers to total weight	26%	
Adhesive power	9,750	Lbs.
Ratio of safe temporary tractive effort to adhesion	100%	
Ratio of safe constant tractive effort to adhesion	36%	

* This motor will deliver the commercial rated output for one hour without heating more than 75° C. above the surrounding air.

Complete Train.

Total weight of loaded motor car	32	Tons.
Weight of two coaches	32	“
Weight of 150 passengers in coaches	10	“
Total weight of loaded train	74	“
Maximum horizontal effort in accelerating train	9,750	Lbs.
Horizontal effort per ton during acceleration	132	“
Maximum power in accelerating uniformly to full speed	412	H. P
Maximum current at 500 volts accelerating train uniformly to full speed	780	Amp.
Time required in accelerating uniformly to full speed	34	Sec.
Distance in which train will acquire full speed	900	Ft.
Horizontal effort, train running uniform speed	1,300	Lbs.
Power consumed, train running uniform speed	106	H. P.
Tractive effort per ton	18.25	Lbs.
Maximum practical negative horizontal effort in braking	13,800	“
Time required to bring train to full stop	16	Sec.
Distance traversed by train during braking	370	Ft.

Train Performance.

Track.	Horse Power.	Current at 500 Volts.	Speed Miles per Hour.	Horizontal Effort.
Level	106	190 amperes.	32	1300 lbs.
1% grade	170	290 “	22	2780 “
2% grade	235	400 “	20.8	4260 “
3% grade	295	505 “	19	5740 “

Data Sheet of Train No. 2.

Character of Service; Elevated Railway.

Number of cars in train	2
Full speed of train on level track (miles per hour)	31
Average speed, stops one-third mile apart	15.8

Motor Car.

Weight of motor car body	10	Tons.
Weight or both trucks	10	“
Weight of two motors	5.5	“
Weight of 75 passengers	5	“
Total weight of loaded motor car	30.5	“
Number of motors on motor car	2	
*Commercial rated power of each	125	H. P.
Safe constant load for each	60	“
Safe temporary tractive effort of equipment	5,600	Lbs.
Safe constant tractive effort of equipment	1,600	“
Weight on drivers	18	Tons.
Ratio of weight on drivers to total weight	35%	
Adhesive power	9,000	Lbs.
Ratio safe temporary tractive effort to adhesion	62%	
Ratio safe constant tractive effort to adhesion	18%	

Complete Train.

Total weight of loaded motor car	30.5	Tons.
Weight of one coach	19	“
Weight of 75 passengers in coach	5	“
	51.5	“

---

* This motor will deliver the commercial rated output for one hour without heating more than 75° C. above the surrounding air.

Maximum horizontal effort in accelerating train	5,640	Lbs.
Horizontal effort per ton during acceleration	109	"
Maximum power in accelerating uniformly to full speed	280	H. P.
Maximum current at 500 volts accelerating uniformly to full speed	500	Amp.
Time required in accelerating uniformly to full speed	37.5	Sec.
Distance in which train will acquire full speed	953	Ft.
Horizontal effort, train running uniform speed	1,000	Lbs.
Power consumed, train running uniform speed	115	H. P.
Tractive effort per ton, train running uniform speed	19.7	Lbs.
Maximum practical negative horizontal effort in braking	11,000	Lbs.
Time required to bring train to full stop	16	Sec.
Distance traversed by train during braking	390	Ft.

Train Performance.

Track.	Horse Power.	Current at 500 Volts.	Speed Miles per Hour.	Horizontal Effort.
Level	92	175 amperes	31	1,013 lbs.
1% grade	135	250 "	24.8	2043 "
2% grade	176	320 "	21.3	3073 "
3% grade	220	390 "	19.9	4103 "

Data Sheet of Train No. 3.

Elevated Railway Service.

Number of cars in train	1
Full speed of train on level track (miles per hour)	26
Average speed, stops one-third mile apart (miles per hour)	15

Motor Car.

Weight of motor car body	10	Tons.
Weight of both trucks	10	"
Weight of two motors	3.5	"
Weight of 75 passengers	5	"
Total weight of loaded motor car	28.5	"
Number of motors on motor car	2	
*Commercial rated power of each	60	.H.P.
Safe constant load for each	25	"
Safe temporary tractive effort of equipment	3,300	Lbs.
Safe constant tractive effort of equipment	700	"
Weight on drivers	16	Tons.
Ratio of weight on drivers to weight	56%	
Adhesive power	8,000	Lbs.
Ratio safe temporary tractive effort to adhesion	41%	
Ratio safe constant tractive effort to adhesion	8%	

Complete Train.

Total weight of loaded train	28.5	Tons.
Maximum horizontal effort in accelerating train	2,600	Lbs.
Horizontal effort per ton during acceleration	91.5	"
Maximum power in accelerating uniformly to full speed	122	H.P.
Maximum current at 550 volts, accelerating uniformly to full speed	220	Amp.
Time required in accelerating uniformly to full speed	36.5	Sec.
Distance in which train will acquire full speed	810	Ft.
Horizontal effort, train running uniform speed	712	Lbs.
Power consumed, train running uniform speed	51	H.P.

* This motor will deliver the commercial rated output for one hour without heating more than 75° C. above the surrounding air.

Tractive effort per ton, train running uniform speed . . .	25	Lbs.
Maximum practical negative horizontal effort in braking . .	5,300	"
Time required to bring train to full stop	14.5	Sec.
Distance traversed by train during braking	305	Ft.

Train Performance.

Track.	Horse Power.	Current at 500 Volts.	Speed Miles per Hour.	Horizontal Effort.
Level . . .	51	90 amperes.	26	712 lbs.
1% grade . .	68	124 "	19.9	1282 "
2% grade . .	85	154 "	17.2	1832 "
3% grade . .	101	182 "	15.5	2422 "

INSTALLATION OF STREET CAR MOTORS.

(General Electric Company.)

In General.

In locating the various parts of the equipment and in wiring the car, particular attention should be taken to secure the following results :

1. Maintenance of high insulation.
2. Exclusion of all foreign material, particularly grease, dirt, and water, from the electrical equipment.
3. The avoiding of fire from arcs, naturally occurring at fuse-box, lightning arrester, etc.
4. The prevention of mechanical injury to the parts.
5. The placing of the parts so as to be accessible for operation and inspection, and yet out of the way of passengers.

Preparation of the Car Body.

The floor should be provided with a trap-door of such size as to allow as free access as possible to the motors. Particular attention is called to the advisability of having the bar across the car between the trap-doors removable, in order that the top of either motor can be thrown back.

The roof should be provided with a trolley board which strengthens it, and protects in case the trolley is thrown off ; it also deadens the noise. A firm support should be provided for the light clusters. Grooves should be cut for the leading wires in the roof moulding, and also in two of the corner posts, one for the trolley wire, the other for the ground wire of the lighting circuit.

On a closed car four 2 in. holes should be bored through the car floor under the seats, one as near each corner of the car as possible.

On one side of the car, four ⅝ in. holes should be bored in a line, and 4 in. apart, to receive the taps from the cable to the leads of motor No. 1. The exact location of these holes depends on the type of motor used. The distance from the center of the axle to the center of this group of holes should be about two and one-half feet for GE motors. On the same side of the car, and in the same line, four other ⅝ in. holes should be bored 4 in. apart, to receive the taps from the cable to the resistance boxes. On the other side of the car three ⅝ in. holes in a line and 4 inches apart, should be bored to receive the taps from the cable to the leads of motor No. 2, and on same side of car and in the same line five other ⅝ in. holes 4 inches apart should be bored to receive the taps for the trolley, resistance, and shunt for Motor No. 2.

Reference should be made to diagram in order that each set of holes shall be on the proper side of the car, and at such a distance from side-sills as to be out of the way of wheel throw.

Measuring about 38 inches from the brake-staff and a suitable distance inside of the dash rail, an oval hole 5 in. x 2¾ in. should be cut in each platform to receive the cables.

On an open car no holes need be bored for the floor wiring except those through the platform.

Installing Controllers.

In the standard car equipment one controller is placed on each platform on the side opposite the brake handle, in such a position that the controller spindle and the brake-staff shall not be less than 36 inches, nor more than 40 inches apart. The exact position depends somewhat on the location of the sills sustaining the platform. The feet of the controller are designed to allow a slight rocking with the spring of the dasher. Two one-half inch bolts secure the feet to the platform. An adjustable angle iron is furnished to be used in securing the controller to the dash-rail. A wire guard is also furnished, to be secured to the platform in such a position that the cables pass through it into the controller. A rubber gasket is furnished with each controller, to be placed between the wire guard and the platform,to exclude water. For dimensions of controller, see Figs. 40 and 41.

Wiring.

This work can be conveniently divided into two parts; namely, **roof wiring** and **floor wiring**.

Roof wiring includes the running of the main circuit wire from the trolley through both main motor switches down the corner posts of the car to a suitable location for connecting to the lightning arrester and fuse box; also wiring the lamp circuit complete, leaving an end to be attached to the ground. Whenever wires lie on the top of the roof, they need not be covered with canvas or moulding, except to exclude water where they pass through the roof. In such cases a strip of canvas the width of the moulding, painted with white lead, should be laid under the wire, and over this and the wire should be placed a piece of moulding extending far enough in either direction to exclude water. The moulding should be firmly screwed down and well painted.

The above wiring should be done if possible while the cars are being built.

Floor wiring may be done after the car is completed without injuring the finish.

Made up cables give far better protection to the wiring, and are easier to install than separate wires, and should be used in the floor wiring if possible. The simplest way of installing them on box cars seems to be as follows:

After the car bodies are prepared according to the above instructions, the cables (one on each side of the car) should be run through holes in the platform, and the connections made to the motors and controllers.

After making connection to the controllers, all slack should be pulled up inside of the car under the seats, and held in place, preferably against the side of the car, by canvas or leather straps. Motor taps should project through the sills for attachment to the flexible motor leads just far enough to permit easy connection, leaving as little chance as possible for vibration. No rubber tubing will be required on taps, as they all have a weather-proof, triple-braided cotton covering outside of the rubber insulation to prevent abrasion. All joints should be thoroughly soldered and well taped. The portions of the cables passing under the platforms should be supported by leather straps screwed to the floors or sills. Cables should never be bent at a sharp angle. The ground wire should run under the car floor rather than under the seats.

On open cars all wires and cables must be run under the car, and should be well secured to the floor with cleats or straps.

A good joint can be made by separating the strands of the tap-wire, and wrapping the two parts in opposite directions around the main wire. Both Okonite and rubber tape are furnished. It is desirable that Okonite should be used first and rubber tape put over it, as the latter will not loosen and unwrap as Okonite will. All openings in the hose should be sewed up as tightly as possible around the wires.

Separate wires can be installed if necessary, observing the following directions :

The floor wires on box cars should be placed under the seats as much as possible. In the few places where it is necessary for wires to cross, wood should intervene in preference to a piece of rubber tubing or loop in the air. This rubber tubing is not necessary where wire is cleated under the floor (as on open cars), if it does not pass over iron work, or is not exposed to mud and water. Where so exposed, it should be covered with moulding, but where moulding is used it should be carefully painted inside and out with good insulating compound to exclude water. The wire passing to the fuse box should be looped downward to prevent water running along the wire and into the box. Care should be taken to avoid metal work about the car in running the wires, and that nails or screws are not driven into the insulation.

In general it is not desirable to use metallic staples and cleats for car-wiring, except about the roof, or inside the car. Where wires are subject to vibration, as between the car bodies and motors, flexible cable must always be used. A certain amount of slack should be left in the leads from the motor to the car body, depending on their length. On cars with swiveling trucks a greater amount of slack is necessary. As slack gives greater opportunity for abrasion, care should be taken to leave only what is absolutely necessary.

Operation and Care of Controller.

When starting, regulate the movement of the handle from point to point so as to secure a smooth acceleration of the car.

Do not run between points.

The resistance points 1st, 2d, 3d, 6th, and 7th, are intended only for the purpose of giving a smooth acceleration, and should not be used continuously.

For continuous running, use the 4th, 5th, 8th, and 9th points, which are shown by the longest bars on the dial.

When using the motor cut-out switches be sure that they are thrown up as far up as they will go.

In case the trolley is off and the hand-brakes do not hold the car, an emergency stop may be accomplished by reversing the motors, and turning the power-handle to the full speed, or next to full speed point.

To examine the controller, which should be done regularly, open the cover, remove the bolt with wrench attached, and swing back the pole-piece of the magnet.

The contact surfaces and fingers should be kept smooth, and occasionally treated with a small amount of vaseline to prevent cutting.

All bearings should be regularly oiled.

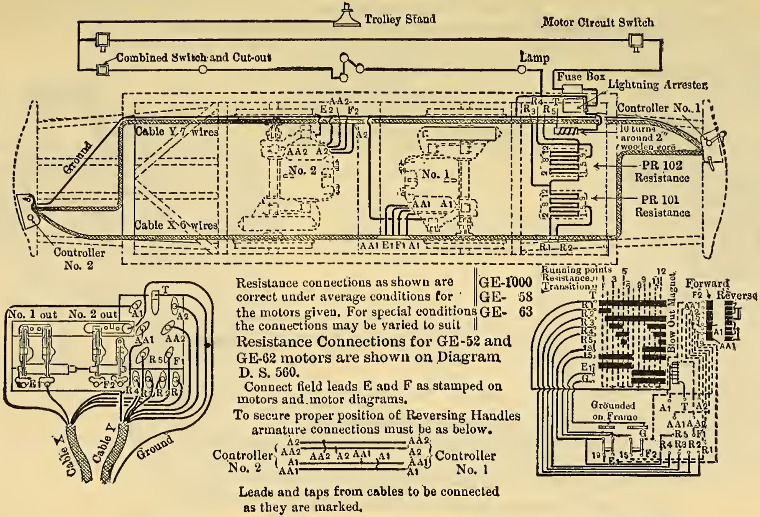
A repellent compound, paraffine, rosin, and vaseline, equal parts by weight, placed in the water-caps of the power and reversing shaft, is an efficient protection against water.

Dirt must not be allowed to collect inside of the controller.

Diagrams of Car Wiring.

In general car wiring is carried out in about the same manner for all styles and sizes of car, more particular description being given above. Wiring differs mainly in details, governed by the number, style and horsepower of motors used.

Diagrams of standard wiring for two motors per car and for four motors per car follow, in Figs. 31, 32, 33, 34. They are all from the G. E. Co. lists, as controllers made by that Company are almost universally used, although many of older design by other companies are still in the field.



Resistance connections as shown are correct under average conditions for the motors given. For special conditions the connections may be varied to suit

GE-1000
GE- 58
GE- 63

Resistance Connections for GE-52 and GE-62 motors are shown on Diagram D. S. 560.

Connect field leads E and F as stamped on motors and motor diagrams.

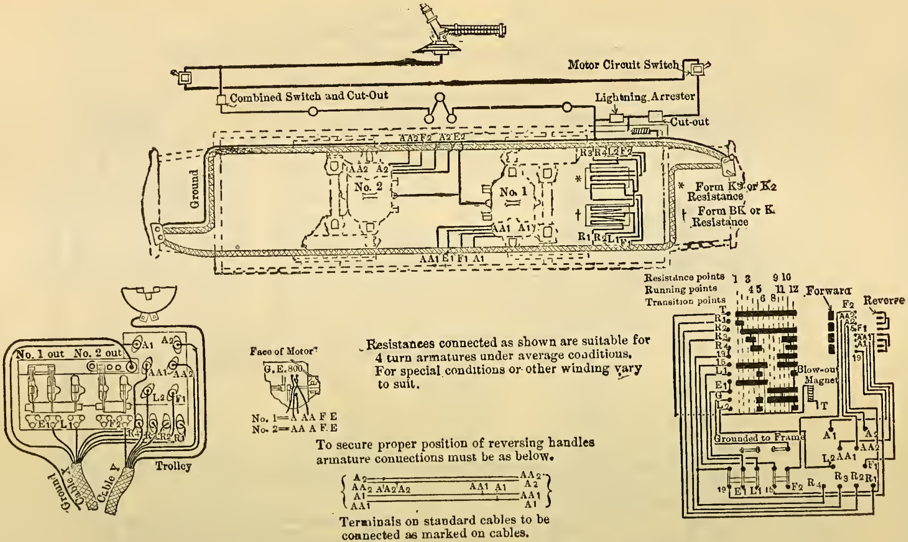
To secure proper position of Reversing Handles armature connections must be as below.

Leads and taps from cables to be connected as they are marked.

CAR WIRING FOR K 10 CONTROLLERS WITH TWO MOTORS

GENERAL ELECTRIC CO. 1898

FIG. 31.



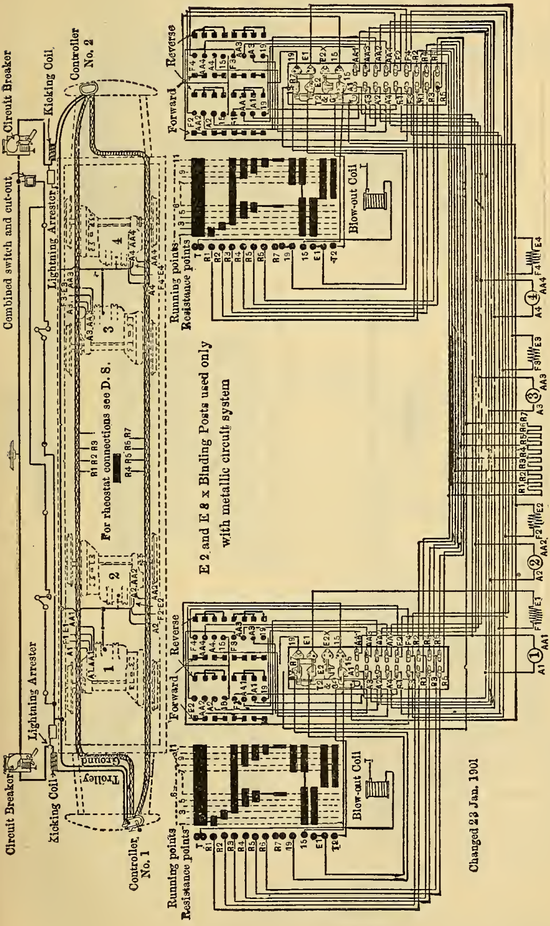
Resistances connected as shown are suitable for 4 turn armatures under average conditions. For special conditions or other winding vary to suit.

To secure proper position of reversing handles armature connections must be as below.

Terminals on standard cables to be connected as marked on cables.

CAR WIRING FOR K 2 CONTROLLER WITH TWO GE-800 MOTORS
GENERAL ELECTRIC CO., 1898.

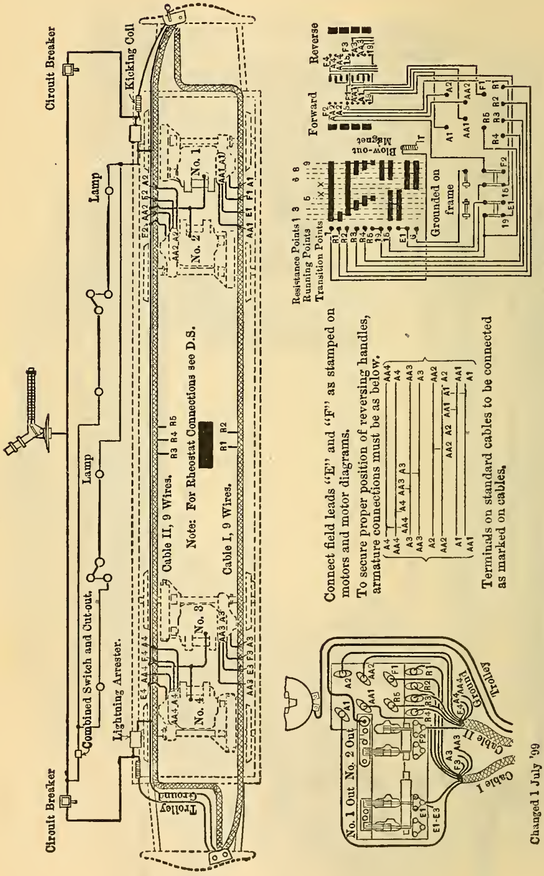
FIG. 32.



Changed 23 Jan. 1901

CAR WIRING FOR K-6 CONTROLLERS WITH FOUR MOTORS
GROUND RETURN SYSTEM, GENERAL ELECTRIC CO., 1899

FIG. 33.



Note: For Rheostat Connections see D.S.

Connect field leads "E" and "F" as stamped on motors and motor diagrams.

To secure proper position of reversing handles, armature connections must be as below.

Terminals on standard cables to be connected as marked on cables.

CAR WIRING FOR K 12 CONTROLLERS WITH FOUR MOTORS

GENERAL ELECTRIC CO., 1899

FIG. 34.

Equipment Lists.

The following is a list of material required for the electrical equipment of one car fitted with two motors :

QUANTITY.	
1	Trolley pole.
1	Trolley base.
2	Motor circuit switches.
1	Lightning arrester.
1	150 ampere magnetic cut-out (fuse-box).
1	Resistance box.
1	Resistance box.
1	Core for kicking coil.
2	Controllers (includes wire guard and gasket, supporting bracket, cap screws, and washers for fastening to dasher).
1	Controlling handle.
1	Reversing handle.
	One of each of these handles is always shipped with each pair of controllers unless specified to the contrary.
75 ft	No. 6 B. & S. strand wire (7-.061 in.) for roof-wiring.
20	100 or 150 ampere fuses.
10	Two-way connectors, ¼ in. hole, No. 6.
30	Brass corner cleats, $\frac{7}{16}$ in. slot.
25	Brass flat cleats, $\frac{7}{16}$ in. slot.
110	½ in. No. 4 R. H. brass wood screws for brass cleats.
25	Wood cleats, ½ in. slot.
25	Wood cleats, ⅜ in. slot.
100	1¼ in. No. 8 R. H. blued wood screws for wood cleats.
1 lb.	Solder.
1 lb.	¾ in. Okonite tape.
1 lb.	1 in. adhesive tape.
	Material for set of cables as follows :
480 ft.	No. 6 B. & S strand wire (7-.064 in.), single braid.
100 ft.	No. 6 B. & S. strand wire (7-.064 in.), triple braid for taps.
41	Brass marking-tags.
64 ft.	1½ in. cotton hose.
1½ lbs.	Rubber tape.
4 lbs.	Paragon tape.
1½ lbs.	Solder.
	This material can be procured made into a "set of cables" without extra cost.
1	Car-lighting equipment.

CONTROLLERS.

Under this heading are included all that type of appliance used for starting and stopping the motors and controlling the speed of the same. As almost all the old forms of rheostat with different steps have been abandoned for the so-called *series-parallel* controller, it is not necessary to describe any other here, nor will any detailed description of those now in use be attempted.

Two distinct forms are now mostly in use ; one, the *magnetic blow-out* type, made by the General Electric Company and used by the Westinghouse Electric and Manufacturing Company ; the other the so-called solenoid blow-out type, made by the Walker Company, of Cleveland, Ohio.

The principle of the magnetic blow-out type was first developed by Prof. Elihu Thomson, i. e., that an electric arc in a strong magnetic field is blown out of line and extinguished or cut in two. This fact is taken advantage of in the controller of the General Electric Company by using a strong electro-magnet to extinguish the arcs formed at the contact-points, when the circuits are broken. The construction is shown in the cut of Series-parallel controller, form K2, following.

The theory of the solenoid blow-out of the Walker Company is said to be that the arc is *lifted* out of place, and eases down the current, thus cutting it off easily, and without bad inductive effects. The following cut shows the connection and supposed action, and further along will be found cuts showing the assembled controller, the same developed, and a diagram showing general dimensions.

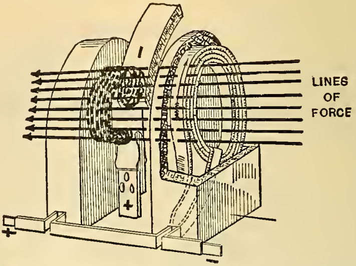


FIG. 35. Enlarged diagram showing theory of Solenoid Blow-out Controller of Walker Company.

Controllers are now made in so many forms and varieties that it is impossible to give more than a few of the combinations which are practically the same everywhere in the United States.

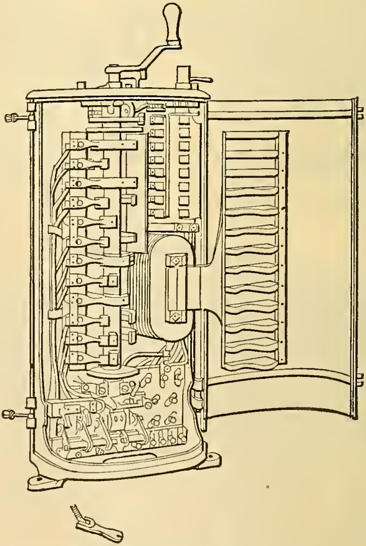


FIG. 36. Series-Parallel Controller, Form K2. General Electric Company.
Used also by the Westinghouse Electric and Manufacturing Company, and others.

The General Electric Company manufactures controllers for all conditions of electric railway service. They are divided for convenience in designation into four general classes, each designated by an arbitrary letter.

Type K Controllers are of the series parallel type, and include the feature of shunting or short circuiting one of the motors when changing from series to parallel connection.

Type L Controllers are also of the series-parallel type, but completely open the power circuit when changing from series to parallel.

Type B Controllers may be either the series-parallel or rheostatic type, but always include the necessary contacts and connections for operating electric brakes.

Type R Controllers are of the rheostatic type and are designed to control one or more motors by means of resistance only.

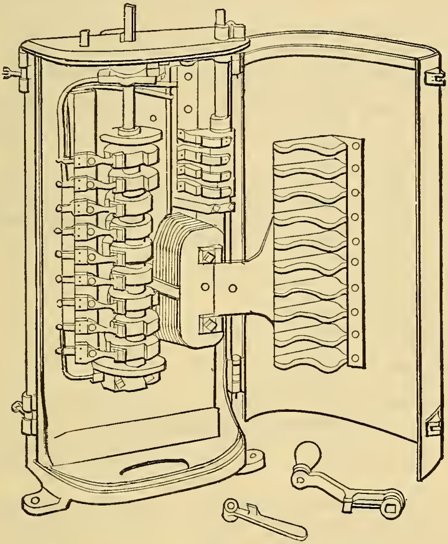


FIG. 37. "R" Type of Rheostatic Controller.

Rheostatic Controllers.

R 11 Controller.

Designed for one 50 h.p. motor.
Can be wired for use with motors using either shunted or full field.
Total number of notches, six.
(The R11 controller has been known as the KR controller.)

R 12 Controller.

Designed for two 50 h.p. motors.
Same as R11 controllers with exception that magnet-coils and contact-fingers are of greater capacity, and reversing-switch is arranged for two motors.

Series Parallel Controllers.

Title.	Capacity.	Controlling Points.	Remarks.
K	Two 35 h.p. Motors.	4 Series. 3 Parallel.	For motors using loop or shunted field.
K–2	Two 35 h.p. Motors.	5 Series. 4 Parallel.	For motors using loop or shunted field.
K–4	Four 30 h.p. Motors.	5 Series. 4 Parallel.	For motors using loop or shunted field.
K–6	Two 80 h.p. Motors or Four 40 h.p. Motors.	6 Series. 5 Parallel.	Connection board so arranged that controller may be used for two or four motors on grounded or metallic circuit.
K–7	Four 30 h.p. Motors.	5 Series. 4 Parallel.	Similar to K–12, but arranged for metallic circuit system.
K–8	Two 50 h.p. Motors.	5 Series. 4 Parallel.	Similar to K–11, but arranged for metallic circuit system.
K–9	Two 35 h.p. Motors.	5 Series. 4 Parallel.	Similar to K–8, but has connecting wires and blow-out coil of smaller capacity.
K–10	Two 35 h.p. Motors.	5 Series. 4 Parallel.	
K–11	Two 50 h.p. Motors.	5 Series. 4 Parallel.	Similar to K–10, but has connecting wires and blow-out coil of larger capacity.
K–12	Four 30 h.p. Motors.	5 Series. 4 Parallel.	The K–12 is a K–11 with reversing switch arranged for four motors.
K–13	Two 125 h.p. Motors	7 Series. 6 Parallel.	
K–14	Four 60 h.p. Motors.	7 Series. 6 Parallel.	
L–2	Two 175 h.p. Motors.	7 Series. 7 Parallel.	
L–3	Four 175 h.p. Motors	9 Series. 7 Parallel.	
L–4	Four 100 h.p. Motors	7 Series. 7 Parallel.	Similar to the L–2, but with additional reversing switch parts for four motors.
L–6	Four 200 h.p. Motors	9 Series. 6 Parallel.	Special for Central London Locomotives. Handle moves in counter-clockwise direction for turning on power.
L–7	Four 200 h.p. Motors	9 Series. 6 Parallel.	Differs from the L–6 in the direction of rotation of the operating handle.

Electric Brake Controllers.

Title.	Capacity.	Controlling Points.	Remarks.
BA	Two 35 h.p. Motors.	5 Series. 4 Parallel. 6 Brake.	Power connections same as K–2. For motors using shunted field for running points.
B–3	Two 35 h.p. Motors.	4 Series. 4 Parallel. 6 Brake.	Has no points for shunting motor fields. Superseded for general use by the B–13.
B–5	Two 50 h.p. Motors.	4 Series. 4 Parallel. 6 Brake.	Similar to B–3, but has heavier connecting wires and blow-out coil. Superseded for general use by the B–23.
B–6	Four 30 h.p. Motors.	4 Series. 4 Parallel. 6 Brake.	Similar to B–3, but has reversing switch and brake contacts arranged for four motors. Superseded for general use by the B–19.

Electric Brake Controllers.—*Continued.*

Title.	Capacity.	Controlling Points.	Remarks.
B–7	Two 100 h.p. Motors.	6 Series. 5 Parallel. 6 Brake.	Has separate brake handle.
B–8	Four 50 h.p. Motors.	6 Series. 5 Parallel. 7 Brake.	Has separate brake handle.
B–13	Two 40 h.p. Motors.	5 Series. 4 Parallel. 7 Brake.	Supersedes the B–3, from which it differs in having contacts for connecting motor armature in series with their respective brake shoes.
B–16	Two 50 h.p. Motors.	5 Series. 4 Parallel. 7 Brake.	Similar to B–23, but has special connections for the surface contact system.
B–18	Two 35 h.p. Motors.	4 Series. 4 Parallel. 6 Brake.	Differs from the B–3 in that it has an extra cut-out switch blade, and connection board arranged for motors using metallic or grounded circuit.
B–19	Four 40 h.p. Motors.	6 Series. 5 Parallel. 7 Brake.	Similar to B–8, having separate handles for power and brake. Supersedes B–6.
B–23	Two 50 h.p. Motors.	5 Series. 4 Parallel. 7 Brake.	Supersedes the B–5. Similar to the B–13, but has connecting wire and blow-out coil of larger capacity.
B–24	Two 40 h.p. Motors.	5 Series. 4 Parallel. 7 Brake.	Similar to B–13, but has cut-out switches arranged for metallic circuit systems.
B–25	Two 50 h.p. Motors.	5 Series. 4 Parallel. 7 Brake.	Similar to B–24, but has connecting wire and blow-out coil of larger capacity.
B–29	Two 50 h.p. Motors.	5 Series. 4 Parallel. 7 Brake.	Similar to B–23, but has separate brake handle.

Rheostatic Controllers.

Title.	Capacity.	Controlling Points.	Remarks.
R–11	One 50 h.p. Motor.	6	For motors using either full or shunted fields for running points.
R–12	Two 50 h.p. Motors.	6	Motors are connected permanently in parallel.
R–14	Two 35 h.p. Motors.	5	Very short and specially adapted to mining locomotives. Motors are connected permanently in parallel.
R–15	Two 75 h.p. Motors.	6	Motors are connected permanently in parallel.
R–16	Four 35 h.p. Motors.	6	Similar to R–15, but has reversing switch arranged for four motors.
R–17	One 50 h.p. Motor.	6	Similar to R–11, but has resistance on the trolley side of the motor instead of on the ground side.
R–19	Two 50 h.p. Motors.	6	Similar to R–17. Motors are connected permanently in parallel.
R–22	Two 50 h.p. Motors.	5	Shape like R–14, others same as R–12. Motors are connected permanently in parallel.

MOTOR COMBINATIONS

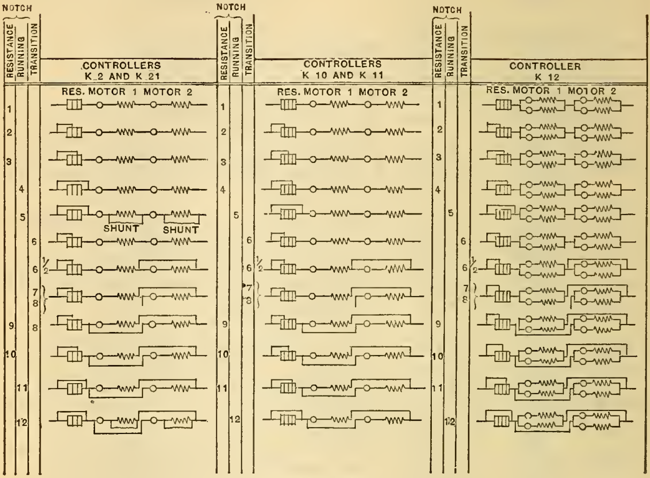


FIG. 38.

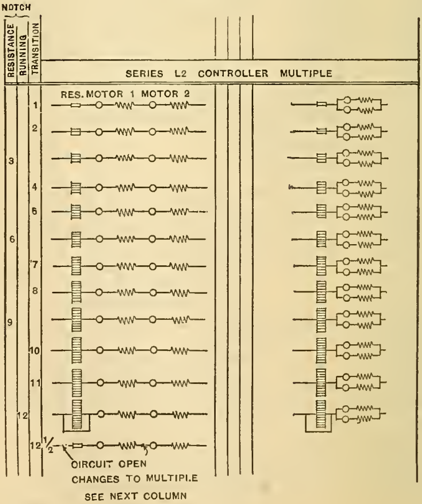
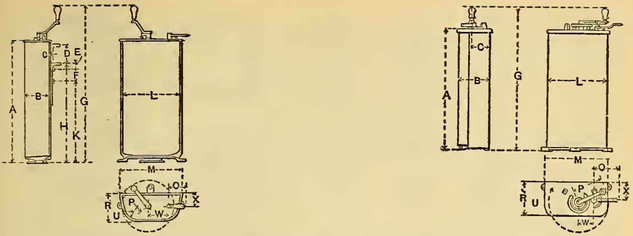


FIG. 39.



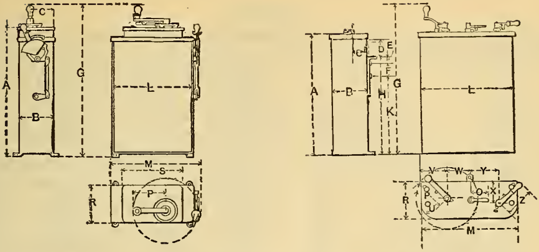
FIGS. 40 and 41. Diagrams for Dimensions of Controllers.

Dimensions of Controllers.

	Type K.												Type L.		
	K	K-2	K-4	K-6	K-7	K-8	K-9	K-10	K-11	K-12	K-13	K-14	L-2	L-3	L-4
	Fig. 40.	Fig. 40.	Fig. 40.	Fig. 40.	Fig. 40.	Fig. 40.	Fig. 40.	Fig. 40.	Fig. 40.	Fig. 40.	Fig. 41.	Fig. 41.	Fig. 42.	Fig. 41.	Fig. 42.
A	$33\frac{3}{16}$	$35\frac{1}{16}$	$35\frac{1}{16}$	$38\frac{3}{4}$	$33\frac{3}{16}$	$33\frac{3}{16}$	$33\frac{3}{16}$	$33\frac{3}{16}$	$33\frac{3}{16}$	$33\frac{3}{16}$	39	$38\frac{7}{8}$	$40\frac{7}{8}$	$45\frac{1}{2}$	$40\frac{7}{8}$
B	$7\frac{3}{16}$	$7\frac{3}{16}$	$7\frac{3}{16}$	$8\frac{7}{16}$	$7\frac{3}{16}$	$7\frac{3}{16}$	$7\frac{3}{16}$	$7\frac{3}{16}$	$7\frac{3}{16}$	$7\frac{3}{16}$	10	10	$10\frac{7}{8}$	13	$10\frac{7}{8}$
C	$2\frac{7}{8}$	$2\frac{7}{8}$	$2\frac{7}{8}$	$3\frac{5}{16}$	$2\frac{7}{8}$	$2\frac{7}{8}$	$2\frac{7}{8}$	$2\frac{7}{8}$	$2\frac{7}{8}$	$2\frac{7}{8}$	$5\frac{3}{4}$	$5\frac{3}{4}$	$8\frac{1}{8}$	$6\frac{1}{8}$	$8\frac{1}{8}$
D	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	...	...	...	...	...
E	1	1	1	1	1	1	1	1	1	1	...	...	...	...	...
F	$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$	...	...	...	...	...
G	$41\frac{11}{16}$	$43\frac{1}{2}$	$43\frac{1}{2}$	47	$42\frac{1}{4}$	$42\frac{1}{4}$	$42\frac{1}{4}$	$42\frac{1}{4}$	$42\frac{1}{4}$	$42\frac{1}{4}$	$46\frac{13}{16}$	$46\frac{3}{4}$	$47\frac{15}{16}$	$53\frac{1}{2}$	$47\frac{15}{16}$
H	29	$29\frac{7}{8}$	$29\frac{7}{8}$	$33\frac{3}{8}$	29	29	29	29	29	29	...	...	...	...	...
K	$24\frac{1}{2}$	$25\frac{3}{8}$	$25\frac{3}{8}$	$28\frac{7}{8}$	$24\frac{1}{2}$	$24\frac{1}{2}$	$24\frac{1}{2}$	$24\frac{1}{2}$	$24\frac{1}{2}$	$24\frac{1}{2}$	...	...	...	...	...
L	$16\frac{5}{8}$	$16\frac{5}{8}$	$16\frac{5}{8}$	$16\frac{1}{2}$	$16\frac{5}{8}$	$16\frac{5}{8}$	$16\frac{5}{8}$	$16\frac{5}{8}$	$16\frac{5}{8}$	$16\frac{5}{8}$	19	$22\frac{3}{4}$	$25\frac{1}{8}$	$28\frac{7}{8}$	$25\frac{1}{8}$
M	$17\frac{1}{2}$	$17\frac{1}{2}$	$17\frac{1}{2}$	$17\frac{1}{4}$	$17\frac{1}{2}$	$17\frac{1}{2}$	$17\frac{1}{2}$	$17\frac{1}{2}$	$17\frac{1}{2}$	$17\frac{1}{2}$	20	$23\frac{3}{4}$	$27\frac{5}{8}$	29	$32\frac{9}{16}$
O	$5\frac{3}{4}$	$5\frac{3}{4}$	$5\frac{3}{4}$	$5\frac{3}{4}$	$5\frac{3}{4}$	$5\frac{3}{4}$	$5\frac{3}{4}$	$5\frac{3}{4}$	$5\frac{3}{4}$	$5\frac{3}{4}$	$8\frac{3}{4}$	$8\frac{3}{4}$	...	$5\frac{11}{16}$	...
P	8	8	8	9	8	8	8	8	8	8	$9\frac{1}{2}$	$9\frac{1}{2}$	$9\frac{1}{2}$	13	$9\frac{1}{2}$
R	$8\frac{3}{16}$	$8\frac{3}{16}$	$8\frac{3}{16}$	$9\frac{1}{2}$	$8\frac{3}{16}$	$8\frac{3}{16}$	$8\frac{3}{16}$	$8\frac{3}{16}$	$8\frac{3}{16}$	$8\frac{3}{16}$	11	11	$11\frac{5}{8}$	14	$11\frac{5}{8}$
S	...	...	...	...	...	...	...	...	...	...	...	...	$18\frac{5}{8}$	...	$18\frac{5}{8}$
U	$5\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$4\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	4	4	...	$3\frac{1}{4}$	...
V	$7\frac{7}{16}$	$7\frac{3}{8}$	$7\frac{7}{16}$	$7\frac{3}{8}$	$7\frac{7}{16}$	$7\frac{7}{16}$	$7\frac{7}{16}$	$7\frac{7}{16}$	$7\frac{7}{16}$	$7\frac{7}{16}$	$10\frac{3}{4}$	$10\frac{3}{4}$	...	$15\frac{1}{8}$	...
W	$6\frac{11}{16}$	$5\frac{13}{16}$	$6\frac{11}{16}$	$5\frac{13}{16}$	$6\frac{11}{16}$	$6\frac{11}{16}$	$6\frac{11}{16}$	$6\frac{11}{16}$	$6\frac{11}{16}$	$6\frac{11}{16}$	5	$8\frac{3}{4}$	...	9	...
X	$4\frac{6}{16}$	$4\frac{5}{16}$	$4\frac{5}{16}$	$4\frac{5}{8}$	$4\frac{5}{16}$	$4\frac{5}{16}$	$4\frac{5}{16}$	$4\frac{5}{16}$	$4\frac{5}{16}$	$4\frac{5}{16}$	$5\frac{1}{2}$	$6\frac{1}{4}$	...	10	...
Y	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Dimensions of Controllers.

	Type B.											Type R.							
	BA	B-3	B-6	B-7	B-8	B-13	B-16	B-19	B-23	B-24	B-29	R-11	R-12	R-14	R-15	R-16	R-17	R-19	R-22
	Fig. 40.	Fig. 40.	Fig. 40.	Fig. 43.	Fig. 43.	Fig. 40.	Fig. 40.	Fig. 43.	Fig. 40.	Fig. 40.	Fig. 43.	Fig. 40.	Fig. 40.	Fig. 40.	Fig. 40.	Fig. 40.	Fig. 40.	Fig. 40.	Fig. 40.
A	36 1/16	36 1/16	35 15/16	36 13/16	42	38	38	40	38	38	38 5/16	33 3/16	33 3/16	21 3/16	33 3/16	29 5/32	33 3/16	33 3/16	21 5/32
B	8 1/8	8 1/8	8 3/16	10 1/4	11 1/4	9	9	9 7/16	9	9	8 11/16	7 3/16	7 3/16	7 3/16	7 3/16	7 3/16	7 3/16	7 3/16	7 3/16
C	3 11/16	3 11/16	3 3/4	4 3/8	5 3/8	4 1/4	4 1/4	3 13/16	4 1/4	4 1/4	3 3/4	2 7/8	2 7/8	2 7/8	2 7/8	2 7/8	2 7/8	2 7/8	2 7/8
D	4 1/2	4 1/2	4 1/2	. . .	. . .	4 1/2	4 1/2	4 1/2	4 1/2	4 1/2	4 5/8	4 1/2	4 1/2	. . .	. . .	. . .	4 1/2	4 1/2	. . .
E	1	1	1	. . .	. . .	1	1	1	1	1	1	1	1	. . .	. . .	. . .	1	1	. . .
F	3 1/2	3 1/2	3 1/2	. . .	. . .	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	. . .	. . .	. . .	3 1/2	3 1/2	. . .
G	44 1/2	44 1/2	44 3/8	45 3/16	50 3/8	46 1/2	46 1/2	48 3/8	46 1/2	46 1/2	46 11/16	41 11/16	41 11/16	28 1/8	41 11/16	37 11/16	41 11/16	41 11/16	28 1/8
H	30 9/16	30 9/16	28 15/16	. . .	. . .	30 5/8	30 5/8	30 5/8	30 5/8	30 5/8	30 5/8	29	29	. . .	. . .	. . .	29	29	. . .
K	26 1/16	26 1/16	24 7/16	. . .	. . .	26 1/8	26 1/8	26 1/8	26 1/8	26 1/8	26 1/8	24 1/2	24 1/2	. . .	. . .	. . .	24 1/2	24 1/2	. . .
L	19	19	25	27 3/8	28 3/8	21 1/2	21 1/2	25	21 1/2	21 1/2	21 1/2	16 5/8	16 5/8	16 5/8	16 5/8	16 5/8	16 5/8	16 5/8	16 5/8
M	19 5/8	19 5/8	25 5/8	28 1/8	29 1/8	22 1/8	22 1/8	25 3/4	22 1/8	22 1/8	22 1/4	17 1/2	17 1/2	17 1/2	17 1/2	17 1/2	17 1/2	17 1/2	17 1/2
O	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	6 3/8	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4
P	9	9	9	9	9	9	9	8	9	9	8	8	8	8	8	8	8	8	8
R	8 13/16	8 13/16	8 13/16	11 1/8	12 1/8	9 3/8	9 3/8	10 1/16	9 3/8	9 3/8	9 11/16	8 3/16	8 3/16	8 3/16	8 3/16	8 3/16	8 3/16	8 3/16	8 3/16
U	6 1/2	6 1/2	6 1/2	4 3/8	4 3/8	5 1/2	5 1/2	5 1/2	5 1/2	5 1/2	5 1/2	5 1/4	5 1/4	5 1/4	5 1/4	5 1/4	5 1/4	5 1/4	5 1/4
V	9 5/16	9 5/16	10 5/16	7 3/4	7 3/4	12 7/8	12 7/8	6 5/8	12 7/8	12 7/8	6 5/8	7 7/16	7 7/16	7 7/16	7 7/16	7 7/16	7 7/16	7 7/16	7 7/16
W	6 1/4	6 1/4	9 1/4	6 3/4	6 3/4	5	5	5 13/16	5	5	5 11/16	6 11/16	6 11/16	6 11/16	6 11/16	6 11/16	6 11/16	6 11/16	6 11/16
X	4 13/16	4 13/16	4 13/16	6 5/8	6 5/8	5 5/16	5 5/16	5 5/16	5 5/16	5 5/16	4 7/8	4 5/16	4 5/16	4 5/16	4 5/16	4 5/16	4 5/16	4 5/16	4 5/16
Y	. . .	. . .	. . .	8 3/8	9 3/4	. . .	. . .	8 7/16	. . .	. . .	5 1/16	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Z	. . .	. . .	. . .	9	9	. . .	. . .	8 3/4	. . .	. . .	8 3/4	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .



FIGS. 42 and 43. Diagrams for Dimensions of Controllers.

THE SPRAGUE MULTIPLE UNIT SYSTEM.

BY FRANK J. SPRAGUE IN STREET RAILWAY JOURNAL, MAY, 1901.

This system, briefly defined, is a system of control of railway motor controllers, whatever their number and wherever situated in a train, through a secondary electric circuit common to all the cars from or through which it is desired to exercise control. The number and position of equipped or unequipped units, and to a certain extent the character of these units, is immaterial, and variation in end relation is likewise a matter of indifference.

The system covers the entire range of service from a single car operated as an independent unit to a train of any length equipped with as much or little power as required.

In General.

Each motor car is equipped with complete power operated apparatus for its motors, and has in addition an independent train line by means of which it can be operated from other cars, as well as operate other cars. This train line terminates in shrouded couplers under the platform at each end of the car. The train lines on different cars, whether equipped with motors or not, are joined by detachable reversible jumpers.

The train line is especially designed to secure reliability. To insure this it carries only small currents, and has but four or five controlling wires. There is no ground wire carried through the train line. Provision is made for a relay line to be carried in the common cable for the operation of the air compressors. The wires are each thoroughly insulated and the cable is protected from mechanical injury. The train line is completely isolated from the local circuits on each car. The operating relays, energized from the train line on each car, are each separately protected so that their failure cannot interfere with the operation of unaffected cars The operation is in no way affected by changes in the sequence of cars.

The train line can be readily cut off from the local circuits on any car.

The local pilot motor circuit and main motor circuits are independent of the train line, so that no derangement of main circuits or apparatus can be communicated to it.

Each pair of motors is controlled by the joint operation of a speed controller and reverser. The main circuit is opened independently by each. Any derangement of either renders that car inoperative. This is secured by interconnection of operating circuits, so that current cannot be continued through motors.

Each car automatically governs the current input in the car, and insures the most efficient acceleration and operation independent of the motorman. Means are also provided to restrain the current input at will by manipulation of the master switch.

Protection is automatically provided against any improper operation at the master switch, or misplacement or failure of any part of the system. In any case, the indicated result will follow a movement of the master switch, or the main circuit will be opened and the apparatus rendered inoperative.

Circuits.

The system is illustrated by an elemental diagram, Fig. 44, two typical circuit diagrams, Figs. 45 and 47, with and without the coast relay, showing also the development of the apparatus, and two corresponding schematic diagrams, Figs. 46 and 48, showing controlling circuits only for single cars. Reference to the diagrams shows that on a fully equipped car there are four distinct circuits, which are shown by distinguishing lines. These are:

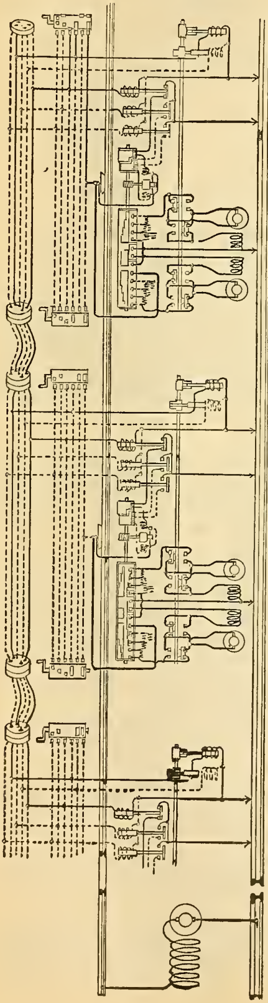


FIG. 44. Elemental Circuits of Multiple Unit System.

Car-motor Circuit. — This includes the main motors, the contacts with the supply circuit, and the reverser, rheostat and motor grouping contacts which are in the circuit of the main motors.

Local Operative or Controlling Circuit. — This includes the relay or magnet coils, pilot motors, or whatever directly moves or controls the main motor controllers, or actuates main controlling contacts when the system is, as here shown, entirely electric, or controls the pilot mechanism if some other power than electricity is used to move the main controllers.

Platform-switch Line. — This on a single car becomes a part of the local operative circuit, and on a train energizes all the local operative or controlling circuits through the intermediary of the particular platform-switch in use, and the electrical train or governing lines on it and the other cars.

Train or Governing Line. — This is the continuing cable running from one car to another, which at one or more points is connected, on the one hand to the platform-switch line, and on the other to the local operative circuits. It is made up of the permanently placed train line on the several cars and the couplers or jumpers connecting them together. It may evidently be common to cars which are equipped with and to cars which are not equipped with motors. It is the independent means of transmitting an initial and governing impulse from any one of a number of points.

Operation.

The specific operation of the apparatus controlled by these circuits is as follows:

On each of the fully equipped cars there are two main motors. Each motor has a single unchangeable set of field coils and an armature. The motor connections and the current flowing therein are determined by three principal switches. There is a reverser for changing the armature connections

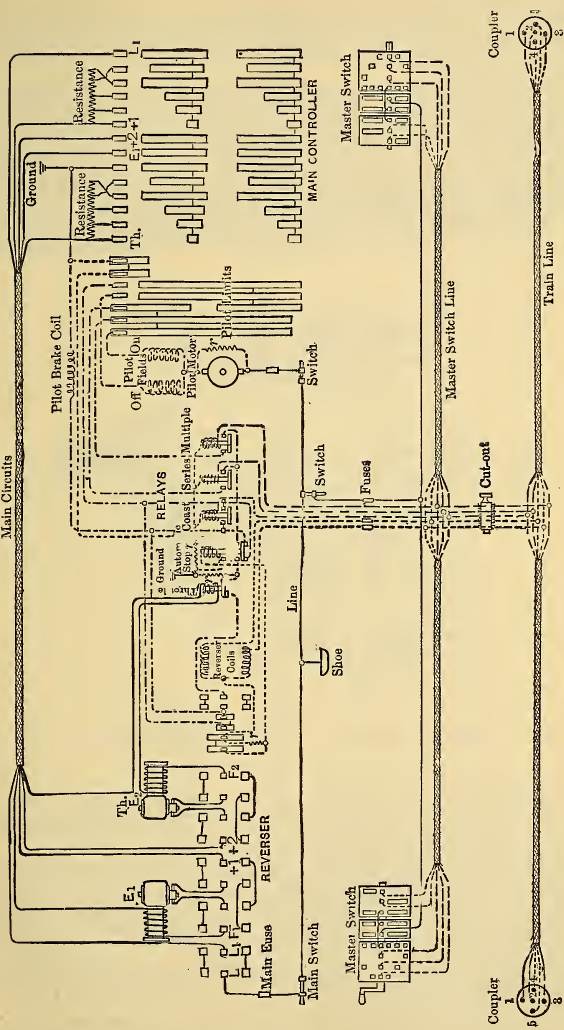


FIG. 45. Typical Circuits, Sprague System.

of the two motors, a rheostat for varying the resistance in the circuit with them, and a motor switch for effecting series or parallel relation. These three pieces of apparatus can be physically separate, or any two or all three can be combined in one structure. As here shown, the two switches which determine speed form one structure, termed the main controller, and the reverser the other.

These main switches are primarily controlled from a master switch on each platform of any equipped car, through a train line and suitable relays and a pilot motor. This master switch is a multiple circuit maker, a means for closing the line supply to one or more independent train wires, each of which operates a relay. This switch has neither mechanical nor electrical connection of any kind with the motor circuits, nor, although it has certain corresponding position, is its movement necessarily coincident with, nor proportional to, the movement of any of the main switches.

In ordinary operation, the two motors are first put in series with each other with suitable resistance, which is cut out until the full half potential

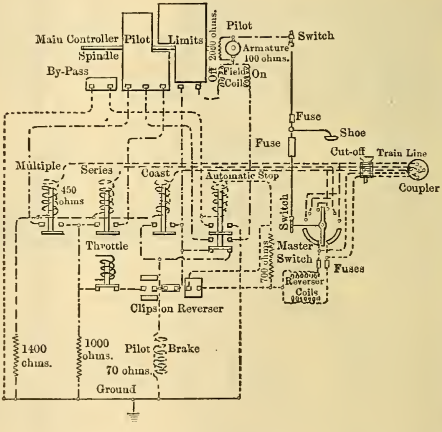


FIG. 46. Schematic Diagram of Control Circuits Only, Sprague System.

is supplied to each motor, which is the half-speed combination. In going thence to full speed, the main circuits are first opened instantly at the main controller, or, if desired, progressively through resistances and independent main contacts, or they can be opened at the reverser.

The motors are then thrown into multiple relation with a resistance in circuit of about one-quarter that used in the first series position, which is progressively cut out until the motors have full potential, and run at their full capacity and speed. The quartering of the resistances on the first position is effected by using independent resistances in each motor; throwing them in series and parallel relation the same as the motors, and using the same progressive steps.

In any position of the controller the current can be cut off either instantly by the reversers, which have independent main-line contacts, or progressively at the main controller.

The reverser contacts for the armatures of the two motors, as well as two extra "line" contacts, are for convenience mounted on a common spindle. The cylinder of the reverser is normally retracted to a middle or open circuit position, and there are two solenoids, one for pulling the cylinder one way for ahead movement of the train, and the other for pulling it the opposite way for backward movement.

Provision is made for dead-beat movement, and also for inter-connection of controlling circuits by contacts on the same cylinder as the main contacts.

The circuit for the reverser passes through the automatic stop coil, and is completed through a by-pass on the controller in the first contact position, or through a contact made by the automatic, so that once opened it cannot be operated unless the controller is in a safe position for the motors.

The cylinder of the main controller is driven with an intermittent motion by a pilot motor through a powerful locked spring, so that the armature of the pilot motor and the spindle of the cylinder do not move either in synchronism or to an exactly like extent. This is necessary to insure freedom from hot contacts and dragging of arcs.

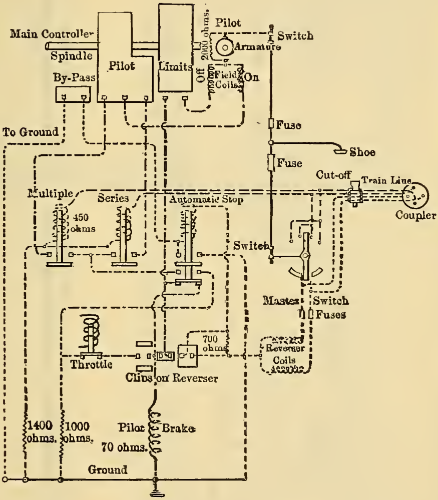


FIG. 47. Schematic Diagram, Control Circuits Only, Without Coast Relay.

The pilot motor is governed by either four or five relays called, respectively, the "coast," "series," and "multiple" relays, the "automatic stop" and the "throttle." Since the "automatic stop" also has coast relay contacts, the separate coast relay may be discarded.

There are three allowable running positions for a pair of motors, — the coast or open circuit position, the series position, when the two motors are in series without any resistance in circuit, and the multiple position, when the two motors are independently across the line without any resistance. In addition, the motors can be run temporarily with more or less of the resistance in circuit for the purpose of switching. On heavy railroad work, such as on elevated and suburban roads, minor variation of running speed in either the series or the multiple relation of the motors by the use of resistances is rarely practiced, and is never necessary save in starting. The

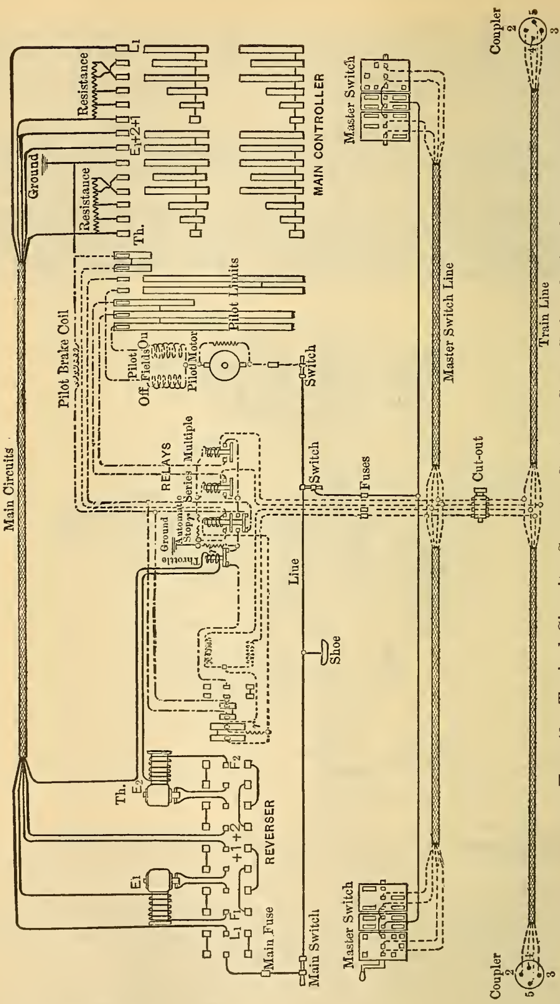


FIG. 48. Typical Circuits, Sprague System, Coast Relay Omitted.

apparatus is especially constructed to discourage any such variation of running speed.

The circuit which operates the pilot motor on each car is a purely local circuit, coming from the car shoes and returning to the track, just as the main circuit of the motor does. It is not connected to the train line or the master switches in any way. Its path is through the field magnets, break

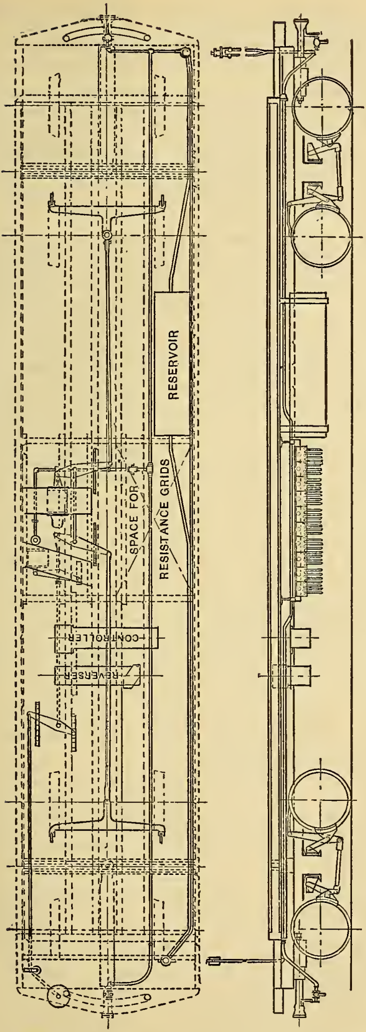


FIG. 49. Car Plan and Platform Elevation.

and armature of the pilot motor, through the contacts of the coast, series, or multiple relays, and also through the contacts of the throttle and automatic stop. If either the throttle or the automatic stop are in an open circuit position it is impossible for the pilot motor to move in one direction, and it is hence impossible for the controller to be advanced, although if in an advanced position it can be moved backward. The circuits through the relay contacts and the pilot motor also pass through limit switches on the controller cylinder. If this control cylinder is in "off" position, and the throttle and automatic stop are in proper positions, closure of the coasting relay would not cause any movement whatever, but closure of the series relay will allow the pilot, if otherwise uninterrupted, to move the controller to the series position, where it will automatically stop. In the same way closure of the multiple relay will move the controller either from the coast position or from the series position to the full multiple position, where it will be automatically stopped. Opening the throttle, however, will either arrest or retard the rotation of the pilot motor and the progression of the controller, and dropping of the automatic stop or opening of the reverser, which is also provided with a coasting contact, will at once return the controller to an open circuit or any other determined position, regardless of the motorman.

The throttle is operated automatically by the current in one of the motors, and serves a double purpose.

It retards or stops the forward movement of the main controller at any desired current increment, and, since it responds to a determinate rise and fall of current, it can become an automatic switch for providing a definite rate of acceleration. It does not prevent any desired slower rate of acceleration, or in any way remove from the motorman the positive operation of the main controller at will within the limits of safe and desirable current inputs. Further reference to its action will be made.

It will be seen, therefore, that the physical operation of the controller is intermittent in character, and certain automatic controlling devices are provided which modify its operation.

A single car will first be considered. The coast, series and multiple relays are energized by platform-switch circuits, which terminate in a master switch or controller at the platform, at which a connection to the supply circuit is also made. To this same master switch are brought also the terminal wires of the solenoids operating the reverser. This master switch is the apparatus manipulated by the motorman, and except as he is limited by the automatic features, or hindered by circumstances which he cannot, and is not intended to, control, all operation either of the particular car or the train is initiated at this point.

The master switch consists of a cylinder with suitable contacts operated by a handle interlocked with the top of the switch. Against the cylinder rest a set of fingers, and between each pair of the fingers is an insulating shield or separator, the separators being mounted on a common spindle. The speed and direction of car movement are initiated at this master switch by the movement of a single handle. The switch has (1) the off or normal position, to which the handle is spring retracted in case the operator lets go of it, (2) for ahead movement, three running positions, coast, series and multiple or full speed, with no contacts between, and (3) for the back movement, two running positions, coast and series or half-speed position. The car can be stopped and reversed by a single throw of the handle of the operator's or master switch from one side of the open position to the other.

It will be noted that there is no physical, nor even any electrical, connection whatever between the master switch and the main controller. There is simply an electrical connection with the three relays spoken of, and with the solenoids of the reverser which form a part of the main control system. Movement, therefore, of this handle only indirectly affects operation of the main parts of the apparatus under certain conditions and when certain circuits permit such operation.

The ordinary operation is that when a motorman wishes to go ahead at half-speed he moves the master controller to the series position. The reverser is instantly set for movement ahead, the series relay is closed, the pilot motor starts up, the driving spring is put under tension, and the controller spindle moves forward intermittently until the pilot limits stop it at the half-speed position. If during this operation the throttle should lift, this advance of the controller cylinder will be retarded or stopped. If the automatic stop should drop, the advance not only will be stopped, but the controller will at once run backward to an open circuit or other determined position without regard to the set of the series relay, or what is the wish of the man at the master switch.

Being at the series position, if the motorman wishes to go at full speed, the handle of the master switch is moved to that position, when similar operations take place at the relays and pilot motor.

Or the operator may move his switch handle at once from the open circuit to the multiple position without any regard to the series position, and the main controller, controlled by the throttle, will advance to full-speed position. Of course the advance of the main controller may be made at will, step by step, by touch-and-go contact at the master switch, and its advance can be arrested instantly. If desirable, when a coast relay is used its connection can be changed so as to, at will, throw the throttle out of action, although this is not desirable.

By minor changes in the controlled circuits they can be arranged so that the operator can operate entirely with the motors in series or entirely in multiple, or either at will. This is because the controller has two circuit positions, one at the beginning of the series combination and one at the beginning of the multiple combination. It is what is known as an open-circuit controller, and provision is made for not only opening circuit in two places on its cylinder, but also independently on the reverser.

Comparison of the movements of the master switch and the main controller illustrate very clearly the inter-connection of controlling circuits and their utility, and how they are intended to provide for every emergency. The master switch has two running advance positions and one running back position, and movement of its handle between those two points in no way affects the main controller; the latter has several positions where it can rest with identically the same position of the master switch handle provided its motion is arrested before it has reached one of its limits; under certain conditions the controller will not make any motion whatever in response to a master switch; under certain other conditions, it will make a partial response, then automatically stop, and without any change of movement of the master switch go ahead again and automatically stop; the controller, under other circumstances, will respond to the master switch, then stop, and immediately, or after an interval, go back to an open circuit or any other predetermined position; under changed circumstances it will advance intermittently to, or toward, some determined position indicated by the master switch, then stop, go backward to some other position, and then go forward again; or in passing from a coast or open circuit to a multiple position, the controller may or may not respond to closure of the series contact. If the motorman wishes to reverse the car while going ahead, with the motors in either the series or the multiple position, the master switch can be instantly thrown to the reverse series position, and the controller while immediately responding, will not in like degree, for as the master switch passes the off position the reversers will open, the main circuit of the motors will be instantly interrupted, the automatic stop on each car will run the controller back to some other determined position, the reversers will then close, and the series relay, which, although set by the master switch, has, up to that moment, been entirely inoperative, will now allow the pilot motor, controlled by the throttle, to intermittently move the controller to the reverse half-speed position.

If the by-pass on the controller is of proper length the reverser will close circuit as soon as the controller has returned to, say, the first resistance position, and it will remain there until the current has dropped below the safe amount.

In short, to all apparent intents and purposes, the controller seems possessed of an independent intelligence, because the relay system and the inter-connection of circuits is such that all local emergencies are provided for, as they must be, without regard to the wishes, intents or carelessness of an operator.

To connect two or more cars together, and to provide for the initiation of the operation of the controllers on such other cars as may be fully equipped from one or more of the master switches, an independent train line is provided, which is the extension of the platform-switch circuit from car to car, through fixed train cables on each car terminating in couplers at the ends of the cars, and flexible and reversible train cables, or jumpers, terminating in couplers with complementary contacts joining the several train cables together at the ends of the cars. These train lines and jumpers are so connected to the coupling heads that the controlling circuits are automatically paired to insure proper operation of the various main controllers from any master switch without regard to what are the abutting ends of the cars, or what is their number or sequence, or how the jumpers are reversed, or whether, as in practice, they are coupled indifferently on one side or other on the cars.

All roads, of course, do not change their sequence in the make-up of trains, but on many the cars are reversed, as in the operation of open-end relays, cross-overs and loops and yards. It follows that not only must there be a pairing of the sets of speed and direction circuits, but the individual speed circuits must always be paired alike, while the individual direction circuits must at times be changed in connection. These conditions have developed an invariable law of connections for the master and train line and jumper connections to get proper co-operation of the motor and like relative directional and hand movements under all circumstances.

The platform-switch circuits, the local operating or relay circuits, and the train-line circuits are joined together by switches which permit such independent connection on each car that controllers on any car can be operated from the master switch on its car, no matter how a train is made up, without the controllers on other cars being affected, or the controllers on as many cars as are desired can be operated from the master switch on another car without the controller on that car being operated, as well as the normal operation of all controllers from any master switch.

Normally, movement then of any master switch (the others for the time being inoperative and held at open circuit) closes like relays on each car, and starts the sequence of operations which I have indicated above for a single car.

Here again, however, the automatic variation of movement already described in regard to a particular controller, takes place independently on each car, and different kinds and degrees of movements of the controllers on different cars could take place simultaneously if necessary.

Not only that, but to provide for difference of wheel diameters, difference of tractive co-efficients on different wheels, and to provide also against any irregular condition on any car, similar movements may be differently timed, and different controllers may take different relative positions when measured by time, each accommodating itself to the limiting current input determined for itself.

It therefore becomes possible, by this combination of positive and semi-automatic control, to combine cars having controllers of different sizes, motors of different capacities, resistances of different gradations, gears of different ratios, and wheels of different diameters, and to successfully operate them all from one or more controlling points. The total weight of equipment per car other than the motors, platform switches, and train cables, is 1,972 pounds. At the time of going to press, both the Westinghouse Electric & Manufacturing Company and the General Electric Company had developed modified forms of multiple control, but few cars equipped with them had been put in actual commercial use.

APPROXIMATE RATES OF DEPRECIATION ON ELECTRIC STREET RAILWAYS.

(Dawson.)

Buildings	1 to 2 %	Feeder cables	3 to 5 %
Turbines	7 “ 9 “	Lighting and current meters	8 “ 10 “
Boilers	8 “ 10 “	Cars	4 “ 6 “
Dynamos and Engines, belted plants	5 “ 10 “	Repair shop and test-room fittings	12 “ 15 “
Belts	25 “ 30 “	Motors	5 “ 8 “
Large, slow-speed steam engines	4 “ 6 “	Rotary transformers	8 “ 10 “
Large, slow-speed direct-driven plants	4 “ 8 “	Boilers and engines	6 “ 10 “
Stationary transformers,	5 “ 6 “	Spare parts	1½ “ 2 “
Storage batteries in central stations	9 “ 11 “	Track work	7 “ 13 “
Trolley line	4 “ 8 “	Bonding	6 “ 10 “
		On remaining capital expenditure	4 “ 6 “

If interest rate is 5 per cent, and plant has to be renewed at the end of 20 years, 3 per cent of original outlay must be reserved annually to provide for renewal.

DEPRECIATION OF STREET RAILWAY MACHINERY AND EQUIPMENT.

Rates Stated by Chicago City Railway in "Street Railway Journal," Dec., 1898.

Power-Station.	Engines, 8 per cent; Boilers, 8 per cent; Generators, 3 per cent; Buildings, 5 per cent.
Cable Machinery.	Cable machinery, 10 per cent; Cables, 175 per cent.
Roadbed.	Rails, 5.5 per cent; Ties, 7 per cent.
Paving.	Granite, 5 per cent; Cedar blocks, 16 per cent; Brick, 7 per cent; Asphalt, 7 per cent; Macadam, 6 per cent.
Cars.	Car bodies, 7 per cent; Trucks, 8 per cent.
Rolling Stock.	Armatures, 33 per cent; Fields, 12 per cent; Gear cases, 20 per cent; Controllers, 4 per cent; Commutators, 33 per cent.
	Wiring and other electrical equipment, 8 per cent.
Line Equipment.	Iron poles, 4 per cent; Wood poles, 8 per cent; Insulation, 12 per cent; Trolley-wire, 5 per cent; Trolley insulation, 7 per cent; Bonding, 8 per cent.

All based upon renewals and per cent of wear.

CAR HEATING BY ELECTRICITY.

Test on Atlantic Avenue Railway, Brooklyn.

Cars.			Temperature F.		Watts Consumed.
Doors.	Windows.	Contents, Cu. ft.	Outside.	Average in car.	
2	12	$850\frac{1}{2}$	28	55	2295
2	12	$850\frac{1}{2}$	7	39	2325
2	12	$808\frac{1}{2}$	28	49	2180
2	12	$913\frac{1}{2}$	35	52	2745
4	16	1012	7	46	3038
4	16	1012	28	54	3160

TRACK RETURN CIRCUIT.

It goes without saying that the return circuit, however made, whether through track alone or in connection with return feeders, should be the best possible under the circumstances. Few of the older roads still retain the bonds and returns formerly considered ample and good enough.

Electrolysis and loss of power have compelled many companies to replace bonds and return circuits by much better types. The British Board of Trade paid especial attention to the return circuit in the rules gotten out by them (see page 504), and many American railroads would have been much in pocket to-day if such rules had been promulgated in the United States at the beginning of the trolley development.

With few exceptions the practice of engineers has been to connect the rail joints by bonds, both rails of a track together at intervals, and both tracks of a double-track road together. To this has sometimes been added track return wires laid between the rails, and in other cases return feeders from sections of track have been run to the power-house on pole lines.

The writer favors the full connection return with frequent insulated overhead return feeders where there may be danger from electrolysis of water and gas pipes; in fact, ample return circuit has been proved time and again to be the only preventive of that trouble.

Careful and continuous attention should be given to bonds from the moment cars are started on a line.

Dr. Bell gives the following ratios of track return circuit to overhead system as being average conditions.

Let $R_{\prime} =$ resistance of track return circuit, and
$R =$ resistance of overhead system;

Then

$R_{\prime} = .1$ to $.2R$. Exceedingly good track and very light load.
$R_{\prime} = .2$ to $.3R$. Good track and moderate load.
$R_{\prime} = .4$ to $.6R$. Fair track, moderate load.
$R_{\prime} = .2$ to $.3R$. Exceptional track and large system.
$R_{\prime} = .3$ to $.7R$. Good track, large system.
$R_{\prime} = .7$ to $1.0R$. Poor track, large system.

In exceptional cases track resistance may exceed that of overhead system.

It is sometimes assumed that $R_{\prime} = .25R$, but this is rather better than usual.

Under ordinary conditions $R_{\prime} = .4R$ is nearer correct.

If formula for copper circuit $=$ c.m. $= \dfrac{11\ I\ Dist.}{E}$ then for $R_{\prime} = 4R$, the constant 11 should be increased to between 14 and 15 in order that copper drop may bear correct proportion to that of the ground return.

Some forms of rail bond are shown on the following pages; most of these are applied to the rail by pressure or hammer riveting, but some of our better road managements are now soldering all bonds by strong heat.

A few roads still use wire secured in the web of the rail by steel channel pins, which is about the easiest and cheapest, as well as the least efficient form of bonding.

As copper bonds have a high value as junk, many of the long type are now stolen from suburban railways, and the tendency is strongly in favor of the concealed or protected bond which is so designed as to go in the space back of the fish plate against the web. For a time these protected bonds were made very short, and no very great attention paid to their flexibility, but experience has proved that no bond of less than eight or nine inches will last well, no matter how flexible. Solid conductor bonds are only available for the outside of fish plates, and not less than two feet in length. In applying the copper bonds to the rails, it is necessary to apply them immediately after drilling the web, unless holes are made at the rail mill and carefully oiled, in which case the oil should be very carefully removed before applying the bond.

Bonds are best applied by a medium using heavy pressure, either by screw or hydraulic pressure, rather than by hammer riveting.

On many of the systems, in large cities, rails are made practically continuous now by use of electrically welded joints or cast weld joints.

In the electrically welded system a piece of iron about nine inches long, two inches wide, and an inch thick is welded across the joint on each side of the rail web by means of a heavy current of electricity applied by special machinery, taking its power from the trolley system. After the straps are welded in position, the tops of the rail ends are carefully ground to an even surface. Contrary to the ordinary ideas of the results of expansion and contraction, but little trouble is experienced by broken joints or bent rails, and in most places, where the method is in use, it has been quite successful. The system is controlled by the Johnson Steel Co. of Cleveland, Ohio.

The cast weld joint is simply a bunch of cast iron cast about the joint after it has been cleaned and prepared by placing a mold under it. The Falk Company of Milwaukee makes a specialty of bonding street railway systems in this manner, and the results seem to have been good.

Several forms of plastic bond have been devised and used to some exent. They all consist of some form of plastic metal held in position between the fish plate and the rail web, the surfaces of both being treated chemically or otherwise, so as to remove scale and oxide so that the plastic material may be applied directly against the web.

Solid Bonds. — This type is simply a heavy copper bar, say No. 0000 B. & S. gauge, with the ends compressed to form a collar, and bent to fit the holes in the rails, and their hammer riveted to place.

A good example is that made by Messrs. Benedict and Burnham, and shown in Figs. 50, 51, 52, and 57.

Benedict and Burnham Solid One-Piece Rail-Bond.

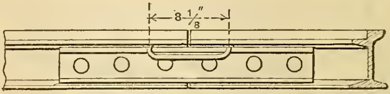


FIG 50. Short thick Bond applied to "Tram" of Girder Rail, allowing constant inspection.

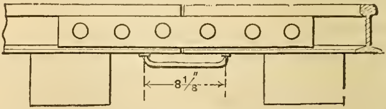


FIG. 51. Short thick Bond applied to Base of either Girder or T Rail.

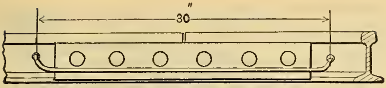


FIG. 52. Solid long Bond clearing the Fish-plate in either Girder or T Rail.

Protected Bonds.—Good examples of these are exhibited in Figs. 53, 54, 55, 56, which show the type of protected bond sold by the Mayer & Englund Co. of Philadelphia. They are applied by a special hydraulic press, and many variations of form are made to fit special cases.

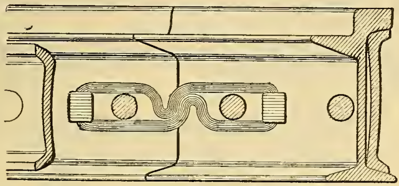


FIG. 53. Showing 7-inch Girder Rail, bonded with one Bond.

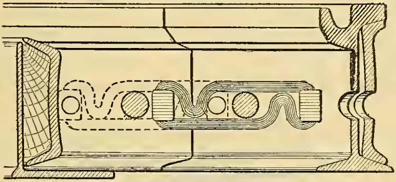


FIG. 54. Showing 7-inch Girder Rail, double bonded with two Bonds, one on each side of rail. Electrical connection of 425,000 c.m.

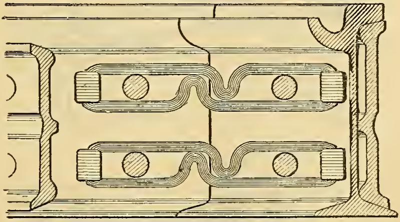


FIG. 55. Showing 9-inch Grooved Girder Rail double bonded with two Bonds, one in each chamber and both on same side of rail. Electrical connection of 425,000 c.m.

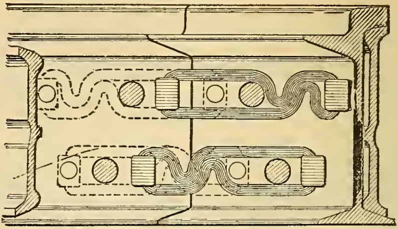


FIG. 56. Showing 9-inch Girder Rail quadruple bonded with four Bonds, two in each chamber, on both sides of rail. Electrical connection of 850,000 c.m.

Another form of this type of bond is that shown in Fig. 59, as made by the Forest City Electric Co. of Cleveland.

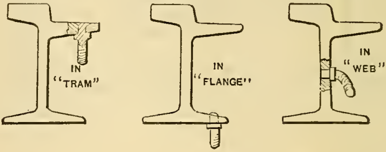


FIG. 57.

Still another form of concealed bond is shown in Fig. 58, and made by I. M. Atkinson & Co., Chicago.

Rail Bond of J. M. Atkinson & Company, Chicago.

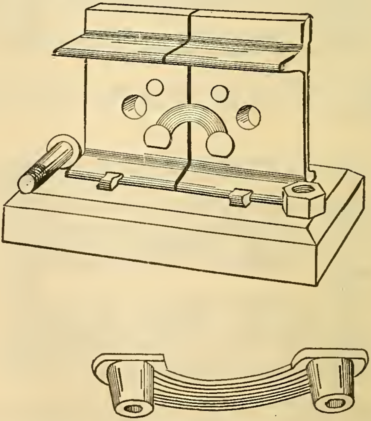


FIG. 58. Applied either single or double under fish-plate.

In some types of bond the plug has a hole through it, and after placing it in the hole in the web of the rail a steel mandrel is driven through to expand the copper outwardly to fill the hole.

Forest City Electric Company Short Bond.

This bond is applied underneath the fish-plate, and secured by a special tool.

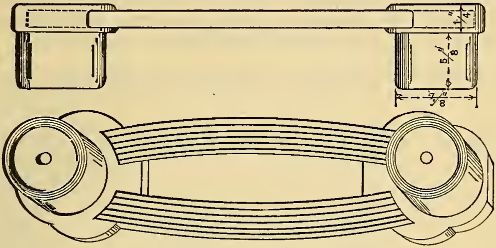


FIG. 59.

In numerous tests of rail bonds, Mr. W. C. Burton, of the J. G. White Co., says it was found that where the copper plug was well pressed home the resistance of the joint between rail and bond did not exceed that of three-eighths inch of the bond itself, even after a year or more of use; and that short bonds, especially those that could be covered by the fish-plate made rail-joint resistance a very small percentage of the total track resistance. He had never found tinned copper any better than the bare metal, and when pressed tight had not noticed any effect whatever from local action.

Table Showing Sectional Areas of Various Rails, the Equivalents in Circular Mils, and the Equivalent Circular Mils of Copper Giving Same Conductivity.

(Figures on rails are for one side of a single track.)

Weight Per Yard.	Area of Single Rail. Sq. in.	Circular Mils of Single Rail.	Equivalent Circular Mils of Copper for Same Conductivity. Conductivity.*
45	4.4095	5,614,400	997,200
50	4.8994	6,238,200	1,108,000
56	5.4874	6,986,700	1,241,000
60	5.8794	7,485,800	1,329,500
65	6.3693	8,109,600	1,440,400
70	6.8592	8,733,400	1,551,200
80	7.8392	9,981,100	1,772,800

* For commercial steel rail use .6 these values.

$$\text{Area in Cir. Mils} = \frac{1{,}000{,}000 \times \text{wgt. per yard}}{10.2052 \times .7854}.$$

$$\text{Equivalent Cir. Mils of Copper} = \frac{\text{Area in cir. mils}}{5.63}.$$

Mr. W. C. Burton, of J. G. White Co., found a very considerable difference in rail resistivity, and numerous tests of modern steel rails showed the specific resistance to be from six to twelve times that of copper, where six has been the factor frequently used. In his own practice Mr. Burton uses a factor dependent upon the chemical properties and the physical treatment of the rail in the rolling-mill.

BOARD OF TRADE REGULATIONS.

For Great Britain.

Regulations prescribed by the Board of Trade under the provisions of Section —— of the —— Tramways Act, 189—, for regulating the employment of insulated returns, or of uninsulated metallic returns of low resistance; for preventing fusion or injurious electrolytic action of or on gas or water pipes, or other metallic pipes, structures, or substances; and for minimizing, as far as is reasonably practicable, injurious interference with the electric wires, lines, and apparatus of parties other than the company, and the currents therein, whether such lines do or do not use the earth as a return.

Definitions.

In the following regulations:—

The expression "energy" means electrical energy.

The expression "generator" means the dynamo or dynamos or other electrical apparatus used for the generation of energy.

The expression "motor" means any electric motor carried on a car and used for the conversion of energy.

The expression "pipe" means any gas or water pipe, or other metallic pipe, structure, or substance.

The expression "wire" means any wire apparatus used for telegraphic, telephonic, electrical signaling, or other similar purposes.

The expression "current" means an electric current exceeding one-thousandth part of one ampere.

The expression "the company" has the same meaning or meanings as in the ——— Tramways Act. 189—.

Regulations.

1. Any dynamo used as a generator shall be of such pattern and construction as to be capable of producing a continuous current without appreciable pulsation.

2. One of the two conductors used for transmitting energy from the generator to the motors shall be in every case insulated from earth, and is hereinafter referred to as the "line"; the other may be insulated throughout, or may be insulated in such parts and to such extent as is provided in the following regulations, and is hereinafter referred to as the "return."

3. Where any rails on which cars run, or any conductors laid between or within three feet of such rails, form any part of a return, such part may be uninsulated. All other returns or parts of a return shall be insulated, unless of such sectional area as will reduce the difference of potential between the ends of the uninsulated portion of the return below the limit laid down in Regulation 7.

4. When any uninsulated conductor laid between or within three feet of the rails forms any part of a return, it shall be electrically connected to the rails at distances apart not exceeding 100 feet, by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or by other means of equal conductivity.

5. When any part of a return is uninsulated it shall be connected with the negative terminal of the generator, and in such case the negative terminal of the generator shall also be directly connected, through the current-indicator hereinafter mentioned, to two separate earth connections, which shall be placed not less than twenty yards apart.

Provided that in place of such two earth connections the company may make one connection to a main for water supply of not less than three inches internal diameter, with the consent of the owner thereof. and of the person supplying the water; and provided that where, from the nature of the soil or for other reasons, the company can show to the satisfaction of an inspecting officer of the Board of Trade that the earth connections herein specified cannot be constructed and maintained without undue expense, the provisions of this regulation shall not apply.

The earth connections referred to in this regulation shall be constructed, laid, and maintained so as to secure electrical contact with the general mass of earth, and so that an electromotive force not exceeding four volts shall suffice to produce a current of at least two amperes from one earth connection to the other through the earth, and a test shall be made at least once in every month to ascertain whether this requirement is complied with.

No portion of either earth connection shall be placed within six feet of any pipe, except a main for water supply of not less than three inches internal diameter, which is metallically connected to the earth connections with the consents hereinbefore specified.

6. When the return is partly or entirely uninsulated, the company shall, in the construction and maintenance of the tramway (*a*), so separate the uninsulated return from the general mass of earth, and from any pipe in the vicinity; (*b*) so connect together the several lengths of the rails; (*c*) adopt such means for reducing the difference produced by the current between the potential of the uninsulated return at any one point and the potential of the uninsulated return at any other point; and (*d*) so maintain the efficiency of the earth connections specified in the preceding regulations as to fulfill the following conditions, viz.:

(1.) That the current passing from the earth connections through the indicator to the generator shall not at any time exceed either two amperes per mile of single tramway line, or 5 per cent of the total current output of the station.

(2) That if at any time and at any place a test be made by connecting a galvanometer or other current indicator to the uninsulated return, and to any pipe in the vicinity, it shall always be possible to reverse the direction of any current indicated by interposing a battery of three Leclanche cells connected in series, if the direction of the current is from the return to the pipe, or by interposing one Leclanche cell, if the direction of the current is from the pipe to the return.

In order to provide a continuous indication that the condition (1) is complied with, the company shall place in a conspicuous position a suitable, properly connected, and correctly marked current indicator, and shall keep it connected during the whole time that the line is charged.

The owner of any such pipe may require the company to permit him at reasonable times and intervals to ascertain by test that the conditions specified in (2) are complied with as regards his pipe.

7. When the return is partly or entirely uninsulated, a continuous record shall be kept by the company of the difference of potential during the working of the tramway between the points of the uninsulated return furthest from and nearest to the generating station. If at any time such difference of potential exceeds the limit of seven volts, the company shall take immediate steps to reduce it below that limit.

8. Every electrical connection with any pipe shall be so arranged as to admit of easy examination, and shall be tested by the company at least once in every three months.

9. Every line and every insulated return or part of a return, except any feeder, shall be constructed in sections not exceeding one half of a mile in length, and means shall be provided for insulating each such section for purposes of testing.

10. The insulation of the line and of the return when insulated, and of all feeders and other conductors, shall be so maintained that the leakage current shall not exceed one-hundredth of an ampere per mile of tramway. The leakage current shall be ascertained daily, before or after the hours of running, when the line is fully charged. If at any time it should be found that the leakage current exceeds one-half of an ampere per mile of tramway, the leak shall be localized and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localized and removed within twenty-four hours. Provided, that where both line and return are placed within a conduit this regulation shall not apply.

11. The insulation resistance of all continuously insulated cables used for lines, for insulated returns, for feeders, or for other purposes, and laid below the surface of the ground, shall not be permitted to fall below the equivalent of 10 megohms for a length of one mile. A test of the insulation resistance of all such cables shall be made at least once in each month.

12. Where in any case in any part of the tramway the line is erected overhead and the return is laid on or under the ground, and where any wires have been erected or laid before the construction of the tramway, in the same or nearly the same direction as such part of the tramway, the company shall, if required to do so by the owners of such wires or any of them, permit such owners to insert and maintain in the company's line one or more induction coils, or other apparatus approved by the company for the purpose of preventing disturbance by electric induction. In any case in which the company withhold their approval of any such apparatus, the owners may appeal to the Board of Trade, who may, if they think fit, dispense with such approval.

13. Any insulated return shall be placed parallel to, and at a distance not exceeding three feet from, the line, when the line and return are both erected overhead, or 18 inches when they are both laid underground.

14. In the disposition, connections, and working of feeders, the company shall take all reasonable precautions to avoid injurious interference with any existing wires.

15. The company shall so construct and maintain their systems as to secure good contact between the motors, and the line and return respectively.

16. The company shall adopt the best means available to prevent the occurrence of undue sparking at the rubbing or rolling contacts in any place, and in the construction and use of their generator and motors.

17. In working the cars the current shall be varied as required by means of a rheostat containing at least twenty sections, or by some other equally efficient method of gradually varying resistance.

18. Where the line or return or both are laid in a conduit, the following conditions shall be complied with in the construction and maintenance of such conduit:

(*a*) The conduit shall be so constructed as to admit of easy examination of, and access to, the conductors contained therein, and their insulators and supports.

(*b*) It shall be so constructed as to be readily cleared of accumulation of dust or other débris, and no such accumulation shall be permitted to remain.

(*c*) It shall be laid to such falls, and so connected to sumps or other means of drainage as to automatically clear itself of water without danger of the water reaching the level of the conductors.

(*d*) If the conduit is formed of metal, all separate lengths shall be so jointed as to secure efficient metallic continuity for the passage of electric currents. Where the rails are used to form any part of the return, they shall be electrically connected to the conduit by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or other means of equal conductivity, at distances apart not exceeding 100 feet. Where the return is wholly insulated and contained within the conduit, the latter shall be connected to earth at the generating station through a high resistance galvanometer, suitable for the indication of any or partial contact of either the line or the return with the conduit.

(*e*) If the conduit is formed of any non-metallic material not being of high insulating quality and impervious to moisture throughout, and is placed within six feet of any pipe, a non-conducting screen shall be interposed between the conduit and the pipe, of such material and dimensions as shall provide that no current can pass between them without traversing at least six feet of earth; or the conduit itself shall in such case be lined with bitumen or other non-conducting damp-resisting material in all cases where it is placed within six feet of any pipe.

(*f*) The leakage current shall be ascertained daily before or after the hours of running, when the line is fully charged, and if at any time it shall be found to exceed half an ampere per mile of tramway, the leak shall be localized and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localized and removed within 24 hours.

19. The company shall, so far as may be applicable to their system of working, keep records as specified below. These records shall, if and when required, be forwarded for the information of the Board of Trade.

Daily Records.

Number of cars running.
Maximum working current.
Maximum working pressure.
Maximum current from earth connections (*vide* Regulation 6 (1)).
Leakage current (*vide* Regulation 10 and 18 *f*.).
Fall of potential in return (*vide* Regulation 7).

Monthly Records.

Condition of earth connections (*vide* Regulation 5).
Insulation resistance of insulated cables (*vide* Regulation 11).

Quarterly Records.

Conductance of joints to pipes (*vide* Regulation 8).

Occasional Records.

Any tests made under provisions of Regulation 6 (2)).

Localization and removal of leakage, stating time occupied.

Particulars of any abnormal occurrence affecting the electric working of the tramway.

Signed by order of the Board of Trade this ________ day of _______ 189__

____

Assistant Secretary, Board of Trade.

OVERHEAD SYSTEM FOR ELECTRIC STREET RAILWAYS.

1. Ladder system, shown in the following cut, formerly somewhat used on small roads, where both feeder and trolley wire of the same size would carry the load. Feeder in this case is simply an enlargement of the trolley wire, and as used might have better been one large trolley wire.

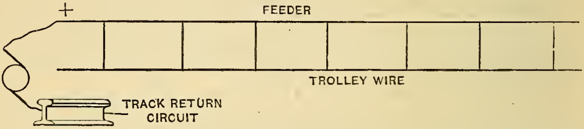


FIG. 60.

2. A modification of the above system is the following. In this second system the trolley wire is cut into sections, and while losing the extra conductivity of the continuous trolley, by placing fuse and switch at the junction of each sub-feeder with the main feeder, each such section may be cut out in case of trouble without depriving the remainder of the system of current.

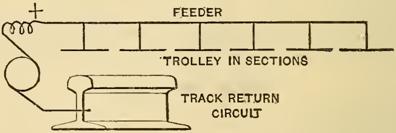


FIG. 61.

Both above systems are now somewhat out of date, although occasionally used on the smaller roads.

3. The system shown in the following cut is more of a real feeding system than either of the previous two.

The trolley wire is connected directly to the dynamo, but is also fed at various points, as at *a*, *b*, *c*, by larger wires tapped into it.

A load at *d* would thus receive current from both feeders *b* and *c*, and the pressure can be more evenly maintained than by either of the previous methods. By making the trolley wire of larger cross-section than is usual in the previous systems, it is possible to have fewer sections and yet maintain a fairly even voltage.

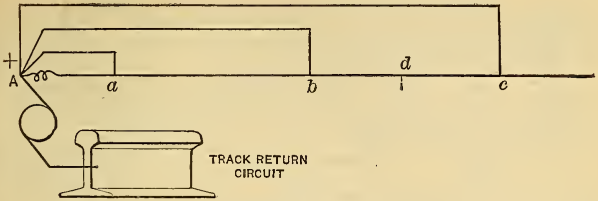


FIG. 62.

4. An obvious modification of the above is shown in the following cut. In this system the trolley wire is again divided into sections, but each section is supplied from its own separate feeder, the size of which may be so calculated as to keep a very even pressure at all points on the line, especially so if the trolley wire be not too small and the sections not too long. It is of course, subject to the objection that the sections receive no help from the remainder of the circuit, but has the advantage that each section may be controlled by switch and circuit-breaker at the station, and if at any part of the system, as at *d*, there is a heavy grade or a heavy massing of cars, cross connection can be made to the feeder *c*, either by switch or by permanent tie. Another method of tying that has been used in some localities is that of connecting the ends of trolley sections together with a small copper wire, say No. 12 B. & S., and thus getting part current both ways; and in case of heavy overload or short circuit on a section the tie-wires will burn off, leaving all other sections free as before. This method is said to be of considerable advantage.

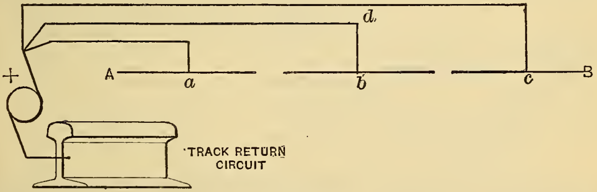


FIG. 63.

5. The following cut shows a combination of the previous methods, such as results from experience in operating larger systems of roads. The principal feeder *C* is tapped at intervals to feed the short and long sections, and in order to maintain even voltage at its distant end, is reinforced at *d* and *e* by the feeders *E* and *F*, while the still farther distant trolley-line sections are fed by the long feeders *G* and *H*, which can be joined as at *f*, if the circumstances call for it.

As mentioned above, this method is the result of actual experience on a line after it has been run, and the loads have developed the points where current is most needed. While systems of overhead lines are always laid out with more or less care, traffic often takes the most erratic changes in direction, and changes its call for current to such an extent that feeders often have to be run to new points, sections have to be joined or new divisions made, or feeders have to be tied; and this cut shows the general result of such actual experience. As a general thing it is not good practice to cut the trolley into any more sections than necessary for safety; and even then a *separable* line, that is, one that can be cut into sections by switches, is better than *separate* sections.

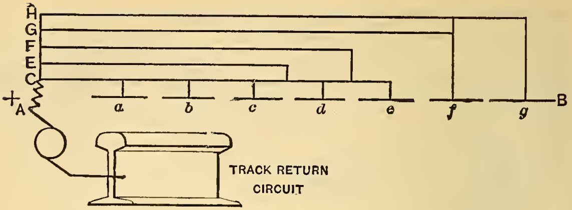


FIG. 64.

6. For long roads the system shown in the following cut may be used with advantage, as, with heavy trolley wire such as should always be used on long lines, the trolley wire can be reinforced by the feeders as shown, so as to maintain a fairly constant pressure, and advantage be taken of all the conductivity of the system. On double-track roads all the trolley system should be united and at frequent intervals, so that advantage may be taken of the full conductivity installed.

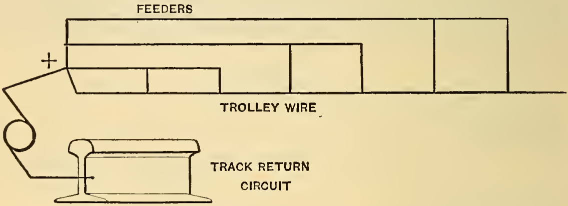


FIG. 65.

7. A system sometimes used on small single-track lines, where feeders are not entirely necessary, but a single trolley wire may be too small, is to run two trolley wires side by side, and at all sidings the wire nearest the siding is run around it, and the cars can pass and the trolleys follow each its own wire without troublesome switches.

CALCULATING THE CONDUCTING SYSTEM.

Dr. Louis Bell gives the following steps as the best to be followed in entering upon the calculation of the conducting system of a trolley road:

1. Extent of lines.
2. Average load on each line.
3. Center of distribution.
4. Maximum loads.
5. Trolley wire and track return.
6. General feeding system.
7. Reinforcement at special points.

It must be said at once that experience, skill, and good judgment are far better than any amount of theory in laying out the conducting system of any road.

Much depends upon the character of the *load factor*, i. e., the ratio of average to maximum out-put; and this, varying from .3 to .6, can only be guessed at by a study of the particular locality, the nature of its industries and working people, the shape of the territory, and the nature of the surrounding country.

1. Map out the track to scale, noting all distances carefully, and dot in any contemplated extensions, so that adequate provision may be made in the conducting system for them. Note all grades, giving their length, gradient, and direction. Divide the road into sections such as may best suggest themselves by reason of the local requirements, but such as will make the service under ordinary conditions fairly constant.

2. The average load on each section will depend, of course, upon the number of cars, and the number of cars upon the traffic. This can only be arrived at by a comparison with similar localities already equipped with street railway, and even then considerable experience and keen judgment of the general nature of the towns are necessary in arriving at anything like a correct result.

3. If the road has been correctly laid out as to sections, the load on each will be uniform and may be considered as concentrated at a point midway in each section. Now, if a street railway were to be laid down on a perfectly level plain, where the cost of real estate was the same at all points, and wires could be run directly to the points best suited; then it would only be necessary to locate the center of gravity of the entire system, and build the power station at that point, sending out feeders to the center of each section. Unfortunately for theory, such is never the case; and cost of real estate, availability of the same, convenience of fuel, water, and supplies will govern very largely the selection of a location for the power-house. Even when all the above points necessitate the placing of the power-house far from the center of gravity of a system, it may be possible to use such center as the distributing point for feeder systems, and even where this is not possible, it is well to keep in mind the center, and arrange the distributing system as nearly as possible to fit it.

All this relates, however, to preliminary determinations for the system as determined at the time, and in large systems will invariably be supplemented by feeders, run to such points as the nature of the traffic demands. A base-ball field newly located at some point on the line not known to the engineer previous to the installation, will require reinforcement of that particular section; and often after a road has been running for some time, the entire location of traffic changes, due to change in facilities, and feeder systems then have to be changed to meet the new conditions, so that after all, location of the center of distribution depends largely on judgment.

4. The predetermination of the maximum or average load is another matter for experienced guessing, as it will depend altogether upon the nature of the traffic, how many people patronize the line, and how often the cars are run.

If the weight of the car and its load be known it is an easy matter to determine the power necessary to propel it; and tables will be found in this section showing the tractive effort necessary, and all other data for such determination.

Bell gives the following formula for the horse-power necessary at the wheel of a car.

Let $P =$ total horse-power.

$W =$ weight of car and load in tons.

$.43 =$ h.p. per ton required at wheel at 20 lbs. per ton for a speed of 8 miles per hour.

$G =$ per cent grade.

Then

$$P = W(.43 + .43G).$$

This applies to straight tracks only, and at a speed of 8 miles per hour, which is often exceeded.

The same authority also states that allowing an efficiency between trolley and car-wheel of 66⅔ per cent, and voltage at the car of 500, 1¼ amperes per ton plus 1¼ amperes per ton for each per cent of grade will be approximately correct. This means an average of about 15 amperes per car, throughout the day, for the ordinary car and road. Long double-truck cars will take nearer 25 amperes, and in the writer's judgment this last is a good average to use for all traffic on ordinary street railways.

The maximum current will rise to four or five times the average where but one or two cars are in use; will easily be three times the average on roads of medium size, while on very large systems it may not be more than double the average. If speeds are maintained on heavy grades the maximum is still further liable to increase.

Another point to be considered in connection with maximum load, is the location, not only of heavy grades, but of parks, ball-grounds, athletic fields, cemeteries, and other such places for large gatherings of people that are liable to call for heavy massing of cars, many of which must be started practically at the same time, and for which extra feeder, and in some cases extra trolley capacity, must be provided.

Having determined the average current per section of track, the maximum for the same, and the extraordinary maximum for ends, park locations, etc., as well as the distances, all data are obtained necessary for the determination of sizes of feeders.

5. The selection of the proper size of trolley is somewhat empirical, but the size may be governed by the amount of current that is to be carried. It is obvious that with given conditions the larger the trolley wire the fewer feeders will be necessary, and yet with few feeders the voltage is liable to vary considerably. In ordinary practice of to-day No. 0 B. & S. and No. 00 B. & S. gauge, hard-drawn copper are the sizes mostly in use, the latter on those roads having heavier traffic or liable to massing of cars at certain localities. On suburban roads using two trolley wires in place of feeders, 0000 B. & S. gauge will probably be best.

Track return circuit has been treated fully in a previous chapter; and all that is needed to say here is, that some skill in judgment is necessary in settling on the value of the particular track return that may be under consideration, in order to determine the value of the constant to be used in the formula for computing the size of wire or overhead circuit. In ordinary good practice this value may be taken as 13, 14, or 15, according as the bonding and rail dimensions are of good type and large.

6. Feeder-points should, in a general way, be so located as to allow no drop in a section of trolley wire exceeding 5 per cent or 25 volts under normal load. This drop is easily determined by the regular formula:

Let $D =$ distance from feeding point to end of the trolley section,
$c.m. =$ circular mils of the trolley,
$E =$ drop in volts,
$13 =$ constant for circuit in connection with a well bonded heavy track,
$I =$ current required per car, usually taken as 15 amperes under running conditions, but more safely taken as 25 amperes.

Then

$$D = \frac{c.m.\ E}{13\ I};$$

and if the trolley wire selected be No. 00 B. & S. $c.m. = 133{,}600$, and as the maximum drop permissible in the trolley wire is 25 volts $D = \frac{133{,}000 \times 25}{13 \times 25}$ = longest section of trolley wire for one car, or 10,231 feet. If two cars are bunched at the end of the section the drop will be twice as great, or the length of section can be but 5,115 ft.; for 3 cars the length will be 3,410 ft.; for 4 cars the length will be 2,558 ft.; and for five cars the length will be 2,046 feet.

The above calculation will be correct for level roads and where the load is well distributed; but the trolley-wire sections must necessarily be shortened up for grades or at such points in the line as heavy massing of cars is liable to take place, as at ball-parks, etc., where people all want to get home at once, and all available cars are started from that point.

In such cases it will probably be safe to allow 50 amperes per car for the section of trolley wire on which the park is located, and the result is then $D = \frac{133{,}000 \times 25}{13 \times 50} = 5{,}115$ ft. for one car, and for n cars the greatest length of section would be $5{,}115 \div n$.

Having calculated all the points on the trolley line at which it should be fed, it remains to calculate the size of feeder for the purpose.

As to the allowable drop in feeders, it is not well to have over 100 volts total drop at the car and 75 volts total drop is better under maximum load, as low voltage at the motors tends to over-heat them to a dangerous degree. Much of the regular drop can be overcome by over-compounding the generators for a rise of potential of about 50 volts.

It is decidedly better practice to make feeder determinations based on the maximum load, as the average load will easily care for itself, but during times of extraordinary crowds, or snow-storms, if the line has not been calculated for such heavy loads, all the motors will heat, and much trouble is liable all along the line.

The writer considers 75 volts drop in feeders under maximum load conditions a safe basis, together with 35 amperes per car for all those liable to be on the section at once. Over-compounding will make up for 50 volts of the drop at the motors at times of heaviest distributed load, so there will be no danger. Feeder calculation will then be

$$\text{c. m. of feeder} = \frac{13 \times D \times 35\, n \text{ cars}}{75}.$$

It is quite obvious that the current-carrying capacity of the feeder must be taken into consideration, in spite of any determination of drop; and this can be found in the chapter on *Conductors*. Sizes of conductors are also governed to some extent by convenience in handling, and it is found that 1,000,000 c. m. is about the largest that can be safely handled for underground work, while anything larger than 500,000 c. m. for overhead circuits is found to be difficult to handle.

7. In cases where it is necessary to feed the trolley wire in short sections, in order to reinforce the trolley wire for heavy grades, sub-feeders are often used, the main feeder being tapped into its center, or at such point in its length as will give the best distribution, as shown in the following cut.

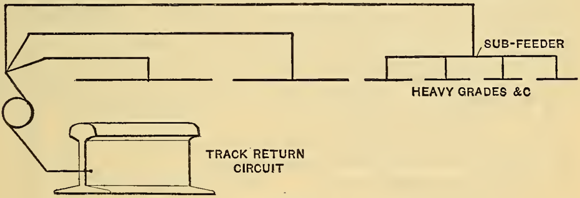


FIG. 66.

For lines having parks at the end, or in fact for any such section, it is perhaps best to run a feeder nearly to the end of the section, then take the trolley line to the feeder at various points comparatively short distances apart, as shown in the following cut; and if the loads are at times especially heavy, the next feeder can be made to assist by cross-connecting, as at *d*.

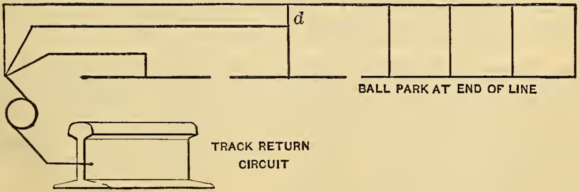


FIG. 67.

In this connection it must be remembered that heavy loads from parks, as well as on grades, do not often come at the same time as heavy loads on other sections, and therefore that the over-compounding may not be but a part of the full-load rise, and it is best under the circumstances to calculate the sizes of such feeders for a smaller drop, say 50 volts maximum instead of 75.

In general it may be said that it is now the usual practice to use a few standard sizes of feeder wire, such as 100,000 c.m., 200,000, 250,000, 500,000, and so connect them as to produce the required results, rather than to carry a large number of various sizes of wire in stock. In fact, this same practice is now carried out in large lighting installations as well, and in those constant pressure is much more necessary than in railway circuits.

Special Methods of Distribution.

For cases requiring excessively large currents carried a considerable distance, or for ordinary currents carried excessive distances, it is usually economy to adopt some special method; and among those most commonly mentioned are: the three-wire system, the booster system, the substation system.

Three-Wire System. This system, patented some time ago by the General Electric Company, has been seldom used, and where used has met with little success, owing to the difficulty met in keeping the system balanced.

The diagram below will assist in making the method plain. Two 500-volt generators are used, as in the lighting system of the same type. The rail return is used as the neutral conductor; and if both trolley wires could be made to carry the same loads, and to remain balanced, then the rail return would carry no current, and no trouble would occur from electrolysis. The overhead conductors could also be very much smaller, as currents would be halved, and the full voltage would be practically 1000.

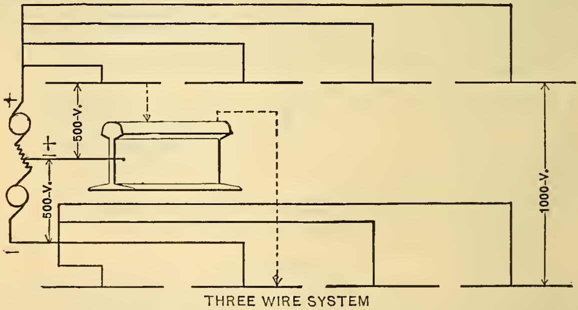
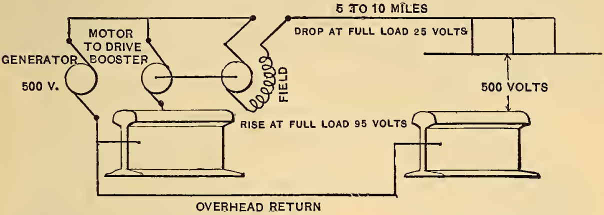


FIG. 68. Three-Wire System.

The Booster System.—Where current must be conveyed a long distance, say five to ten miles, and be delivered at 500 volts, it is hardly good economy to install copper enough to prevent the drop; and if the voltage of the generator be raised sufficiently to deliver the required voltage, the variations due to change of load will be prohibitive.

In such cases a "booster" can be connected in series with the feeder, and automatically keep the pressure at the required point, as long as the generator delivers the normal pressure.

The "booster" is nothing more than a series-wound dynamo, connected so that all the current of the feeder to which it is attached flows through both field and armature coils, and the voltage produced at the armature terminals is added to that of the line, and as the voltage so produced is in proportion to the current flowing, it will be seen that the pressure will rise and fall with the current. This is now used in many instances, both in lighting and for railway feeders, and especially in feeding storage batteries, and has met with entire success. The following cut is a diagram of the connections.



BOOSTER SYSTEM

FIG. 69.

Return Feeder Booster.—Major Cardew, Electrical Engineer for the Board of Trade, some time ago devised a method of overcoming excessive drop in track return circuits by the use of insulated return feeders, in series with which he placed a booster.

The booster draws current back toward the station, adding its E.M.F. to that in the feeder. Cardew used a motor generator, the series field of which was separately excited by the outgoing feeder for the same section of road. Thus the volts "boosted" were in direct proportion to the current flowing. H. F. Parshall, in adopting the return feeder booster for some of his work in England, used a generator in place of the motor-generator of Major Cardew, exciting the field by the current flowing out on the trolley feeder, thus producing volts in the armature in proportion to the current flowing. The following diagram shows Parshall's arrangement.

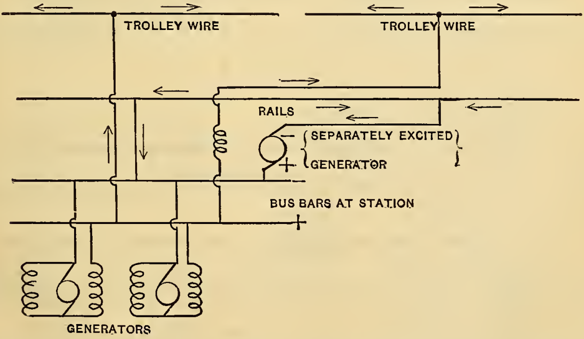


FIG. 70. Modification of Major Cardew's System of Track Return Booster for Preventing Excessive Drop in Rail Return Circuits.

Sub-Station System.—Where traffic is especially heavy, and a railway system widespread, it is now the practice to use one large and very economical power station with high-pressure generators, now invariably polyphase alternators, and to distribute this high-pressure alternating current to small sub-stations centrally located for feeding their districts, and there changing the current by means of static and rotary transformers into continuous current of the requisite pressure, in the case of railways 500 or 550 volts. Such systems have already been mapped out for the Manhattan Elevated Railway, and for the Metropolitan Traction Company of New York, and are now in operation, as well as on the Central Underground Railway of London.

The following diagrams will assist in making the system plain.

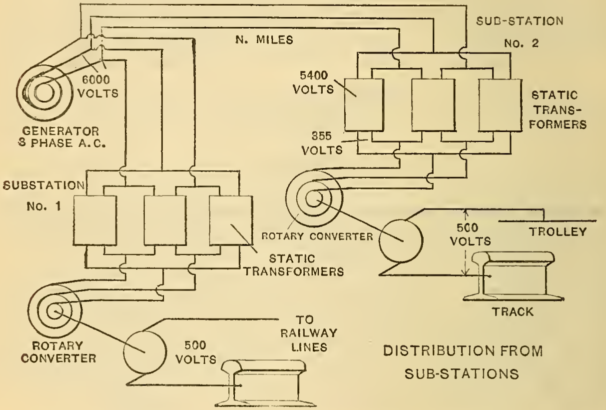


Fig. 71.

TESTS OF STREET RAILWAY CIRCUITS.

The following tests are condensed from an article by A. B. Herrick in the *Street Railway Journal*, April, 1899.

The following instruments will be required :

A barrel water rheostat to take say 100 amperes.
A voltmeter reading to 600 volts.
A voltmeter reading to 125 volts.
An ammeter reading to say 150 amperes.
A pole long enough to reach the trolley wire, with a wire running along it having a hook to make contact.

Use one generator at the station, and have the attendant keep pressure constant.

Test for Drop and Resistance in Overhead Lines and Returns.

The car containing the above equipment of instruments is run to the end of the section of conductor which it is desired to test, where a line circuit-breaker divides the sections.

The instruments are then connected as shown in Fig. 73.

It is clear now that if the switch G be closed, current will flow through the rheostat and be measured by the ammeter. We now have the trolley and feeder B for a pressure wire back to the station, and the reading of voltmeter C therefore gives the drop between the station and the point A

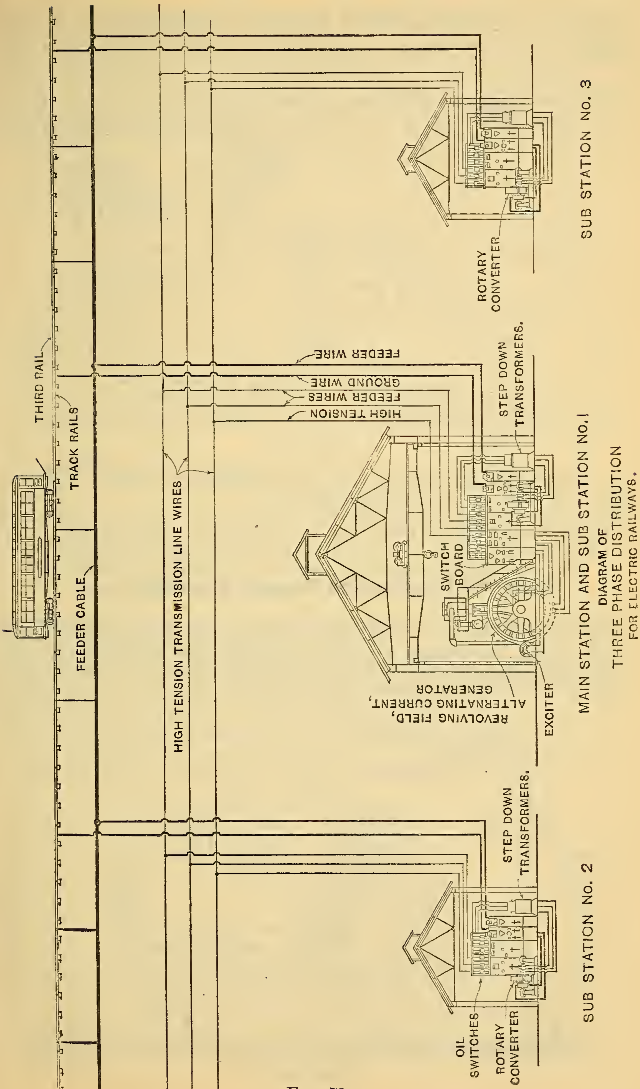


DIAGRAM OF
THREE PHASE DISTRIBUTION
FOR ELECTRIC RAILWAYS.

FIG. 72.

in the feeder and trolley carrying the load. Voltmeter D shows the drop across the rheostat; and if the sum of readings C and D be deducted from the station pressure, the difference will be the drop in the ground return.

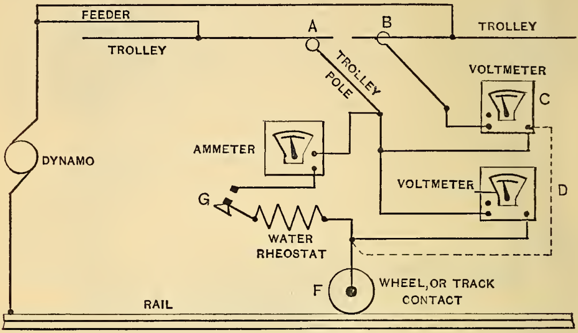


FIG. 73.

The station pressure can be taken by changing the lead of voltmeter C down to F as shown by the dotted line.

The drop on A and its resistance having been found, the trolley-pole can be swung around and the same data be determined for the circuit B.

To Read the Ground Return Drop Directly.

Open the station switch on that feeder that is being used as pressure wire, and ground the feeder to the ground bus through a fuse for safety.

Connect the instruments as shown in the following cut; then when the switch G is closed and current flows, the drop from A to F read on voltmeter C will be the drop in the ground return from F to X.

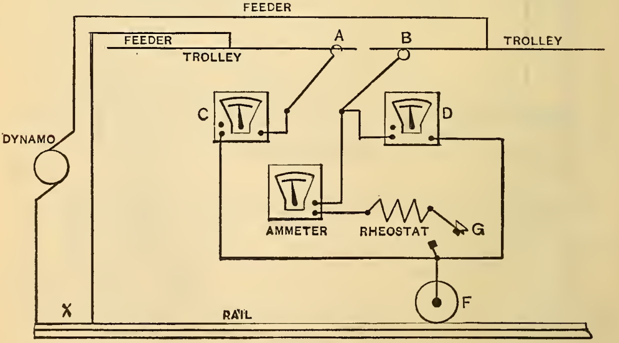


FIG. 74.

To Determine Drop at End of Line.

For use on double-track lines only, unless a pressure wire can be run to the end of line from the last line circuit-breaker.

Break all cross connections from feeder to trolley-wire for one track, as at *n*; connect this idle trolley to the next one back toward the station, as at C, then make the tests as in the two methods described above, connections being shown in the following cut.

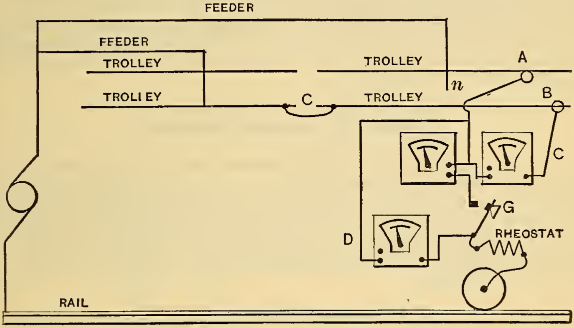


FIG. 75.

To Determine the Condition of Track Bonding, and the Division of Return Current through Rails, Water or Gas Pipes, and Ground.

The cut below shows the connections for this test as applied to a single track, or to one track of a double-track road.

Ground the feeder A at the station, or rather connect it to the ground bus through a fuse. Then connect the track at C to A by the pole E through the ammeter M. The drop between points F and D will be the drop through the rail circuit between C and D, due to the current flowing.

If connection be made to a hydrant, or other water connection, and to a gas-pipe, as at X, still retaining the rail connection at C, more current will

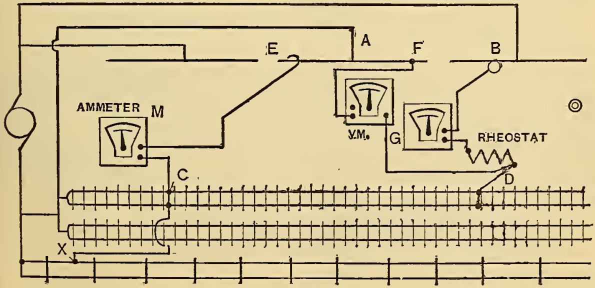


FIG 76.

flow through ammeter M, due to providing the metallic return through A for the water-pipe, and the first reading of the ammeter M is to the second reading as the resistance of the water-pipe is to that of the rail return, and the current returning to the station will distribute itself between the two paths in proportion to the readings mentioned. If ammeter G be read at the same time, the difference between its reading and the sum of the other two readings will be the amount of current returning by other paths than the rail and water-pipe. If C is near the station it may be necessary to break the ground connection between rails and bus, so that all current may return over the metallic circuit A.

To determine condition of bonds, move the contact C back towards D, and the decrease in drop as shown by the *vm.* will be very nearly proportional to the length of track, except where a bad or broken bond may be located, when the change will be sudden.

TESTING RAIL BONDS.

It is not commercially practicable to measure the exact resistance of rail joints, as such resistance is small under ordinary circumstances, and all the conditions vary so much as to prevent accurate measurement being made. The resistance of rail joints is therefore measured in terms of length of the rail itself, and there are numerous instruments devised for the purpose, nearly all being based upon the principle of the wheatstone bridge, the resistance of the rail joint being balanced against a section of the rail, as in the following diagram.

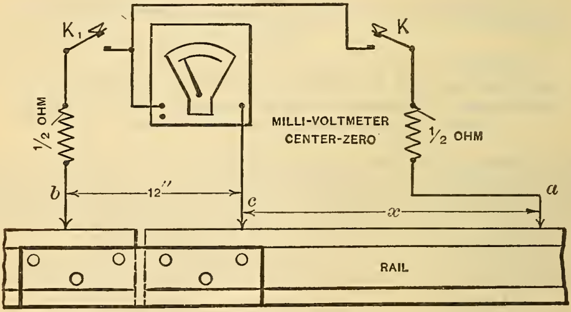


FIG. 77. Diagram of Method of Testing Rail Joints.

A Weston or other reliable milli-voltmeter, with the zero point in the middle of the scale, is the handiest instrument for making these tests. The points b and c are fixed usually at a distance of 12 inches apart, the point a is then moved along the rail until there is no deflection of the needle when both switches are closed. The resistance of the joint or the portion between the points b and c is to that of the length, x, inversely as the length of the former is to that of the latter, all being in terms of the length of rail, or,

Let

x = distance in inches between points a and c,
y = distance between the points c and b,
v = resistance of joint in terms of length of rail,

then,

$$v = \frac{x}{y},$$

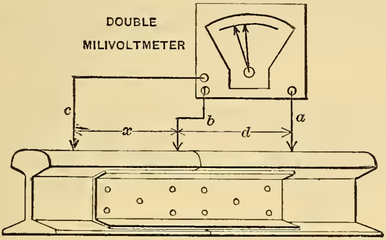
and if $x = 36$ inches and $y = 12$ inches,

then

$$v = \frac{36}{12} = 3 \text{ times its length in rail.}$$

Another scheme for testing rail joints is pointed out by W. N. Walmsley in the "Electrical Engineer," December 23, 1897.

In the following cut, the instrument is a specially designed, double milli-voltmeter, both pointers having the same axis, and indicating on the same scale.



WALMSLEY'S RAIL TESTER

FIG. 78.

The points ab are at a fixed distance d, the point c being movable along the rail. Points a and b are set on the rail astride the joint, as shown; the point c is then moved along the rail until the pointers on the instrument coincide, indicating the same drop. Then the resistance of x is the same as d, in terms of the size of rail used.

Harold P. Brown has devised an instrument for testing rail joints with little preparation. It consists of two specially shielded milli-voltmeters of the Weston Company's make, put up in a substantial wooden case, the top of which is made up in part of two folding legs which, when unfolded, cover six feet of rail. These legs form one length, which is divided by slots into two lengths, one of one foot, the other five feet long. The instrument is placed alongside the track in such position that the leg rests on the rail, and the joint to be tested is between the ends of the shorter branch or leg, while five feet of clear rail are included between the ends of the longer leg.

The instrument terminals are connected to small horseshoe magnets, that fit into the slots in each leg, and when rested on the rail always make the same pressure of contact, the poles being amalgamated and coated with a special soft amalgam, called Edison Flexible Solder.

With the five feet of rail as a shunt, the instrument will read to 1500 amperes.

There are several separate resistance coils and binding-posts supplied for different sizes of rail in common use, so that the dial of the milli-voltmeter needs but one scale.

The second milli-voltmeter measures the drop around the one foot of joint, and has coils so arranged to permit of reading .15, 1.5, 15. volts.

A reading of the current value is taken from the five feet of rail, and a simultaneous reading of the drop across the joint and one foot of rail is also made. The resistance of the latter is then found by ohm's law,

$$R = \frac{E}{I}.$$

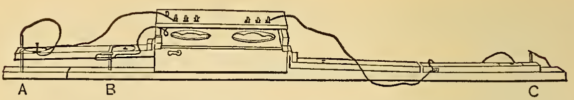


FIG. 79. Brown's Rail-bond Testing Instrument.

Street Railway Motor Testing.

Barn test for efficiency :—

Put a double-flange pulley on the car axle for the application of a prony brake, pour water inside the pulley to keep it cool. Use common platform scale, as shown in cut.

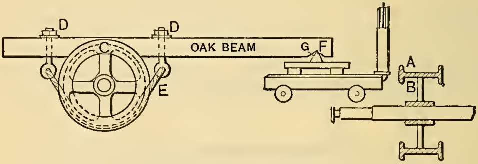


FIG. 80.

Then let $D =$ distance from center of axle to point on scales in feet, measured horizontally.

$\pi = 3.1416$,
$R =$ revolutions per minute,
$E =$ voltage at motor,
$I =$ amperes at motor,
$T =$ force applied to balance scales, in pounds.

$$\text{Then B. H. P.} = \frac{2\pi D R T}{33{,}000}.$$

$$\text{B. H. P. at 500 volts} = \frac{\left(2\pi DR \times \frac{500}{E}\right) T}{33{,}000}.$$

$$\frac{EI}{746} = \text{E.H.P. supplied to motor.}$$

$$\frac{500\ I}{746} = \text{E.H.P. supplied to motor at 500 volts.}$$

$$\text{Efficiency of motor} = \frac{\text{B.H.P.}}{\text{E.H.P.}} \times \frac{\text{B.H.P. at 500 volts}}{\text{E.H.P. at 500 volts}}.$$

Draw-bar Pull and Efficiency Test Without Removing Motor from Car.

Rig up lever as shown in cut, being sure the fulcrum *A* is strong enough to stand the pull. Posts, as shown, make good fulcrum ; have turn buckle *F* for taking up any weakness.

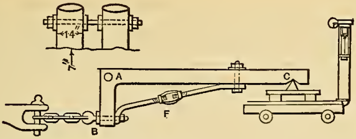


FIG. 81.

Let $D =$ diameter of car wheel in feet.
$\pi = 3.1416$,
$T =$ force on scale in pounds,
$L =$ length of long arm of lever,
$L_{\prime} =$ length of short arm of lever,
$R =$ revolutions per minute.

Place a jack-screw under each side of the car, and lift the body until there is only friction enough between wheels and rail to keep the speed of revolutions down to the normal rate.

Then

$$\text{Draw-bar pull} = T \frac{L}{L_{\prime}},$$

and

$$\text{B.H.P.} = \frac{T \frac{L}{L_{\prime}} D \pi R}{33{,}000}.$$

and the efficiency is the same as before,

i.e.

$$\frac{\text{B.H.P.}}{\text{E.H.P.}} = \text{efficiency}.$$

Mr. A. B. Herrick has devised a testing-board for street-railway repair shops that will greatly assist in making all inspection tests, and which is described in the "Street Railway Journal" for January, 1898, pages 11 and 12.

FAULTS AND REMEDIES.

Car Will not Start:

a. Turn on lamps; if they burn, trolley and ground wires are all right and current is on line.

b. If lights die down when controller is thrown on, trouble may be poor contact between rails and wheels, or car may be on "dead" track.

c. If car works all right with one controller, fault may be open circuit, or poor contact in the other. Throw current off at canopy, or pull down the trolley and examine the controller.

d. See that both motor cut-outs are in place.

e. Fuse may be blown; throw canopy switch and replace.

f. See that motor brushes are in place and intact, and make good contact.

g. Car may be standing on "dead" or dirty rail; in either case connect wheels to next rail by wire. It is better to open canopy switch while connecting wire to wheels, or a shock may be felt.

h. Ice on trolley wheel or wire will prevent starting.

Sparking at Commutator Brushes:

a. Brushes may be too loose; tighten pressure spring.

b. Brushes may be badly burned or broken, and therefore make poor contact on the commutator. Replace brushes with new set, and sandpaper commutator surface smooth.

c. Brushes may be welded to holder, and thus not work freely on commutator surface.

d. Commutator may be badly worn and need renewing.

e. Commutator may have a flat bar, or one projecting above the general surface ; commutator must then be turned true in lathe.

f. Dirt or oil on commutator may produce sparking ; clean well.

Flame at the commutator may be produced by : —

a. Broken lead wire or coil, producing a greenish flame, and burning two bars usually diametrically opposite each other. If left too long the two bars will be badly burned, as will also the insulation between.

Temporary relief can be had by putting a jumper of solder or of small wire across the burned bar, connecting the two adjacent bars to each other ; one jumper is enough.

b. A short-circuited field coil, or a field coil improperly connected, will produce flare at commutator. Short-circuited coil can be found by voltmeter test across terminals showing drop in coil. Wrong connection can be detected by pocket compass.

Incandescent Lamps sometimes burn out or break. Replace with new ones. If they do not burn when switch is on,

a. Examine each for broken filament.

b. Examine for poor contact in socket.

c. Examine switch for poor contact or broken blades.

d. Examine each part of circuit, switches, line, and sockets with magneto, which will locate opening. The wire may be broken at ground or trolley connections.

Brakes Fail to Operate:

In great emergency only, throw controller handle to *off*, reverse reversing-switch, and turn controller handle to first or second notch.

In sliding down grades, or when there is time, proceed as follows :

a. Throw controller handle to *off* point.

b. Throw canopy switch *off*.

c. Reverse reversing-switch.

d. Throw controller handle around to last notch. Both methods are more or less strain on the motors, but the second is somewhat less so than the first.

Grounds: Either on field or armature coils will nearly always blow fuse ; it can then be tested out.

Bucking: When running along smoothly, a car will sometimes commence jerky, bucking motions, and should be thoroughly examined at once. It may be due to a ground of field or armature that may short-circuit one or the other, either fully or intermittently. Injured motor may usually be located by smell of burning shellac, and can be cut out at the controller, and the car run in with the good motor.

Mud and water splashing on commutator will sometimes produce bucking, and often a piece of wire caught up from the track may do the same.

ELECTROLYSIS OF WATER AND OTHER PIPES.

(From Report of the Electrical Bureau of the National Board of Fire Underwriters, on Electrolytic Deterioration of Water Pipes.)

Recent reports show that the destructive effects of electrical currents on subterranean metal pipes are becoming sufficiently marked in many parts of the country to seriously interfere with the service the pipes are intended to perform.

Underground water mains have broken down, because of faults unquestionably due to electrolytic action ; and smaller service pipes have been weakened to such an extent as to break at critical moments, when excess pressure is put upon them at intervals during a fire. Measurements show that conditions unquestionably exist in nearly every district in the United States covered by a trolley road, which are favorable for destructive action on the subterranean metal work in the vicinity, and pipes taken up in many of these districts show unmistakable signs of harmful effects. The general nature of this action, and the causes which bring it about, are too often seen to need elaborate description. Briefly it may be compared to the action which takes place in an electro-plating bath.

The current which enters the bath through the nickel or silver metal suspended therein, flowing through the bath and out through the object to be plated, ultimately brings about the destruction of the suspended piece of metal. Similarly the current from a grounded trolley system flowing through the earth in its course from the cars back to the generating station selects the path of least resistance, which is generally for the whole or a part of the way the underground water mains, and at points where it leaves the pipes to reach the station the iron of the pipe wastes away until at points the walls become too thin to withstand the pressure of the water, and a breakdown ensues. The difference of potential necessary to bring about this action is very small, — a fraction of a volt, — and consequently in all districts where potential differences are found between water-pipes and the surrounding earth, such actions can be assumed to be taking place; for dampness, and the salts necessary to produce electrolysis, are present in all common soils.

Whenever, then, a reading is shown by an ordinary portable voltmeter registering tenths of a volt with the positive binding-post in electrical connection with a water-pipe or hydrant, and the negative binding-post in electrical connection with an adjacent lamp post, car track, or metal rod driven in the earth, electrolytic action will be found upon examination to be taking place at that point which will ultimately result in the destruction of the water-pipe.

The only certain remedies for this evil are obviously to keep the current from using the pipes as a conductor, or to keep it from flowing from the pipes through the surrounding soil. The first remedy necessitates a complete metallic circuit for the railway, and the second a joining of pipes by wires wherever potential differences are found. Trolley roads having absolutely no ground connections will not be installed as long as the present trend of practice prevails, and consequently an absolutely complete metallic circuit for such roads cannot be secured. Bonding all underground pipes together with wires of sufficient carrying capacity to prevent current flow through the earth would also be obviously impossible. By a judicious employment of part of each remedy, however, it has been demonstrated that the evil can be so largely reduced as to be practically negligible; and it is to securing these improvements in the numerous trolley districts of the country that the energies of everyone interested should be devoted.

Referring to the diagram shown in Fig. 82, it is seen that the current will pass from the generator out over the trolley line, through the motor to rail. Through rails and pipe the current flows back to the power-house. There are obviously two paths open for the current. One a return through the rail, the other a return through the earth and any existing gas-pipes, water-mains, or other metallic structures that may be in its path in the earth. The current flowing through these two paths in parallel is plainly inversely proportional to the resistance of these two paths. Therefore, in a general way the current will leave the rails at A, flowing into the water-pipe at B, and will again leave the water-pipe at C and enter the rails. Here, then, is an electric current flowing between metallic structures that may be called electrodes at places in the return path from the motor to station. All that remains, then, to promote electrolytic action is the presence of some solution which will act as an electrolyte.

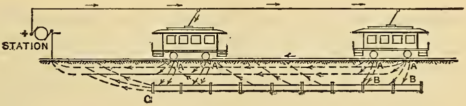


FIG. 82.

Observation has shown that the earth, especially in the larger cities, contains a large percentage of metallic salts in solution, which will readily act as electrolytes upon the passage of electric current. It can be seen, then, referring to this diagram, that if there exists in the ground sufficient moisture of some metallic salt, electrolytic action will take place between the electrodes A and B, and between the electrodes C and the rails. The metals of this electrolyte will be deposited at B and on the rails, while the active part of the electrolyte will be found at A and C. Consequently, corrosion of the metallic structure may be expected at A and C, and at all points where current is found leaving the metallic structure. Such conditions as are shown in Fig. 82 exist in practically all of the railroads in this country. The rail and feeder returns offer one path for the flow of current; and as the earth with its water-pipes and gas-pipes offers a parallel path, the amount of current flowing through the earth will then depend upon the resistance of the return path in the track and feeders. If, at a point in the track return there exists a joint of somewhat high resistance, this high resistance will tend to prevent the current flowing back through the rails. The other return path of the current offered is through the earth and water-pipe. Consequently, electrolytic action in any metallic structure which may occur in the earth path of the return current is practically almost directly proportional to the faultiness of the construction in the rail return. In the earlier electric roads the positive terminals of the generators were connected to ground. This arrangement of the polarity of the street railway has a tendency to distribute the points of danger on water-pipes, gas-pipes, cable-sheathing, or any other underground metallic structure throughout a large and extended territory. By reversing the polarity of the railway generator, bringing the positive terminal to line and negative to ground, the points where the current leaves these metallic structures will be brought much nearer the power station, and will be localized in a much smaller area. At the same time that these danger points or points of positive potential are brought closely to the power station, it can be seen that the volume of current flowing from these danger points has been proportionally increased, and with it the amount of electrolytic action or corrosion.

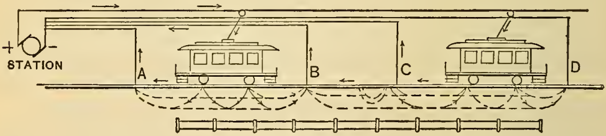


FIG. 83.

On the whole, the placing of the current positive to line appears to be a material advantage. Corrosive action is very much enhanced in a limited area, but being in a limited area and definitely located, it may be easily watched and remedies applied. With the current negative to line, the action at a given danger point may be considerably less than under the other condition; but as the danger district is widespread, and as the conditions are continually changing, it would be very difficult to locate precisely the danger points. Consequently the results of electrolytic action are likely to appear at unexpected points.

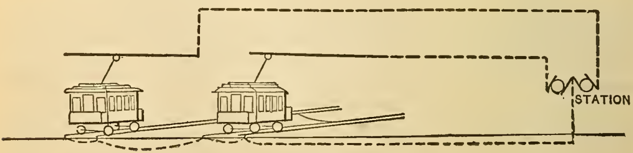


FIG. 84.

From the electric railway standpoint, the prohibitive expense of the requisite addition of copper to make a complete circuit is advanced, together with the impracticability of a double-trolley system that is apparently a necessary concomitant of the metallic return; and these arguments have a certain weight. There is no question but that the complete metallic return is in the beginning a more expensive installation, but per contra few railway companies have any idea of the energy now expended in returning the energy delivered by the power station through the poor conductivity of the average railway track with its surrounding earth.

It has been suggested that corrosion from the underground current could be avoided by operating the railway as a three-wire system in which the trolley wires would form the two sides, and the ground play the part of a neutral wire. The feasibility of a three-wire system depends upon the ability to obtain a double track through the entire railway territory, and the adoption of such a car schedule as to render the loading of the two sides of the system essentially equal. Such a railway could rarely be successfully operated excepting in cities that are essentially level, and in which the traffic was exceedingly uniform. The probability is that in practice electrolytic action would not be wholly avoided; and due to inequality in car loading and car scheduling it would be impossible to locate the danger points in the system, and therefore impracticable to employ methods of correction.

Harold P. Brown has proposed an arrangement which is diagrammatically outlined in Fig. 85. At the station at least two or more generators are required, the division of units being such that there is at least one special generator of about one-quarter the total capacity of the station, which is to be connected, as indicated in the diagram, directly to the pipe structures in the street. The remainder of the station generators are, as usual, connected to the rails or to the return feeds. If, now, the special machine be operated at a few volts higher potential than the rest of the station, it is quite evident that its action will be to render the pipe structures to which the negative pole of the special generator is connected electro-negative to the rest of the system, thus obviating electrolytic action. Such an arrangement of station machinery is undoubtedly a palliative. It is by no means a cure, for in case in any part of the pipe system there happens to be a high resistance joint, such a joint would become a point of inflection in the current, being electro-positive on one side and electro-negative on the other side. It is, perhaps, possible to locate such joints by means of a careful voltmeter survey, but only at the expense of considerable time and trouble; and when dangerous spots of this kind are determined, the resistance of the joint must be obviated either by some form of bond or other device. It will be readily perceived that in many instances pipe structures will not return near enough to the station to render such an action as is outlined in the diagram possible, and frequently the pipe lines may be parallel to the railway track for a considerable distance, and then lead away from the station in such a way as to render the application of this method impractical. Under these circumstances it will be necessary to determine by means of a voltmeter

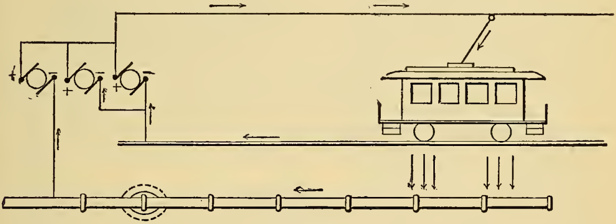


FIG. 85.

survey the condition of the underground structures, and run to the danger points a special conductor.

Very recently Mr. Farnham has proposed an additional solution of the electrolytic problem, which appears to be one of considerable merit. The usual conditions, together with the remedy proposed, are outlined in Figs. 82 and 86. Under ordinary circumstances, the railway system is operated as shown in Fig. 82.

The positive pole of the generator is connected to the trolley wire, and current passes from the station over the trolley wire, and then to the rails. From this point it returns to the station by the route of least resistance, whether through the ground, the rails, or a neighboring pipe line, as the case may be. At all points where the current leaves the pipe line or other underground structure, the line becomes electro-positive to its surroundings and affords points of danger, as is indicated in the diagram.

Suppose the circuit to be arranged as shown in Fig. 86. Here, as in the previous case, the positive pole of the generator is connected to the trolley wire, but the negative pole is not connected to ground in any way. On the contrary, the generating station is carefully insulated from earth, the negative pole being connected to a set of return feeds that may be strung along the route of the railway on the same poles that carry the positive feeds. At frequent intervals, say at every pole, or every other pole, the return feed, which is otherwise carefully insulated, is connected to the rails only through sets of variable resistances, as indicated on the diagram. These resistances are proportioned in such a manner as to render all paths from and to the station of precisely the same resistance — that is to say, from the station the resistance of the circuit to the farthest car and back to the station will be the same as the resistance from the station to the nearest car and back to the station.

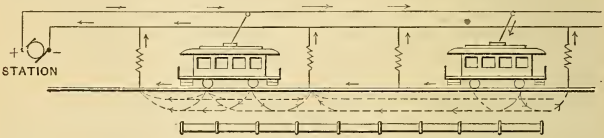


Fig. 86.

A consideration of the diagram will render it quite evident that as the generators at the station are entirely insulated, and as the return feeds are connected at frequent intervals to the rails in such a manner as to render all the paths of equal resistance, no current will flow from the rails, excepting such as passes from any car to the two nearest points of return to the return feeds; and under these circumstances there is little or no tendency for the current to leave the rails and pass to any adjacent underground structures. It is, of course, conceivable that a pipe line may be so near the rails — within a few inches of them, perhaps — that a slight amount of electricity may escape to the pipe line for a few feet. Such cases would have to be particularly guarded, but would form an exceedingly infrequent exception to the general rule.

The objection to be urged against this expedient will inevitably be the additional expense required in the erection and maintenance of the return feeds, for this expedient amounts to giving the railway a complete metallic circuit; only using the rails to carry current between the adjacent poles.

I. H. Farnum in a paper before the A.I.E.E. gives the following conclusion, viz.,

First — All single-trolley railways employing the rails as a portion of the circuit cause electrolytic action, and consequent corrosion of pipes in their immediate vicinity, unless special provision is made to prevent it.

Second — A fraction of a volt difference of potential between pipes and the damp earth surrounding them is sufficient to induce the action.

Third — Bonding of rails or providing a metallic return conductor equal in sectional area and conductivity to the outgoing wires is insufficient to wholly prevent damage to pipes.

Fourth — Insulating pipes sufficiently to prevent the trouble is impracticable.

Fifth — Breaking the metallic continuity of pipes at sufficiently frequent intervals is impracticable.

Sixth — It is advisable to connect the positive pole of the dynamo to the trolley lines.

Seventh — A large conductor extending from the grounded side of the dynamo entirely through the danger territory, and connected at every few hundred feet to such pipes as are in danger, will usually insure their protection.

Eighth — It is better to use a separate conductor for each set of pipes to be protected.

Ninth — Connection only at the power station to water or gas pipes will not insure their safety.

Tenth — Connection between the pipes and rail, or rail return wires outside of the danger district, should be carefully avoided.

Eleventh — Frequent voltage measurements between pipes and earth should be obtained, and such changes in return conductors made as the measurements indicate.

THIRD-RAIL SYSTEMS.

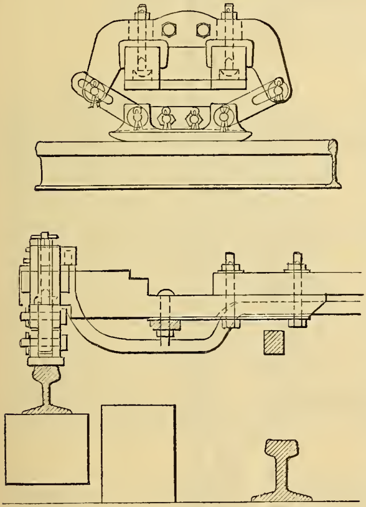


FIG. 87. Trolley, Metropolitan West Side Elevated Railway, Chicago, 1895.

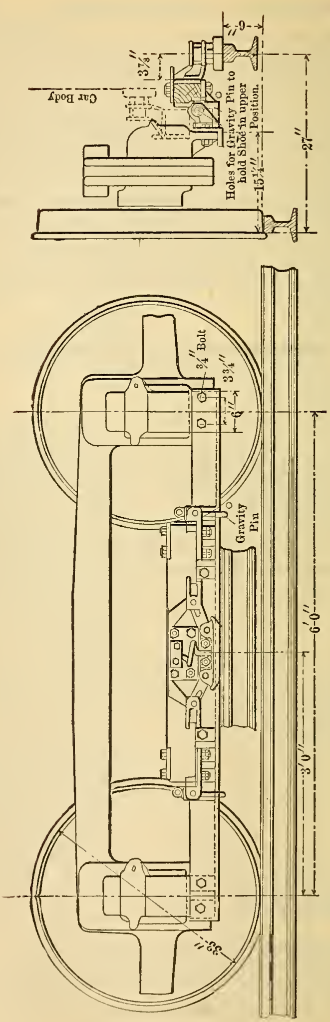
The use of an insulated rail alongside of or between the rails of the regular track, for carrying the current for the motors, was one of the earliest forms used for electric railroads; but until its use on the Intramural Railway at the World's Fair, Chicago, in 1898, demonstrated its success and reliability when well laid down, there had been so many defects in the construction, and faults from its use, that the overhead trolley wire was substantially the only method given any attention. The complete success of the system as laid down at the Fair resulted in the installation of the third or conducting rail on three of the Chicago elevated railways during the years 1895–1896; and being constructed in a rational and mechanical manner, the success has been complete and continuous.

The Metropolitan West Side Elevated Railway started the use of the third rail in 1895. This rail is of steel T, supported upon wooden blocks placed at one side of the tracks, and the current is collected from this rail by four iron brushes suspended from each car.

The Lake Street Elevated Railway laid down a third-rail system in 1896. This rail is supported upon pillar insulators six feet apart, and is protected by wooden guard rails.

The Northwestern Elevated Railway started its use of a third-rail system in 1896.

All the above-named roads make use of the track and structure for return circuit, and the electrical pressure used is about 500 volts.



Elec. World Engineer.

FIG. 88. Diagrams of Truck, Showing Shoe-Lifting Mechanism.

In Fig. 88 is shown a very good form of attachment for third-rail contact-shoe, as used on the Albany and Hudson Railway and Power Company line. This shoe can be turned up out of the way when entering city streets, and the regular overhead trolley that is hooked down on the top of the car while on the private right-of-way, can be used.

In the East, perhaps the best-known example of the use of the third rail is that of the Nantasket branch of the New York, New Haven, and Hartford Railroad, which was equipped in 1896. The voltage used is 500.

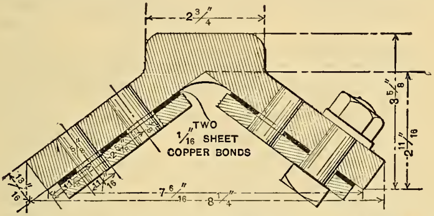


FIG. 89. Section of Third Rail at Joint, Nantasket Branch N. Y., N. H., & H. R. R., 1896.

The rail section used is inverted V in form, weighs 93 pounds per yard, and is supported without fastening on wooden blocks tenoned into the ties. There is a contact shoe weighing 25 lbs. hanging loosely from the motor trucks at either end of the cars, and making contact by its weight. As there is a break in the conducting rail at all crossings and turnouts, the shoe at the front end always makes contact before the rear shoe leaves the last rail.

As the conducting rail is but five-eighths inch above the ties and earth lightning jumps to ground freely; and experience shows that the distance of this rail above the ground is scarcely wide enough, as the power current also frequently jumps over.

Where the third rail breaks at crossings, etc., the ends are connected by well-insulated cable laid in wooden duct underground. Sloped wooden approaches are placed at the ends of the third rail at these breaks in order that the contact shoe may ride up onto the rail easily.

The third-rail system as used on the above-named railroad is said to be inexpensive of construction and quickly laid. There is little wear and tear on the rail or contact shoe, and large amounts of current can be collected without danger.

Other examples of the use of the third rail are the New Britain and Hartford, Conn., branch of the N. Y. & N. H. Railroad, the New York and Brooklyn Bridge, and the Brooklyn Elevated Railways.

CONDUIT SYSTEMS OF ELECTRIC RAILWAYS.

Previous to 1893 hundreds of patents were granted on conduit and other sub-surface systems of carrying the conductors for electric railways, and hundreds of experiments were carried on; but it has been only since that year that capitalists have had the necessary courage to expend enough money to make a really successfully operating road. The work was put into the hands of competent mechanical engineers, who perfected and improved the mechanical details, and the electrical part of the problem was by that means rendered very simple.

The Metropolitan Street Railway Company of New York, and the Metropolitan Railroad Company of Washington, decided, in 1894, that, by building a conduit more nearly approaching cable construction, the underground electric system could be made a success. The former contracted for its Lenox Avenue line, and the latter for its Ninth Street line. The New York road was in operation by June, 1895; the Washington road by August of the same year; and they continue to run successfully. While modifications have been made in some details since these roads were started, yet the present construction is substantially the same. These roads were the first to avoid the almost universal mistake of spending too little and building unsubstantially where new enterprises are undertaken. The history, in these particulars, of the development of overhead trolley and conduit roads is to-day repeating itself in the third-rail equipment of branch and local steam roads.

The Metropolitan Railroad, in Washington, used yokes of cast iron placed on concrete foundations, and carrying the track and slot rails. The slot rails had deep inner flanges, with water lips to prevent dripping on conductors. The conductor rails were T bars 4 inches deep, 13 feet 6 inches long, 6 inches apart, and were suspended from double porcelain corrugated insulators filled with lead and mounted on cast-iron handholes. A sliding plow of soft cast iron collected the current. During the first few months of its operation there were but few delays, mostly due to causes other than electrical defects. Some trouble came from short-circuiting of plows, which was remedied by fuses on plow leads, and a water rheostat at the power-house. The flooding of conduits did not stop the road, although the leakage was 300 to 550 amperes. Under such circumstances the voltage was reduced from 500 to about 300. The average leakage on minus side, when tested with plus side grounded, was one ampere over 6,500 insulators. The positive side always showed higher insulation than the negative, possibly due to electrolytic action causing deposits on the negative pole.

The Lenox Avenue line of the Metropolitan Street Railway was the first permanently successful underground conduit line in the United States. The cast-iron yokes were similar to those used on their cable lines, placed 5 feet apart. Manholes were 30 feet apart, with soapstone and sulphur pedestal insulators located under each, carrying channel beam conductors, making a metallic circuit. At first the voltage was 350, but it was gradually raised to 500. The pedestal support was afterwards abandoned, and suspended insulators used every 15 feet, at handholes. At one time iron-tube contact conductors were tried, but they proved unsatisfactory.

The details of track construction for underground or sub-surface trolley railroads are essentially of a special nature, and are determined in every case by the local conditions and requirements. They belong to the civil engineering class entirely, and will not be treated here in any way other than to show cuts of the yokes and general construction.

The requirements of the conduit for sub-surface trolley conductors are first, that it shall be perfectly drained, and second, that it be so designed that the metallic conductors are out of reach from the surface, of anything but the plow and its contacts. Another requisite is that the conducting rails and their insulated supports shall be strong and easily reached for repairs or improvement of insulation.

The conducting rails must be secured to their insulating supports in such a manner as to provide for expansion and contraction. This can be done by fastening the center of each section of bar solid to an insulated support at that point, and then slotting the ends of the bar where they are supported on insulators. The ends of the bars will be bonded in a manner somewhat similar to the ordinary rail bonding.

The trolley circuit of the sub-surface railway differs from the ordinary overhead trolley system in that while the latter has a single insulated conductor, and return is made by the regular running rails, the former has a complete metallic circuit, local, and disconnected in every way from track return.

The contact rails must be treated like a double-trolley wire, and calculations for feeders and feeding in points can be made after the methods explained for overhead circuits and feeders earlier in this chapter. Feeders and mains are usually laid in underground conduits for this work, and the contact rails may be kept continuous or may be divided into as many sections as the service may demand, taps from the mains or feeders being made to the contact

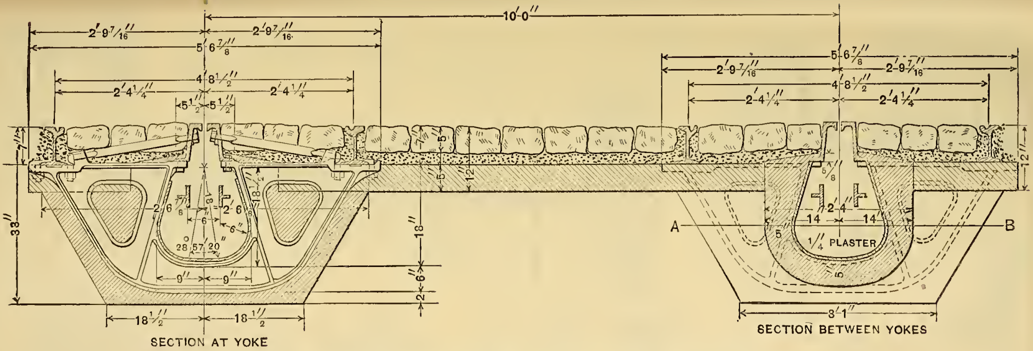


FIG. 90. Section of Conduit, Metropolitan Railroad, Washington, 1895.

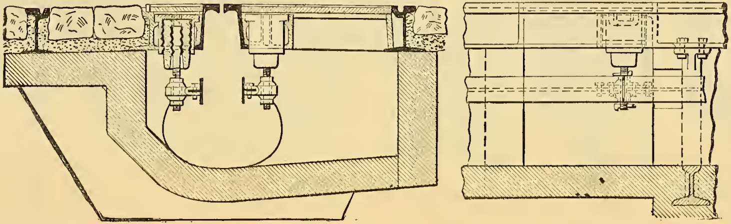


FIG. 91. Plan and Section of Conduit, showing G Conductor Support, Metropolitan Railroad, Washington, 1895.

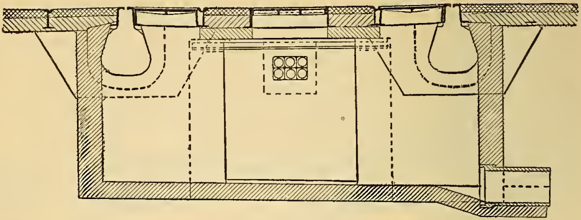


FIG. 92. Drainage at Manhole of Conduit, Metropolitan Railroad, Washington, 1895.

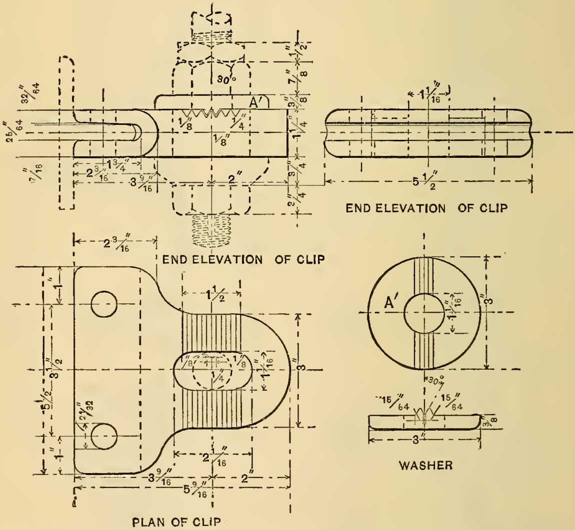


FIG. 93. Clip and Ear for Conduit, Metropolitan Railroad, Washington, 1895.

rails at such points as may be determined as necessary. All the insulated conductors should be of the highest class; may be insulated with rubber or paper, but should in any case be covered with lead. Especial care should be taken in making joints between the conducting rail and copper conductor so that jarring will not disturb the contact.

Other than the above few general facts it is difficult to say much regarding this type of electric railway, for it is so expensive to install that it can be used in but a few of the largest cities, and in every case will be special, and require special study to determine and meet the local conditions. The reader is referred to the files of the street railway journals for complete descriptions of the few installations of this type of electric railway.

Following are a number of cuts showing the standard construction of electric conduits as designed and built by the Metropolitan Street Railway Company, of New York. The system of railway may be said to use all the latest methods, including wire-carrying conduits along side or under the tracks, as will be seen by the next cut.

The porcelain insulator here shown for supporting the contact rails is very substantial in design and construction, and by its location at a hand-hole is easily reached for cleaning, repairs, and replacement. The *plow* has also received careful attention, and those now used as standard by the Metropolitan Company leave little to be desired.

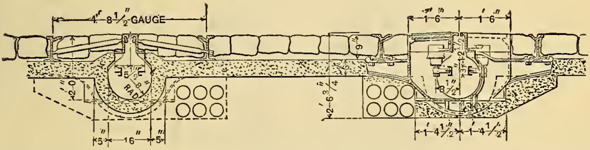


FIG. 94. Section of Conduit, Metropolitan Street Railway, New York. — Standard Work, 1897–98.

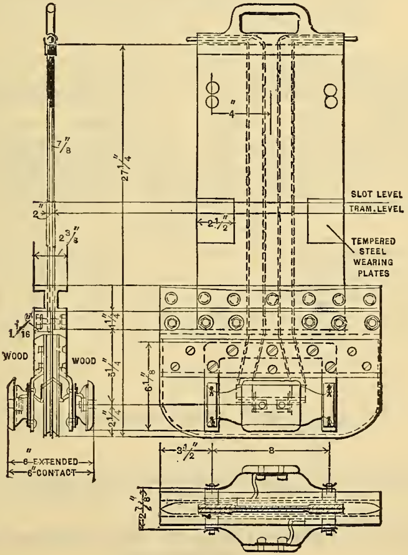


FIG. 95. Section, Side and End Elevation of Plow, Metropolitan Street Railway, New York. — Standard Work, 1897–99.

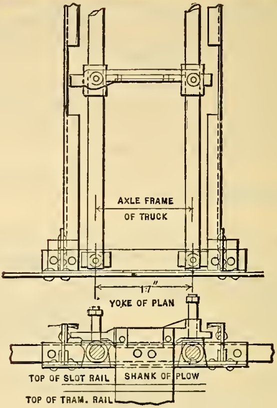


Fig. 96. Plan and Elevation of Plow Suspension from Truck, Metropolitan Street Railway, New York. — Standard Work, 1897-98.

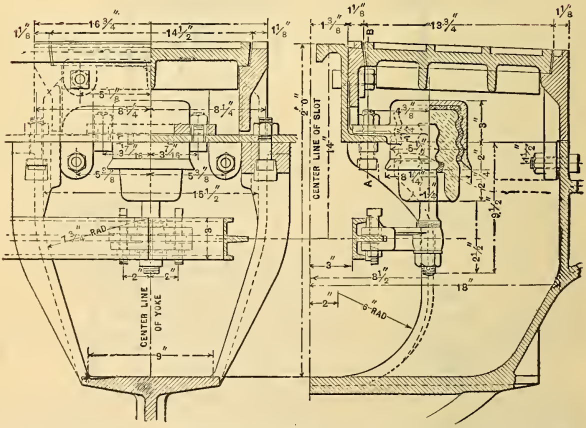


Fig. 97. Section and Elevation of Insulator, Metropolitan Street Railway, New York. — Standard Work, 1897-98.

SURFACE CONTACT OR ELECTRO-MAGNETIC SYSTEMS.

The development of surface contact systems began even earlier than the use of the overhead-trolley wire, and many patents have been issued on the same. Most of these failed through ignorance of the requirements, and timidity of capital in taking up a new device answers for others.

The Westinghouse Electric and Manufacturing Company and the General Electric Company finally took the matter up, and being equipped with vast experience of the requirements, and the necessary engineering talent and apparatus, have each developed a system that is simple to a degree, and is said to cost but half as much to install as the conduit system, and to offer advantages not known to that or other systems.

I quote as follows from a bulletin issued by the Westinghouse Electric and Manufacturing Company.

Some Advantages of the System.

No poles, overhead wires, or troublesome switches are employed. The streets, yards, and buildings are left free of all obstructions.

The facility with which freight cars can be drilled in yards and through buildings, without turning the trolley whenever the direction of a motor car or locomotive is reversed, and the absence of the necessity of guiding the trolley through the multiplicity of switches usually found in factory yards and buildings, is of great advantage, permitting, in fact, the use of electric locomotives where otherwise electricity could not be used.

The only visible parts of the system, when installed for street railway work, are a row of switch boxes between the tracks, flush with the pavement, and a double row of small contact buttons which project slightly above the pavement, and do not impede traffic in any way.

This system can be used in cities where the use of the overhead trolley is not permitted, and if desired the continuation of the road in the suburbs can be operated by the cheaper overhead system. It would only be necessary to have a trolley base and pole mounted on the car, the pole being kept down when not in use.

There are no deep excavations to make. The system can be installed on any road already in operation without tearing up the ties.

The cost is only about one-half that of a cable or open conduit road.

The insulation of all parts of the line, the switches, and the contact buttons is such that the possibility of grounds and short circuits is reduced to a minimum.

The system is easy to install, simple in operation, and reliable under all conditions of track and climate.

Finally, the system is absolutely safe. It is impossible for anyone on the street to receive a shock, as all the contact buttons are "dead" excepting those directly underneath the car.

Requirements.

In devising this system the following requirements of successful working were carefully considered.

The insulation must be sufficient to prevent any abnormal leakage of current.

The means for supplying the current to the car must be infallible.

The apparatus must be simple, so that inexperienced men may operate it without difficulty.

The system must operate under various climatic conditions.

Finally, absolute safety must be assured.

WESTINGHOUSE SYSTEM.

This system includes the following elements.

First. Electro-magnetic switches, inclosed in moisture-proof iron cases. Each switch is permanently connected to the positive main or feeder which is laid parallel to the track.

Second. Cast-iron contact plates or buttons, two in each group, placed between the rails and electrically connected to the switches. A separate switch is provided for each group of buttons.

Third. The conductor forming the positive main or feeder. This is completely inclosed in wrought-iron pipe, and is connected to the various switches.

Fourth. Metal contact shoes or bars, suspended from the car trucks; two bars on each car.

Fifth. A small storage battery carried upon the car.

The operation of the system is described as follows, and is illustrated by cuts making plain the text.

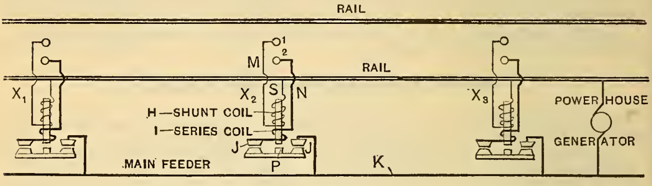


FIG. 98. Diagram of Switch Connections.

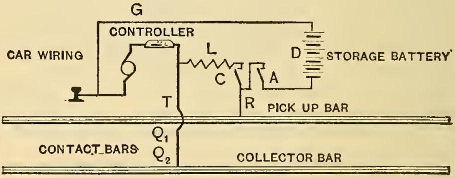


FIG. 99. Diagram of Car Connections.

Electro-magnetic switches, X_1, X_2, X_3., inclosed in water-tight casings, are installed at intervals of about 15 feet along the track to be operated. Each switch is provided with two windings, I and H, which are connected by the wires N and M to two cast-iron contact buttons, 1 and 2, which are mounted on suitable insulators and placed between the rails.

Each car to be operated on this system is provided with two spring-mounted T steel contact bars, Q_1 and Q_2, and a few cells of storage battery in addition to the usual controllers and motors. The contact bars are mounted at the same distance apart as the contact pins, 1 and 2, so that as the cars advance along the track the bars will always be in contact with at least one pair, as the length of the bar exceeds the distance between any two pairs by several feet.

Suppose a car is standing on the track over the switch X_2, the contact bars, Q_1 and Q_2, being then in connection with the buttons 1 and 2 respectively. The first step is to "pick up" the current, i.e., render the buttons 1 and 2 alive.

Switch A is first closed; this completes the circuit from the storage battery, D, through the wiring, R, contact shoe, Q_1, button No. 1, and shunt coil, H, to the ground. The current passing through H magnetizes the core, S, which in turn attracts the armature, P, closing the switch and establishing connection between the 500-V main feeder K, and button No. 2, through the contacts, JJ, coil I, and wiring N. Switch C is now closed and switch A opened; the switch X_2 is kept closed, however, by the current flowing from button No. 2 through bar Q_2, connection T, resistance L, connection R, bar Q_1, button No. 1, connection M, coil H to ground.

The car now proceeds on its way, current from the main passing through connection T, to the controller and motors. When the car has advanced a short distance the contact bars make connection with the pair of buttons connected to switch X_3. Current then passes from bar Q_1 through the shunt coil of this switch. The operation described above is then repeated. As soon as the bars leave the buttons 1 and 2, current ceases to pass through the coils I and H of switch X_2, and this switch immediately opens by gravity, leaving the buttons connected to it dead and harmless. As connection with the main has already been established through switch X_3, there will be a continuous flow of current from the feeder, and no flash will occur either at the button or the switch.

It will be observed that all the current passing to the car from the main through switch contacts J J passes through the series coil, I, holding the switch firmly closed and precluding all possibility of its opening while current is passing through the contacts, even should the circuit through coil H be interrupted. Although the act of "picking up the current" requires some time to describe, it takes in practice only a few seconds.

Two separate switches, A and C, are shown in the diagram; but in practice one special switch of circular form is provided, and the necessary combinations required for "picking up the current" are made by one revolution of the switch handle.

The battery need only be employed to lift the first switch; for after that has been closed, the contact shoes bridge the main voltage over from one set of pins to another, as described, thus closing the successive switches, without further attention from the motorman.

The battery is charged by leaving switches A and C closed at the same time.

The Switch.

Fig. 100 shows the general arrangement of switch, bell, and pan. The switch and magnet are mounted upon a marble slab, which is secured in the bell by means of screws to the bosses, B B.

The switch magnet, M, is of the iron-clad type. It is secured to the upper side of the marble base, and is provided with a fine (shunt) winding for the "pick up" current, and a coarse (series) winding through which the working current passes.

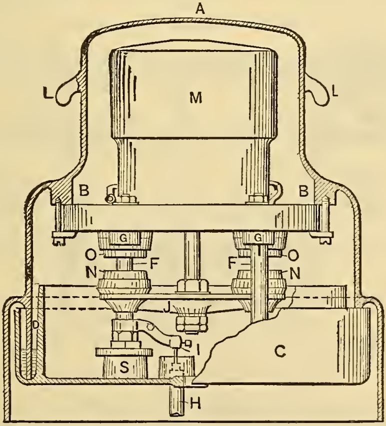


Fig 100. Section of Switch, Bell, and Pan.

When magnetized the poles attract an armature attached to a bridge piece, J, each end of which carries a carbon disk, N. R, R, are guides for the bridge piece, J. Directly above each of the carbon disks, N, is a stationary disk, O, mounted upon a marble base. One of the disks, O, is permanently connected by means of one of the contact cups, G_1, as explained later, to the positive main cable, and the other, through the series coil and cup, G_2, to the positive contact button.

The pan, C, is provided with four bosses, S, to support the vertical split pins, F, which are insulated from the pan. These pins slide into receptacles, G, on the switch base. The pins, F, are provided with connectors, I, for the purpose of making connection with the several cables, H, which pass through the holes in the under side of the pan. The pan is completely filled with paraffine after the connections are made, thus effectually keeping out all moisture.

The object of the bell, A, and the pan, C, with the split pins, F, and the cups, G, is to provide a ready means of examination of the switch without disconnecting the wires. The bell can be lifted entirely free of the pan. In replacing it, it is only necessary to see that a lug, T, on the side of the cover, fits into a slide, U, on the frame. When in this position the split pins make connections with their corresponding cups, G.

The bell, A, is provided with lugs, L, to facilitate handling; and also a double lip, W. The inner portion of this lip fits into and over the annular groove, D, of pan C. This groove is filled with a heavy non-vaporizing oil. The outer portion of lip, W, prevents water from entering the groove. The object of the groove, D, and the lip, W, is to make a waterproof joint to protect the switch and cable terminals without the necessity of screw joints or gaskets. The bells are all tested with 25 pounds air pressure; they may be entirely submerged in several feet of water without affecting the operation of the system.

The Contact Buttons are made of cast iron. They are about 4½ inches in diameter, and, when installed on paved streets, project about five-eighths of an inch above the pavement and offer no obstruction to traffic. This is sufficiently high to enable the collector-bars to make contact, and at the same time to entirely clear the pavement. For open-track installations they are substantially mounted in a combination unit as described below.

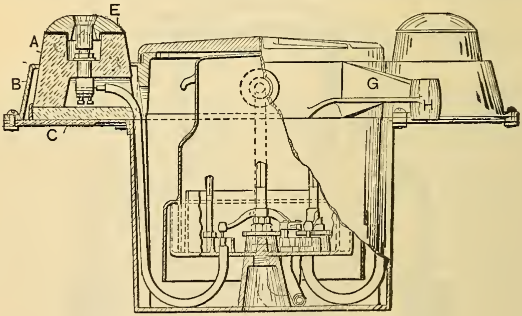


FIG. 101. Section of Combination Unit.

The Combination Units.

The bell and pan are entirely inclosed in a cast-iron switch-box. This box and the contact buttons are made into a complete unit as shown in Fig. 101. Each unit consists of three separate castings. The cylindrical cast-iron box, which incloses the switch, bell, and pan, is bolted into a recess provided for that purpose in the bottom of the spider-like structure, which is a separate casting, consisting of box rim, receptacles for the button insulators, and supporting arms. The removable lid is the third casting.

The insulators, A, Fig. 101, are made of a special composition, and are cemented into the tapered cups, B, and supported by the iron plates, C. The contact buttons, E, are mounted on top of these insulators and stand, when installed, about one inch above the rail.

The four arms, G, are secured to the ties by means of the bosses, H, thus reducing to a minimum the labor of leveling the boxes and avoiding the necessity of special ties.

Mains and Wiring.

The positive main or feeder is incased in a 1¼-inch iron pipe, and passes directly through each switch-box, and a tap is made to each switch, the switch-boxes being all connected by the iron pipe, as per cut below.

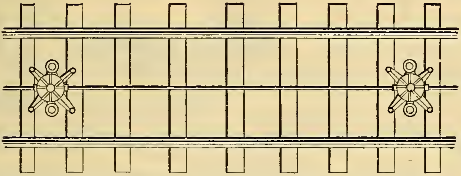


FIG. 102. Track Equipped for Track Return Circuit.

No additional wires are used to interconnect the coils or contacts of adjacent switches.

The Contact Bars are of steel, of ordinary T section. They are supported from the car trucks by two flat steel springs and adjustable links. These bars are inclined at the ends so that they may readily slide over the buttons and over any ordinary obstacle.

Insulated Return Line.

In case it is considered best not to use the rails as the return line, insulated mains for this purpose may be included in the system. It is only necessary to install another row of contact buttons, another collecting bar, and to use double-pole switches. Fig. 103 illustrates an installation of this kind. For all ordinary work, however, the ground return is satisfactory.

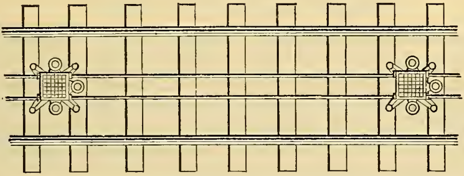


FIG. 103. Track Equipped for Insulated Return Circuit.

Modifications of the System.

The description given on the preceding pages applies to the system as installed for yard and similar work. Modifications can be made and detail matters arranged according to the requirements of each case.

Street Railway Work.

The foregoing description applies to installations where the track is open (unpaved),and where it is unnecessary to make provision for traffic crossing the tracks except at certain points. For street railway work, the switch-boxes are preferable installed outside the track, while the buttons are placed between the rails and mounted on a light metal tie, as shown in Fig. 104.

The operation of the system is exactly the same as in open-track work. Connecting wires pass from the buttons under the tie to the switch-boxes. For double-track work the switches are installed between the two tracks, and the boxes may be built to hold two switches, one for each track.

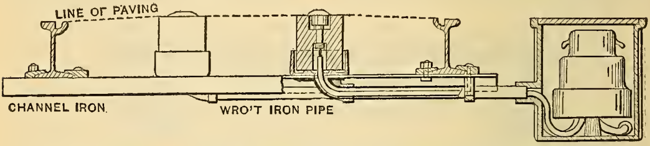


FIG. 104. Section of Track Equipped for Street Railway Service.

When, as is sometimes necessary, the buttons are placed in a single row, it is necessary that the "pick-up" current should be of the same voltage as that of the main circuit, and consequently the car-wiring indicated in Fig. 105 is used, instead of that shown in Fig. 99.

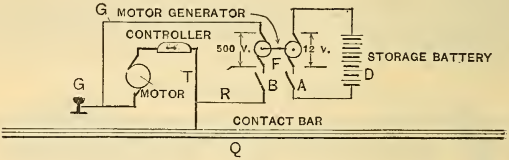


FIG. 105. Diagram of Car-Wiring.

Referring to Fig. 105, the method of "picking up" the current is as follows: Switch A is first closed; this completes the circuit from a storage battery D, through a small 500-volt motor-generator F, which immediately starts. As soon as it is up to speed, which only requires a few seconds, switch B is closed; current then passes from F through the wiring R, to contact shoe Q, and then through the switch magnet, as explained on page 538. Switches A and B are then opened, thus stopping the motor-generator, which need only be used to operate the first switch. The successive switches are closed, as described on page 538.

This arrangement of a high-voltage "pick-up" may also be used advantageously with two rows of buttons where the track is liable to be obstructed by mud or snow.

Sectional Rail Construction.

For suburban railway or similar service two light rails may be substituted for the two rows of contact buttons, as shown in Fig. 106. The cars are then equipped with contact shoes instead of bars. These rails are insulated from the ground, and may also be insulated from each other wherever desirable, thus breaking them up into sections, which are each controlled by a single switch. The sections may be made of any desired length to suit the conditions. For example, between stations they may be 500 or more feet long, while near stations or crossings, where anyone is liable to come in contact with the rail, the length of a section may be reduced to 50 feet or less. The electrical operation of two-rail installations is the same as when two rows of buttons are used. The sectional switches along the tracks are entirely under the control of the motorman, and the rails may be rendered "dead" at any moment should occasion arise.

The Westinghouse Company uses a system of surface contact all over its large works at East Pittsburg, and another plant has been in operation for some time at Indian Head, Md.

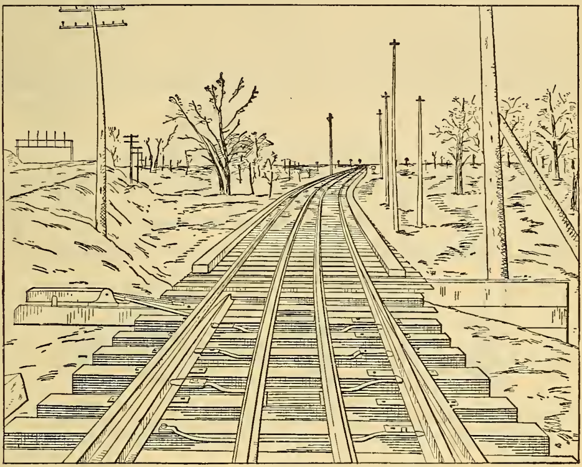


FIG. 106. Sectional Rail Installation.

GENERAL ELECTRIC SYSTEM OF SURFACE CONTACT RAILWAY.

Following is a description of the surface contact system, as developed by the General Electric Company, and practical application of it has been made at Monte Carlo, and at the company's works at Schenectady. The description is from a report made by W. B. Potter, Cf. Eng. of the Railway Department, and written by Mr. S. B. Stewart, Jr.

In the operation of electric cars, by the closed conduit surface plate contact system of the General Electric Company, the current is collected for the motor service by means of two light steel shoes carried under the car, making contact with a series of metal plates, introduced along the track between the rails, automatically and alternately energized or de-energized by means of switches grouped at convenient places along the line; the method of the switch control being such that in the passage of the car, in either direction, it is impossible for any plate to become alive except when directly under the car body.

In ordinary street car practice, the contact plates are spaced approximately ten feet apart, positive and negative plates being staggered, as shown in Fig. 107, which admits of but three plates ever being covered at any one time by the shoes, which are so designed as not to span more than two plates of the same polarity.

In grouping the switches it is customary to locate them either in vaults constructed between or near the tracks, or in accessible places along the side of the street, the location and spacing of groups and number of switches in each group being based upon a comparative cost between the style of vault or other receptacle, and the amount of wire with ducts between the contact plates and their corresponding switches.

The main generator feeder is carried to each vault or group, and auxiliary feeders from it are distributed to each switch, the track rail being utilized for the return circuit.

The operation or performance of this system can be readily traced out by reference to Fig. 107. It will be seen that the current in its passage to the motor from the positive generator conductor passes to contact A of switch No. 2 through the carbons on its magnet armature (which has been lifted by the energized coil G) to contact plates B and C, through the contact shoe D to the controller and motor, coming out at contact shoe E to the contact plate F, when it passes through the coil of the automatic switch G, energizing it and returning by the track-rail H; thus maintaining contact at switch No. 2 armature carbons as long as the shoes remain on the contact plates C and F. It should now be noted that contact plate B is energized

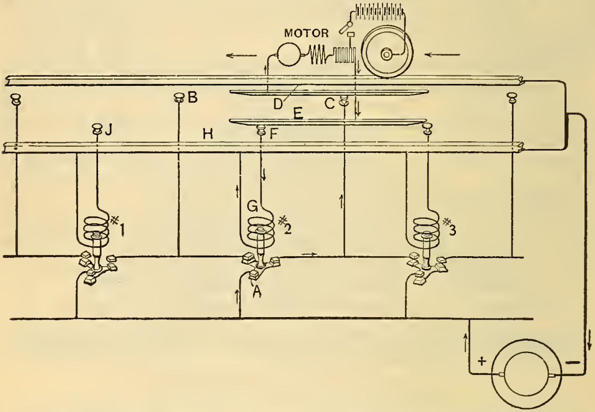


FIG. 107. Diagram of Connections for Surface Contact Railway Plate System, General Electric Co.

as stated above. As the car proceeds, the shoe D spans the plates B and C, thereby keeping the coil of switch No. 2 energized after shoe has left plate C, and until shoe E comes in contact with plate J, which immediately energizes coil No. 1, thus making the preceding contact plate energized, preparatory to the further advance of the car. It will be noted in the above description of the performance of the system, that we have assumed switch No. 2 on Fig. 107 as closed; it should therefore be understood that an auxiliary battery circuit is necessary in starting or raising a first switch, preparatory to its armature being held in contact position by the generator current, which current energizes the preceding contact plates consecutively as described above.

The battery current is brought into the automatic switch circuit momentarily during the period of first movement of handle of the controller in starting a car, the transition of the controller cylinder also bringing the generator current in connection with the battery for a short period of time, thus replenishing the elements sufficiently to operate the switches. The battery is also used to supply current for lighting the car, the generator circuit being disconnected while the car is at rest.

Surface Contact Plates.

The surface contact plates are made of cast iron, with wearing surfaces well chilled, designed to be leaded into cast-iron seats in such a manner that they are thoroughly secure, but can be readily removed by special tongs for the purpose. The seat is imbedded in a wooden or composition block set into a cast-iron box, the latter being spiked or screwed to the tie. A brass terminal is fastened to the seat for the reception of the connecting wire from the switch. See Fig. 108.

As stated above, the plates are usually located 10 feet apart for straight line work, but somewhat closer on curves, depending upon the radius of the curve and length of contact shoe. The negative and positive contact plates are staggered with a uniform angular distance between them, situated not less than 10 inches from the track rails.

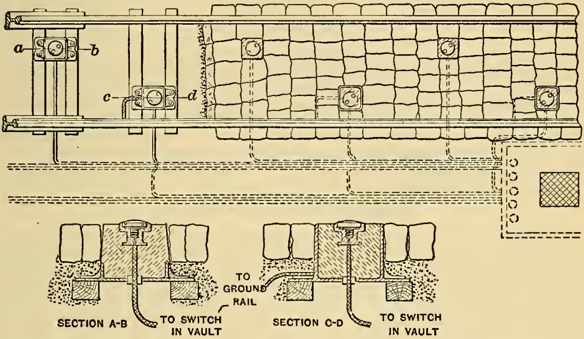


FIG. 108. Plan and Section of Track, Monte Carlo, Europe. General Electric Company's Surface Contact System, 1898.

Surface Contact Switch.

The automatic switches are constructed on the solenoid principle, the armature or core of which is employed in closing the contacts as shown in

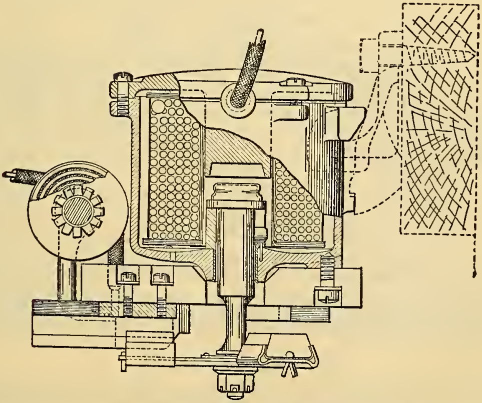


FIG. 109. Automatic Switch for Open Conduit, Surface Plate Contact System.

Fig. 109. The end of the armature core is provided with a pressed sheet-steel carbon-holder, for the purpose of supporting the carbon contacts which are held in place by bronze clips and cotter pins which can easily be removed. The pressed-steel carbon-holder can also be detached with little trouble by removing the end holding it to the core. Copper plates are secured to the slate base for contact surfaces and the attachment of feeder-wires. The wire of the solenoid is wound on a copper spool and placed in a bell-shaped magnet frame, and a pole-piece, slightly recessed to receive the end of the armature core when the switch is in a closed position, is attached to the top cover, and extends part way down through the winding. The recess in the armature increases the range of the magnet, making the attraction uniform except at the point of contact where the power increases rapidly, thus securing an excellent contact. A blow-out magnet coil is connected in series with the feeder current, and so situated that the influence of its poles is used to rupture any arc that might be formed while the switch is opening; however, this blow-out magnet is used simply as a precautionary device, as under ordinary conditions there is no arcing, the succeeding automatic switch closing the circuit before it is opened by the preceding one. Each vault or group of switches should be provided with cut-outs or an automatic circuit breaker to protect them in the event of short circuits.

Surface Contact Shoes.

The contact shoes are made of "T" steel of light section, the suspension for which is an iron channel beam extending longitudinally with the truck frame directly under the motors, with a substantial wooden cross-arm attached to each end for the shoe-supporting casting, the shoes being attached to these supporting castings by a spring equalizing device for maintaining the shoes at the proper height, and also for making them flexible enough to meet any slight variations in the contact plates and track rails. The shoes when in their correct position should never drop over one-fourth inch below the surface contact plates, and are designed so that they may raise three-fourths of an inch or more above them. See Fig. 110.

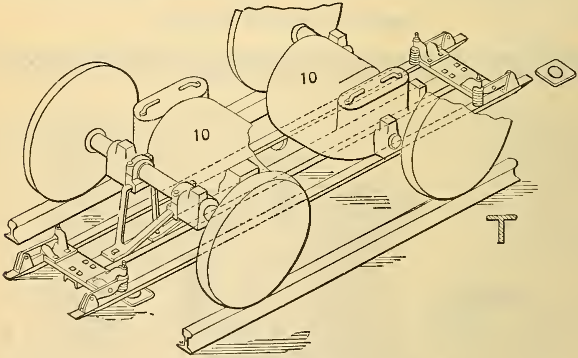


FIG. 110. Collecting Shoes, Monte Carlo, Europe.
General Electric Company's Surface Contact System, 1898.

A screw adjustment is provided to lower the shoes as they wear away, or to take care of any other discrepancies due to wear of parts, etc.; if they are allowed to drop too low they will interfere with rail crossings, causing short circuits.

Storage Batteries.

It requires for closing the first automatic switch when starting, and for lighting the car approximately, ten storage battery elements capable of 35 amperes rate of discharge for five hours.

The batteries are only slightly exhausted in making the initial connections through the automatic switch, as it only takes approximately 15 amperes momentarily to perform this work, the battery is immediately recharged by current which has passed through the motors. The battery serving as a rheostatic step, this momentary charging does not represent any extra loss of energy.

The circuit connections of the battery are accomplished in the controller, and require no attention on the part of the motorman.

Car Lighting.

The amount of recharging derived from the motor circuits is sufficient to operate the automatic switches, but where lighting of the car is done from the same battery, an additional recharge is required.

Assuming that 10 20-volt lamps are used for lighting a car, the batteries will need to be recharged every night about five hours, at an approximate rate of 25 amperes.

It is customary to run leads from both the positive and negative terminals of the batteries to charging-sockets attached to the under side of one of the car sills in a convenient place for connection to the charging-wire.

A small generator of low potential (30 volts) driven by a motor or other method is required for supplying current for recharging the batteries where the desired low-potential current is not accessible, and the wiring from the charging source should be run to a location in the car-house most convenient for connections to the battery sockets. These locations may be fixed either in the pits or on posts at the nearest point to where the cars will be stationed, and there should be flexible lead wires attached to plugs for connecting to the battery circuit on the car. In wiring the car-house for the battery connections, it would be found convenient to designate the polarity of the various wires either by different colored insulation or tags, and the plugs at the ends of the flexible leads should be marked plus and minus to avoid mistakes in making connections with the car battery receptacle.

Motors and Controllers.

The motor and controller equipment used with the surface plate contact system is standard apparatus as ordinarily employed for electric car service, with the exception that provision is made in the controller for cutting in and out the storage battery while starting the car.

Care of Apparatus.

As success in the operation of the contact plate system depends largely on the care of the apparatus, a few general remarks on the subject will not be out of place here.

Care should be taken that the contact plates are kept clean, and they should be frequently inspected, the roadbed being well drained. Any small quantity of water temporarily standing over the tracks, however, would do little harm, as the leakage through the water would not be sufficient to create a short circuit, although this condition should not be allowed to exist any length of time.

The automatic switches should be carefully inspected and all cast-iron parts thoroughly coated with heavy insulating paint, and a test for insulation or grounds be made frequently, and all the parts kept clean and free from moisture.

The contact shoes, in order to prevent leakage, should have their wooden supports well protected with a coating of an insulating paint, and should also be occasionally cleaned.

The storage batteries should be properly boxed and should have the customary care which is necessary to keep them in good working order.

TRANSMISSION OF POWER.

The term "*Transmission of Power*," as used by electrical engineers, has come to have a conventional meaning which differentiates it from what must be considered its full meaning. Any transmission of electric current, for whatever practical purpose, whether for lighting, heating, traction, or power-driving, must of course be a transmission of power; but the conventional meaning of the term as now used by electrical engineers and others eliminates many of these objects, and is held to mean simply the transmission of electric current from a more or less distant point or station to a center from which the power is distributed, or to power motors at different points in a factory or other installation. While the distances over which electric current is transmitted for arc lighting in some large cities and in many small places far exceed the length of line of the ordinary or average power transmission, yet the former is never alluded to as transmission of power. The same condition obtains with traction, the transmission of current covering miles of territory, and yet it is only alluded to as power transmission when the current is transmitted from a central point to various sub-stations from which it is distributed.

The engineering features of *transmission of power* will all be found treated under the separate heads in their respective chapters, and the following is a short *resumé* of the subject matter.

Building:		PAGE
Structural conditions and material		792
Motive Power:		
Water power:	Turbines, etc.	926
Steam power:	Boilers and appliances	829
	Engines and appliances	916
Shafting and pulleys		946
Belting and rope drive		951
Generators:		
Dynamos:	direct current	232
	alternating current	232
	double current	232
Transmitting Appliances:		
Switchboards		585
Transformers, step up		331
Rotaries		286
Cables and pole lines		92
Conduits, etc.		203
Distributing Appliances:		
Sub-stations and terminal houses		331
Transformers, step down		331
Switchboards, high tension and secondary		331
Rotary converters		286
Direct current motors		270
Synchronous motors		281
Induction motors		274
Frequency changers		274
Distributing circuits		92

Much has been written regarding the relative values of the different methods of transmitting power, and comparison is often made between the following types, *i.e.*,

a. Wire rope transmission.
b. Hydraulic transmission, high pressure.
c. Hydraulic transmission, low pressure.
d. Compressed air transmission.
e. Steam distribution for power.
f. Gas transmission.
g. Electrical transmission.

All of the first six methods listed have so many limitations as to distance, efficiency, adaptability, elasticity, etc., that electricity is fast becoming the standard method. The matter of efficiency alone is one of the best arguments in its favor, and I take from Dr. Bell's book, "*Electric Power Transmission*," the following table of the efficiencies such as have been found in practice.

System.	Per Cent Efficiency at	
	Full Load.	Half Load.
Wire rope	68	46
Hydraulic high pressure	53	45
Hydraulic low pressure	50	50
Pneumatic	50	40
Pneumatic reheated, virtual efficiency . . .	65	50
Electric	73	65

For short distances out of doors, transmission by wire rope is much used both in the United States and Europe, and where but few spans are necessary, say less than four, the efficiency is very high.

Hydraulic transmission is in considerable use in England, but except for elevator (lift) service is in little use in the United States.

Pneumatic transmission is in wide use in Paris, but not so for general distribution in the United States, although for shop transmissions for use on small cranes and special tools is making good progress.

Electrical transmission is so elastic and so adaptable to varied uses, and has been pushed forward by so good talent, a not small factor, that its progress and growth have been simply phenomenal. In one place alone, that of traveling cranes for machine shops, it has revolutionized the handling of material, and has cheapened the product by enabling more work to be done by the same help.

Electric Power Transmission may be divided into two classes, *i.e.*, long distance for which high tension alternating current is exclusively used; and local or short distance transmission for which either direct current or polyphase alternating current are both adapted, with the use of the former largely predominating, owing perhaps to two factors, *a*, the much earlier development of direct current machinery, and *b*, to the fact that a large number of manufacturers are engaged in the building of direct current machinery. Both types of current have their special advantages, and engineering opinion is, and will probably remain, divided as to which has the greater value.

Long distance transmission is now accomplished by both three-phase three-wire, and by the two-phase four-wire systems, with the former predomileating for the greatest distances, owing to economy of copper. Each system has certain advantages over the other, and both have strong advocates among engineers. For the distribution of very large amounts of power the three-phase system presents a strong point in its economy of copper, and another in simplicity of switching appliances.

Every case of electric transmission presents its own problem, and needs thorough engineering study to decide what system is best adapted for the particular case. It is, therefore useless to enter into any detailed discussion here, as all the engineering details are treated of elsewhere in the book under the respective departments. The economic discussion does not enter into the engineering problem except in the preliminary study, which has presumably been satisfactory before reference is necessary to this book.

Limitations of Voltage. — While 10,000 volts pressure was used with some distrust for a time previous to 1898, since that time 15,000, 20,000, 25,000, and 40,000 volts have been and are still in use with substantial satisfaction.

Properly designed glass or porcelain insulators, made of the proper material, and tested under high pressure conditions, cause little trouble from puncture or leakage. The latter is its own cure, for the reason that the leakage of current over the surface of the insulator dries up the moisture. Dry air, snow, and rain-water are fairly good insulators, and offer no difficulties for the ordinary high voltages. Dirt, carbon from locomotive smoke, dust from the earth, and such foreign material that may be lodged on the insulators, are sure to cause trouble. In the West and some sections of the East many insulators are broken by bullets fired by the omnipresent marksman.

Oil insulators have proved worse than useless, as dirt and dust, to say nothing of bugs, are gathered by the oil, and produce very bad results; they were introduced in the United States in some of the early high-voltage installations, but after a short time the cups holding the oil had to be broken off.

Glass makes the surest insulator, as the eye can make all necessary tests; but it is so fragile that porcelain is more commonly used. It is not safe to accept a single porcelain insulator without a test with a pressure at least twice as great as that to be used. The interior of the porcelain should be perfectly vitreous, and should not absorb red ink so that it cannot be wiped off perfectly clean.

A convenient way of testing such insulators is to invert a number, say a dozen, in a pan of salt water; fill the pinhole with more water of the same kind. Connect the pan with one terminal of a high potential transformer, and use as the other terminal a piece of metal, say a spike or old battery zinc pencil which will be connected to the opposite terminal of the transformer, and inserted in the pinhole of each insulator. A double-pole switch should be used to open and close the low-pressure side of the testing transformer. Under these conditions one insulator is tested at a time, and good porcelain will stand very high pressure before a breakdown. Heavy sea-fog is about as bad a condition as can be assumed for high voltage transmission. Mr. Ralph D. Mershon of the Westinghouse E. & M'fg. Co. made a long series of tests at Telluride, Col., on the high-pressure lines in use there.

At 50,000 volts there will be a brush discharge or leakage from one wire to the next that can be seen at night, and makes a hissing noise that can be heard a hundred feet or more. This brush discharge begins to show at about 20,000 volts, on dark nights, and increases very rapidly, as does also the power loss at 50,000 volts and higher. This loss depends upon the distance apart of the conductors and their size. Above 50,000 volts the losses become serious, the discharge disposing of a large amount of energy. For these reasons, wires should be kept well apart and be of as small size as other properties will allow.

The wave form of E. M. F. used also influences the brush discharge, being the least in effect for sine wave curves of E. M. F., and being much increased by the use of the sharp, high forms of curve.

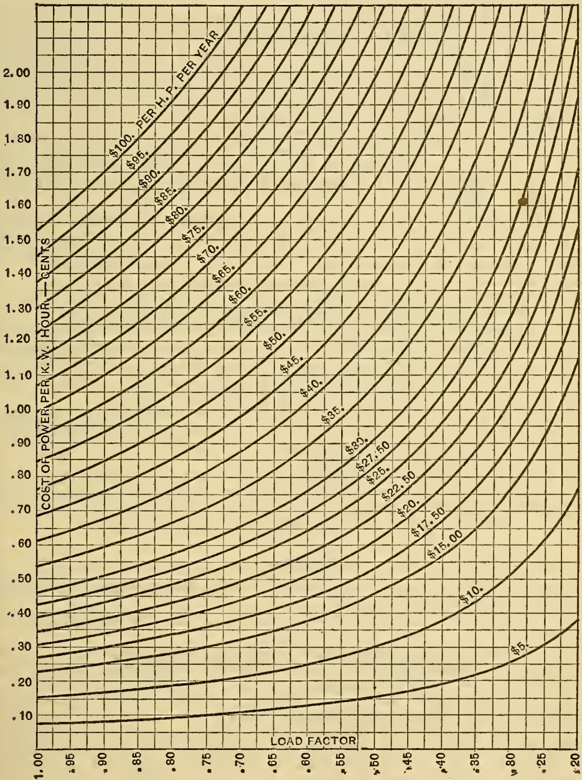
Line inductance, capacity, and resonance, unbalancing of phases, etc., have caused little trouble in practice, although they should be given serious consideration, especially for lines carrying heavy currents.

In regard to the frequency to be adopted for power transmission, one has to be governed by the case in hand, and the commercial frequencies available at economical cost.

Since the success of the Niagara plant the frequency used there, 25 per second, has become a standard for power transmission purposes, but should be avoided if much arc or incandescent lighting is to be done. Other frequencies, such as 30 and 60, are in common use, the latter being the favorite for plants having a mixed output of power and lighting.

It must be remembered that the higher the frequency, the more troublesome are the rotary converters that may be connected to the system.

Induction motors and synchronous motors of the revolving field type are now almost perfection, and are useful to counteract each other's effects on lines, and both give their best results at low frequencies. Alternating arc lamps cannot be used with any satisfaction on a frequency less than 40.



Curve for reducing cost of power per maximum horse-power per annum in dollars to cost per kilowatt-hour in cents at various load factors.

ELECTRIC STORAGE BATTERIES.

Partly condensed from articles by Joseph Appleton in "Electrical Engineer."

An electric *storage battery*, or *accumulator*, is a combination of cells, each of which is a unit.

In the ordinary lead, sulphuric acid type, a *cell* is made up of three parts — the jar, or box, the plates, and the electrolyte.

The *jar*, or *containing-box*, may be of any good non-conducting and acid-proof material of sufficient strength and rigidity to support the plates and the electrolyte. In the smaller stationary types the jar is oftenest made of glass or of hard rubber, the latter especially for portable cells where lightness is of moment. Portable cells are now often made of hard wood lined with lead. Large cells for central-station work are made of heavy planks, well jointed, and lined with five-pound sheet lead.

Stationary cells should always be supported upon some well-designed insulator, such as porcelain, so constructed as to have a retaining-cup of oil, in order to maintain a high degree of insulation. They are also generally set up from the floor a short distance, most often on stringers of well dried and filled hard wood.

The *plates* are of two kinds, positive and negative, arranged alternately, there always being one more negative than positive. A set or group of these plates is commonly known as an element. All positive plates are connected together, as are also all negative plates, but the positives and negatives are separated from each other by insulating strips of some kind.

The *electrolyte* used with all lead batteries — and no others are in extensive use at the present time — is sulphuric acid diluted with water to a s.g. of 1.15 to 1.30 according to the type. The acid must be free from impurities, such as arsenic, nitric or hydrochloric acid, and the water must be distilled.

Storage or secondary batteries of the ordinary lead, sulphuric acid type may be divided into two classes, the Planté and the Faure. Both are lead elements in dilute sulphuric acid, but are formed differently.

The *Planté* type is constructed of lead plates so designed as to present a large surface area to the action of the electrolyte, the active material being formed on the plates, either electrically, by charging and discharging, commonly called "forming," or chemically.

In the *Faure*, commonly known as the *pasted*, type the active material is applied mechanically to a lead conducting-plate or grid. The material may be active when applied, or may be such that it can be converted into active material by electrical or chemical formation.

Plates.

The *positive* plate is of lead, upon which a coating of peroxide of lead has been formed or mechanically applied.

The *negative* plate is of pure lead, the surface of which is spongy or porous in its formation.

The peroxide and spongy lead are the portions of the plates which are subjected to the chemical action, and are called the active material, the lead body of the plates serving practically as a support for the active material.

The chemical condition of the plates and acid differs when charged and discharged. At full charge the positive plate has a dark brown coating of peroxide of lead, the negative plates having the porous or spongy condition above described, of dark slate color, and the electrolyte being of full specfic gravity and strength. In this condition, when the positive and negative poles are connected through an external circuit an E.M.F. is set up in the cell, a current flowing through the circuit from the positive plate. When discharged, the positive plates have a chocolate, and the negative a light slate color. A drab color on the positive indicates sulphating or an over discharge.

Chemical Action.

The chemical action taking place during *charging* is as follows: the current enters at the positive pole, passing through the acid to the negative. Both plates contain sulphate of lead, due to the preceding discharge, and the net result of the passage of the current is to decompose this sulphate, and at the same time to transfer all the oxygen from the negative to the positive. At the completion of the charge, the negative is entirely free from oxide, and the positive contains no oxide lower than the peroxide, though it may still contain some sulphate. The reduction of the sulphate of lead forms free sulphuric acid, and, of course, increases the density of the electrolyte. The complete account of the chemical reactions in charging is too extensive to be given here.

If charging is continued after all the active material has been converted to peroxide of lead and spongy lead, oxygen and hydrogen gas will be given off in bubbles.

In *discharging*, the sulphur radical in the acid combines with the active material on both plates, forming sulphate of lead, the specific gravity of the electrolyte being reduced. When all the active material has been acted upon, the cell is discharged, as an equilibrium has been created between the positive and negative plates, and the E.M.F. set up by the chemical action has been reduced to zero. In practice the E.M.F. is never allowed to fall below 1.8 volts.

The chemical reactions are given as follows, by Frankland.

If the buff lead salt be the active material of the battery plates, the following equations express the electrolytic reactions taking place in the cell:—

I. In charging—

(a.) Positive Plates.

$$\underset{\text{Buff lead.}}{S_3Pb_5O_{14}} + \underset{\text{Water.}}{3OH_2} + O_5 = \underset{\text{Lead Peroxide.}}{5PbO_2} + \underset{\text{Sulphuric Acid.}}{3SO_4H_2}.$$

(b.) Negative Plates.

$$S_3Pb_5O_{14} + 5H_2 = 5Pb + 3SO_4H_2 + 2OH_2.$$

II. In discharging—

(a.) Positive Plates.

$$5PbO_2 + 3SO_4H_2 + 5H_2 = S_3Pb_5O_{14} + 8OH_2.$$

(b.) Negative Plates.

$$5Pb + 3SO_4H_2 + O_5 = S_3Pb_5O_{14} + 3OH_2.$$

If the red lead salt be the active material, then the following equations express the same electrolytic reactions:—

I. In charging—

(a.) Positive Plates.

$$\underset{\text{Red lead Salt.}}{S_2Pb_3O_{10}} + O_2 + 2OH_2 = \underset{\text{Lead Peroxide.}}{3PbO_2} + \underset{\text{Sulphuric Acid.}}{2SO_4H_2}.$$

(b.) Negative Plates.

$$S_2Pb_3O_{10} + 4H_2 = 3Pb + 2SO_4H_2 + 2OH_2.$$

II. In discharging—

(a.) Positive Plates.

$$3PbO_2 + 2SO_4H_2 + 2H_2 = S_2Pb_3O_{10} + 4OH_2.$$

(b.) Negative Plates.

$$3Pb + 2SO_4H_2 + 2O_2 = S_2P_3O_{10} + 2H_2.$$

It is, however, very questionable whether these salts play any important rôle in the normal reaction of the cell.

The various oxides of lead are as follows : —

Plumbous or sub-oxide	Pb_2O.
Plumbic oxide, litharge	PbO.
Triplumbic oxide, or red lead minium	Pb_3O_4.
Diplumbic oxide	Pb_2O_3.
Monoplumbic dioxide, or peroxide	PbO_2.

CALCULATION OF E.M.F. OF STORAGE BATTERY.

Streintz.

Let $E=$ E.M.F. required.
$S=$ Specific gravity of the electrolyte.
$s=$ Specific gravity of water at the temperature of observation.
Then $E=1.850+.917\,(S-s)$.

Wade.

$W=$ work in joules.
$Q=$ coulombs of electricity passed through the electrolyte.
$H=$ number of calories liberated by the recombination of a unit weight of one of the decomposed ions.
$e=$ its electro-chemical equivalent.
$c=$ its chemical equivalent.
$h=$ electro-chemical equivalent of hydrogen $=.00001038$.
$J=$ Joule's coefficient $=4.2$.
$E=$ E.M.F. required.
Then $W=QE=QJeH$.
$E=JeH$.
$e=hc$.
$E=JhcH=4.2\times.00001038\;cH=.0000436\;cH$.

$$cH=\frac{\text{heat of formation}}{\text{valency}}.$$

$$E=\frac{.0000436\times\text{heat of formation}}{\text{valency}}.$$

$$1\text{ volt}=\frac{.0000436\times 46{,}000}{2}.$$

$$E=\frac{\text{heat of formation in calories}}{46{,}000}.$$

CALCULATION OF THE CAPACITY OF A STORAGE BATTERY IN AMPERE HOURS.

The current in ampere hours maintained by the consumption of any given chemical substance varies with the change of valence and inversely with the molecular weights of the transforming substance. The combustion of liberation of 1 pound of hydrogen corresponds to 12,160 ampere hours.

The theoretical capacity in ampere hours may be calculated as follows : —

$V=$ change of valence of the ions.
$W=$ the sum of the molecular weights affected.
$12{,}160=$ capacity per pound of hydrogen.

Then
$$\text{Capacity per pound}=\frac{12{,}160\times V}{W}.$$

In lead-lead-sulphuric acid cells the above formula gives 40.24 ampere hours as the capacity per pound of lead sulphate.

The above formula is based on the supposition that the entire material of both plates is transformed into lead sulphate. This is never accomplished, and Fitzgerald gives as a safe rule :

.53 oz. lead peroxide and the same weight of spongy lead per ampere hour for a 10-hour rate of discharge,
.62 oz. for a 5-hour rate,
.70 oz. for a 3-hour rate,
1 oz. for a 1-hour rate.

All above for the ordinary thickness and an electrolytic density of 1,200.

THE HYDROMETER.

The hydrometer is an instrument for determining the density of liquids. It is usually made of glass, and consists of three parts: (1) the upper part, a graduated stem or fine tube of uniform diameter; (2) a bulb, or enlargement of the tube, containing air; and (3) a small bulb at the bottom, containing shot or mercury, which causes the instrument to float in a vertical position. The graduations are figures, representing either specific gravities or the numbers of an arbitrary scale, as in Beaumé's, Twaddell's, Beck's, and other hydrometers.

There is a tendency to discard all hydrometers with arbitrary scales, and to use only those which read in terms of specific gravity directly. This tendency is all the more to be indorsed, as there are considerable discrepancies in the different tables professing to give the Beaumé scale, the following one being, perhaps, as much quoted as any.

Beaumé's Hydrometer and Specific Gravities Compared.

Degrees Beaumé.	Liquids Heavier than Water, sp. gr.	Liquids Lighter than Water, sp. gr.	Degrees Beaumé.	Liquids Heavier than Water, sp. gr.	Liquids Lighter than Water, sp. gr.	Degrees Beaumé.	Liquids Heavier than Water, sp. gr.	Liquids Lighter than Water, sp. gr.
0	1.000	. . .	19	1.143	.942	38	1.333	.839
1	1.007	. . .	20	1.152	.936	39	1.345	.834
2	1.013	. . .	21	1.160	.930	40	1.357	.830
3	1.020	. . .	22	1.169	.924	41	1.369	.825
4	1.027	. . .	23	1.178	.918	42	1.382	.820
5	1.034	. . .	24	1.188	.913	44	1.407	.811
6	1.041	. . .	25	1.197	.907	46	1.434	.802
7	1.048	. . .	26	1.206	.901	48	1.462	.794
8	1.056	. . .	27	1.216	.896	50	1.490	.785
9	1.063	. . .	28	1.226	.890	52	1.520	.777
10	1.070	1.000	29	1.236	.885	54	1.551	.768
11	1.078	.993	30	1.246	.880	56	1.583	.760
12	1.086	.986	31	1.256	.874	58	1.617	.753
13	1.094	.980	32	1.267	.869	60	1.652	.745
14	1.101	.973	33	1.277	.864	65	1.747	. . .
15	1.109	.967	34	1.288	.859	70	1.854	. . .
16	1.118	.960	35	1.299	.854	75	1.974	. . .
17	1.126	.954	36	1.310	.849	76	2.000	. . .
18	1.134	.948	37	1.322	.884	. .	. . .	. . .

Strength of Dilute Sulphuric Acid of Different Densities at 15° C. (59° F.). (*Otto.*)

Per Cent. of H_2SO_4.	Specific Gravity.	Per Cent. of SO_3.	Per Cent. of H_2SO_4.	Specific Gravity.	Per Cent. of SO_3
100	1.842	81.63	23	1.167	18.77
40	1.306	32.65	22	1.159	17.95
31	1.231	25.30	21	1.151	17.40
30	1.223	24.49	20	1.144	16.32
29	1.215	23.67	19	1.136	15.51
28	1.206	22.85	18	1.129	14.69
27	1.198	22.03	17	1.121	13.87
26	1.190	21.22	16	1.116	13.06
25	1.182	20.40	15	1.106	12.24
24	1.174	19.58	14	1.098	11.42

Ordinarily in Accumulators the densities of the Dilute Acid vary between 1.150 and 1.230.

Conducting Power of Dilute Sulphuric Acid of Various Strengths. (*Matthiessen*).

Specific Gravity.	Sulphuric Acid in 100 parts by Weight.	Temperature. C.°	Relative Resistances. Ohms per cub. centim.
1.003	0.5	16.1	16.01
1.018	2.2	15.2	5.47
1.053	7.9	13.7	1.884
1.080	12.0	12.8	1.368
1.147	20.8	13.6	.960
1.190	26.4	13.0	.871
1.215	29.6	12.3	.830
1.225	30.9	13.6	.862
1.252	34.3	13.5	.874
1.277	37.3	. . .	.930
1.348	45.4	17.9	.973
1.393	50.5	14.5	1.086
1.492	60.6	13.8	1.549
1.638	73.7	14.3	2.786
1.726	81.2	16.3	4.337
1.827	92.7	14.3	5.320
1.838	100.0	. . .	. . .

FIG. 1. Small Hydrometer. 4 inches long.

Conducting Power of Acid and Saline Solutions.

Copper (Metallic) at 66° F.	100,000,000.	
Sulphuric Acid . . . . 1 Measure Water . . . . 11 Measures (Equal to 14.32 parts by weight of Acid in 100 parts of the mixture), at 66° F. . .	98.0	approximate.
Sulphate of Copper, saturated solution at 66° F.	6.1	“
Chloride of Sodium, saturated solution at 66° F.	35.0	“
Sulphate of Zinc, saturated solution at 66° F.	6.4	“

FIG. 2. Standard Hydrometer. 8⅜ inches long.

INSTALLATION AND CARE.

In small batteries, in which the cells are small enough to be handled when assembled, the cells may all be assembled before placing. Large cells have to be assembled in place, as they will seldom permit change of position without considerable inconvenience.

The *battery-room* should be dry, well lighted and ventilated, and of moderate temperature, as the evaporation of electrolyte is apt to be troublesome in heated rooms.

All exposed iron work should be painted with an acid-proof paint; in fact, all metal work exposed to the acid fumes should be painted for its protection.

The floor of the battery room is preferably of brick, tile, or cement, laid so it will drain easily to some common outlet. Wooden floors should never be used unless protected by lead trays to catch any stray acid.

The battery room should preferably be located as near the power-house as possible, thus reducing the cost of connecting conductors, and possibly using the same attendants.

Cells should be arranged so as to be easily accessible for examination and repairs. Large cells are seldom placed in more than one tier, but the smaller ones can be erected in two or three tiers.

Where cells are of glass they may be conveniently set in trays on a bed of sand, and the trays be set on insulators. Wooden tanks are set directly on insulators, as they are always built of sufficient strength to support their weight and contents.

Cell Connections.

In small cells the plates of one polarity are usually connected by a lead strap that is cast on the plates in a bunch, the strap of one cell being connected to that of the next by a bolt or screw clamp or weld. All battery connections should be of ample sectional area to avoid loss, and, as lead is the metal mostly used for such purposes, and as compared with copper has about seven times the resistance, it is especially important that its area be large.

The best method of connecting the positive group of plates to the adjacent group of negative plates in the next cell is to *burn* or weld the two to a lead strap of large cross-section; and, in case of very heavy currents, a copper conductor may be embedded in this lead strap.

Lead-Burning Apparatus.

The hydrogen flame has the special property of not oxidizing, or otherwise soiling the lead, and is therefore used for melting together two lead surfaces, notably that between cells and the sheet lead lining of the tanks.

Hydrogen gas is generated in a vessel from sulphuric acid and zinc. The gas is collected and passed through a water bottle to a burner, where it is mixed with air that has been forced into the burner by a pump or bellows, the mixture being ignited for the welding.

The use of this burner requires some skill and practice, especially in joining the edges of sheet lead, as it is very apt to burn away. All plate terminals, and all lead connections of any kind, must be scraped clean before connecting up.

Acid.

Sulphuric acid made from pyrites is not suitable for storage battery use; only that made from sulphur should be used. Ordinary sulphuric acid contains many impurities that are apt to be injurious to the plates, notably, copper, iron, arsenic, nitric and hydrochloric acids.

The acid should only be diluted with pure distilled water. and the *acid should always be poured into the water*, and never *vice versa*. Mix carefully, as much heat is generated.

Tests for Impurities.

Copper and Arsenic. — To a fresh solution of hydrogen sulphide, H_2S, add an equal quantity of the diluted electrolyte, which must be diluted far enough so that no white precipitate is thrown down. A black precipitate generally shows presence of copper, although it may be lead, if the acid has already been used in batteries; a yellow precipitate shows presence of arsenic.

Iron. — To a small quantity of the diluted electrolyte add a few drops of nitric acid, HNO_3, and heat; when cold add a few drops of solution of potassium-sulphocyanide, KCNS; the presence of iron will be shown by a deep red color.

Nitric Acid. — Make up a solution or diphenylamine, $NH(C_6H_5)_2$ as follows: ½ gm. $NH(C_6H_5)_2$, 100 cc. strong sulphuric acid. H_2SO_4, 20 cc. of water H_2O; to a small quantity of this solution, in a test tube, add a small quantity of the diluted electrolyte, which must not have been in use; the presence of nitric acid will be indicated by the appearance of a blue color.

Hydrochloric Acid. — To a small quantity of the proposed diluted electrolyte add two or three drops of nitric acid, HNO_3, heat this in a test tube, then let it cool; now add two or three drops of nitrate of silver, $AgNO_3$. The presence of hydrochloric acid will be indicated by precipitated or cloudy appearance.

First Charge.

Charging current should always be ready for application when the electrolyte is put in the cells, as it injures plates to stand in the acid without being charged.

The first charge should be carried on for a much longer period than any of the subsequent or working charges, as it virtually completes the formation of the plates.

See that the *positive* pole of the charging dynamo is connected to the *positive* pole of the battery.

The voltage of charging commences at about 2 volts per cell, and rises to 2.6 volts at the full charge while taking current at the normal rate shown on the maker's lists.

The curves in Fig. 3 show the voltage of a cell during charge and discharge at the normal rate.

Continue the first charge for at least 10 consecutive hours, and 20 or 30 would be preferable. The first charge is usually about twice the capacity of a battery, and should be made at the normal rate.

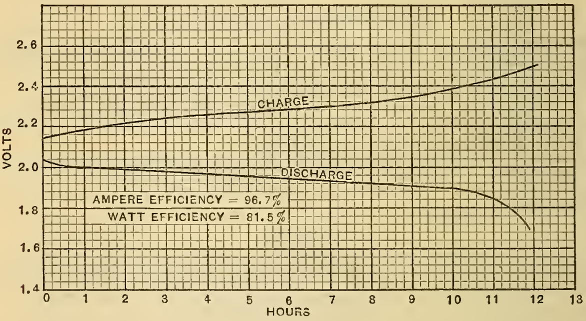


FIG. 3.

This cut shows the general forms of the charge and discharge curves at any rate; but in commercial use cells are almost always worked at much higher rate than shown in the cut, and give lower efficiencies. For example, a five-hour rate of discharge is quite usual, and in some cases even higher rates. Some of the larger users of the Electric Storage Battery Company's cells usually overcharge 15 per cent. So the ampere efficiency is 85 per cent, and the watt efficiency about 72 per cent.

The specific gravity of the electrolyte will drop during the first few hours of the first charge, but will rise again, as the process continues, until its maximum point is reached at full charge. If the s. g. be 1.000 at the start it will decrease to about 1.180, and rise again to about 1.210 at full charge.

As the charge nears completion, bubbles of gas will rise from both plates, and the charging current should then be reduced, as the active material is becoming fully formed, and cannot take up all the gas set free from the decomposition of the acid. As the amount of gas liberated is in proportion to the current flowing gasing will decrease as the current is decreased.

It is especially important with the *pasted* plates that charging be commenced immediately after the electrolyte is put in, as the plates are apt to sulphate otherwise, sulphating being the formation of a coating of sulphate of lead between the grid and the active material, which practically insulates the two from each other, and is very difficult to reduce. Sulphating will also occur with pasted plates if discharged too low. The planté form of plate is not so susceptible to injury from sulphating.

It will take 20 or 30 discharges to fit a new battery to give its full capacity, and it is well to charge for 25 per cent longer time at normal rate for the first few months. In ordinary work the battery will retain its normal condition with a charge of 10 per cent in excess of the discharge.

General Charging.

During ordinary charging of the battery keep in view the following points : —

Charge at normal rate, or lower, except in emergency.

Under normal charging conditions 2.5 volts may be considered full charge, although it can be charged higher than this on an over-charge.

The specific gravity of the electrolyte is a good indication of the condition of the cell; but care must be taken that it is of uniform density throughout, as during charging the electrolyte at the bottom of the cell will become denser unless agitated, as the sulphuric acid liberated from the active material falls to the bottom.

The water in the electrolyte will evaporate, exposing the top of the plates, unless replaced, which should be done through a hose or tube reaching to the bottom of the cell, as water added otherwise will stay on top, being lighter than the acid.

The specific gravity of its electrolyte is the best possible guide to the condition of a cell, as it may appear fully charged by gasing and by the voltage, and yet its condition be such as to cause these appearances when only partly charged. As the hydrometer measures the density of the liquid in the upper part of the cell only, care must be taken that the electrolyte be stirred up so that the density will be the same throughout the cell, or nearly so; of course the difference will be greater in the deeper cells. As the density of the electrolyte is due to the sulphuric acid in it, and the sulphuric acid is liberated from the active material in proportion to the charge given, the s. g. is always a true indication of the condition of the cell as to its charge.

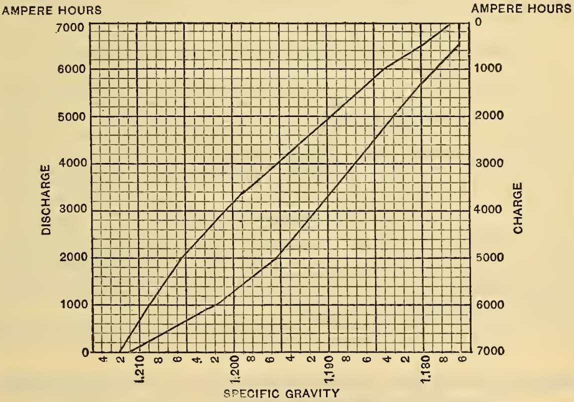


FIG. 4. Curve of Specific Gravity at Charge and Discharge.

Although not always the most economical, the highest efficiency and longest life are obtained when the battery is charged slowly, never exceeding the normal rate. Conditions of plant operation will determine the most economical method for each installation.

Each cell should be tested with a voltmeter and hydrometer once a week. Any cell found with voltage low should be examined thoroughly for any foreign substance that may have short-circuited it. This will be indicated by low specific gravity and lack of gas given off, and voltage rising slowly at the end of a charge, when it should rise quickly.

Always reduce charging current near the end of charging, so as not to waste energy by escape of gas.

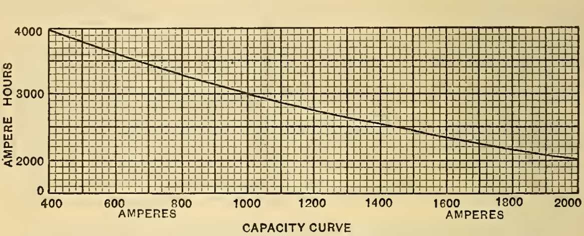


FIG. 5. Curve of Variation of Capacity.

When discharging at normal rates, never discharge a battery below 1.8 volt. In discharging at high rates 1.8 volt will be reached before the battery is discharged to the same condition as at normal discharge owing to the internal resistance, producing a greater fall of potential in accordance with the *IR* law.

Capacity at Different Rates of Discharge.

The output capacity of a battery will decrease as the rate of discharge increases; but the efficiency will not, as commonly supposed, decrease in the same degree, as the decrease in capacity is due to the fact that at high discharge rates the point is soon reached where the cell is unable to maintain the rate of discharge. But when apparently completely exhausted at a high rate, a cell will still furnish current at a lower rate, and on recharging it will be found that only the amount taken out, plus the usual excess, is necessary to recover the full capacity. The internal losses, however, are greater at high rates, which reduces the efficiency to some extent.

If cells are given short periods of time to recuperate, during excessive discharge, they will give practically the same capacity as at normal discharge.

The General Electric Company is now making a recording wattmeter, especially adapted for storage batteries, that will show at all times the amount of energy in the battery. as its reading will decrease with discharge and increase as a charge is put in.

Never allow a battery to stand without charge; even half charge is better than none. and full charge is much the best.

SOME OF THE ADVANTAGES OF STORAGE BATTERIES.

For Central Station.

The chief points of advantage are:

(1.) Reduction in coal consumption and general operating expenses, due to the generating machinery being run at point of greatest economy while in service, and being shut down entirely during hours of light load, the battery supplying the whole of the current.

(2.) The possibility of obtaining good regulation in pressure during fluctuations in load, especially when the day load consists largely of elevators, and similar disturbing elements.

(3.) To meet sudden demands which arise unexpectedly, as in the case of darkness caused by storm or thunder showers; also in case of emergency due to accident or stoppage of generating plant.

(4.) Smaller generating plant required where the battery takes the peak of the load, which usually only lasts for a few hours, and yet where no battery is used, necessitates sufficient generators, etc., being installed to provide for the maximum output which, in many cases, is about double the normal output.

All the above advantages apply quite as well to batteries in the power-house of street railways, and for maintaining the voltage at or near the end of a branch they are of inestimable benefit.

They can be so installed as to take care of both railway and lighting load, as is done at Easton, Pa.

For Large Office Buildings.

Many of the same advantages mentioned in the above paragraphs apply quite as well to large isolated plants; some of those in the modern office-building being much more extensive than a large proportion of the central stations throughout the country.

In many such plants the night operatives can be dispensed with, as the battery will take all the lighting load.

The load-peak on most office buildings is pretty heavy between four and six o'clock in the winter afternoons, and will run up very rapidly if a shower comes up in summer, sometimes getting ahead of extra engines. The storage battery can always take the load until new generators can be started.

Running the dynamos at a more even load is also more economical.

For Small Isolated Plants.

For country residences and the like, where buildings are far from any central supply, a dynamo or two run by a gas or oil engine, with batteries used for storing the output, enables one to have all the advantages of the current, and with comparatively little care, as the plant need be run but once or twice per week in order to keep the battery stored. This is of especial advantage when there is a small water-power.

Telephone and Telegraph.

Many storage cells are now in use in telegraph and telephone work, where they have replaced many hundreds, if not thousands, of gravity cells.

Miscellaneous Uses.

For the horseless or motor carriage storage batteries are well adapted, and are in considerable use.

Train-lighting is done to a small extent by storage batteries.

Launches for lakes and rivers are now often propelled by storage batteries.

Street-cars are occasionally equipped with storage batteries, and in some localities have had a precarious success.

INSTRUCTIONS FOR UNPACKING, SETTING UP, AND USING STORAGE BATTERIES.

(By the Electric Storage Battery Company.)

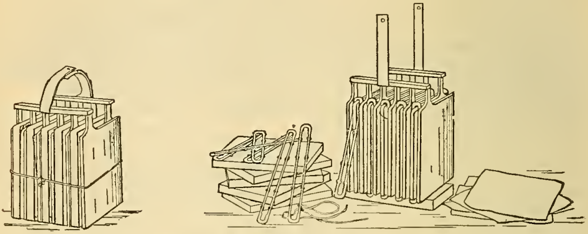
1. The elements are packed in the following way: one set of each positive and negative plates, i.e., a complete element, is packed together in position with sheets of paper and pieces of wood between the plates. A piece of string is tied around same to keep it compact and tight (see illustration, Fig. 6). Take the elements out of the packing cases carefully, and see that they are free from all dirt and foreign material. Place each element on a piece of wood, as shown in Fig. 7; cut the string and take out the paper and wood. Space the plates so that the separating rings can be placed in position on the positive plates, two to each positive plate. Be sure

that the containing jar is clean before placing the element in it. In setting up the larger elements it is advisable to tie a piece of string around the element after all the rubber separating rings are in position to prevent the plates and rings shifting while being placed in the containing-jar. The string must, of course, be removed as soon as the element is in the containing-jar.

2. Place cells in position on battery stands.

3. Scrape the lead lugs before connecting up, so that both surfaces present a bright metallic appearance.

4. See that all bolt connectors are well screwed up, otherwise resistance and consequent heating will result. Always be sure that the cells are connected up in series; i.e., positive of one cell to negative of the next.



FIGS. 6 and 7.

There is always one more negative plate than positive in every cell. The negative (pole) plates are of a grayish color, and the positives are generally light brown when new. The free pole at one end of the series will, in consequence of this, be a positive, that of the other end being a negative.

5. When all the cells are connected up in this manner, the electrolyte may be added, provided the charging current is available. The electrolyte must never be allowed to stand for more than two (2) hours in new cells before the charging is started.

To make Acid.

6. "Oil of Vitriol" is of much higher specific gravity than that required for the cells, and must never be used unless diluted. It must be free from impurities, such as arsenic, nitric or hydrochloric acid, and must be diluted with pure water to a specific gravity of twelve hundred (1,200), or 25° Baumé, as shown by the hydrometer at a temperature of 60° Fahrenheit. In mixing the electrolyte, the acid must always be poured into the water, and never the water into the acid.

7. Always see that the electrolyte is cold before pouring into the cells. It is advisable to mix it at least twelve (12) hours before using.

8. The initial charge must be commenced immediately the cells are filled at about one-third (⅓) of the normal rating for four (4) hours, then increased to the normal current, at which it should be continued for twenty (20) consecutive hours, if not longer, until the positive plates are of a dark brown color, and the voltage is 2.6 volts per cell while charging at the normal rate. If possible do not stop charging at the above period, but continue at a lower rate, gradually reducing the charging current until one-fourth (¼) of the normal rate is reached, at which rate it should be continued until the cells reach a voltage of 2.6 volts per cell.

9. In subsequent charges and in general use, it is only necessary to charge until the voltage is 2.5 per cell while charging. It is advisable to charge the cells once a week until the voltage per cell is 2.5 volts on about one-third (⅓) the normal charging rate.

10. The cells may be discharged down to 1.8 volt per cell, on closed circuit at normal rate; but their efficiency and life will be improved if the discharge is not regularly carried to this point, but is stopped before the

cells become so nearly emptied. The cells must never be allowed to stand idle if more than seventy-five (75) per cent of their capacity has been used.

11. If a battery is to remain idle for a long time, it should first be fully charged and then given a recharge, enough to bring it to a boil, at least once a week. If, for any reason, this weekly charge is impossible, the battery should be thoroughly charged; then syphon the electrolyte from each cell, being sure to refill each cell with water immediately thereafter. Then start discharging the battery at its normal rate, which will only last a few hours; then decrease the resistance in the battery circuit until it is almost short-circuited. The battery should be in the water about thirty-six (36) hours, the acidulated water being then drawn off.

12. To put the cells in commission again, replace the electrolyte, and proceed as per instructions for first charge.

13. The specific gravity of the electrolyte should be twelve hundred (1,200), or 25° Baumé, when the cells are fully charged.

14. Always see that the plates are well covered with electrolyte.

15. The cells should be individually tested at regular intervals with a low-reading voltmeter and a hydrometer. It is very essential that the voltage of each cell should be recorded at the end of every charge and discharge. If any cell reads low, give it immediate attention, as otherwise serious results may ensue.

Partial List of Manufacturers of Storage Batteries.

United States.

Electric Storage Battery Company, Philadelphia, Pa.
Electro-chemical Storage Battery Company, New York, N. Y.
American Battery Company, Chicago, Ill.
Willard Electric and Battery Company, Cleveland, O.
Gould Storage Battery Company, Depew, N. Y.

England.

The Electrical Power Storage Company.
Chloride Electrical Storage Syndicate.
D. P. Accumulator Company.
Crompton & Howell.
Epstein Company.

France.

Société Anonyme pour le Travail Électrique des Méteaux.

Germany.

The Tudor Company.

Battery for Private Residence.

The battery should have a capacity to supply one-half the lamps wired for eight or ten hours on one charge. The average use is much less, and the battery will supply ordinary calls for two or three days on a charge.

The capacity of the engine and dynamo should be equal to that of the battery at the eight-hour discharge rate, so that on special occasions, when all the lamps are needed, both dynamo and battery can supply current together.

The best method of installation will be dictated by local conditions, but, up to 200 lamps capacity, a shunt-wound dynamo that will give 150 volts pressure is probably the best.

The best method of regulating a plant of this small capacity is by counter E.M.F. cells, placed in series between the battery and lamps, being all in when the battery is fully charged, and cut out one at a time as the pressure falls.

Counter E.M.F. cells are simply unformed lead plates, mounted in the same manner as are the regular plates, and placed in opposition to the regular battery.

The use of counter E.M.F. cells enables one to charge the battery at the same time that lights are being supplied from it, as the counter E.M.F. cells will absorb the extra pressure necessary for charging.

Where it is desired to charge the battery at the same time that lamps are operated, 18 counter E.M.F. cells are necessary; but where the battery can be charged when lights are not in use, as is easily done in the ordinary house, but 7 counter E.M.F. cells are necessary.

The cuts following show two methods of controlling the pressure, the first diagram being with the use of counter E.M.F. cells as described above, while

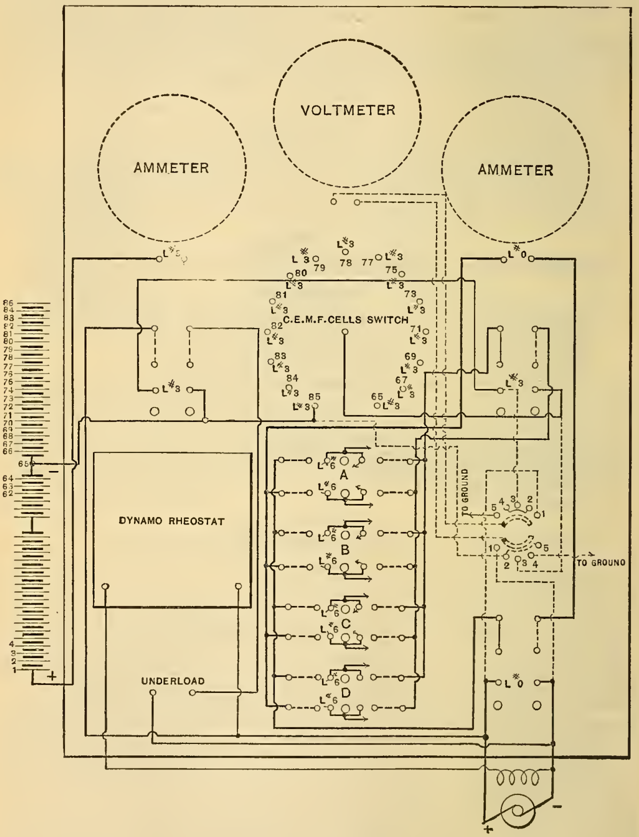


DIAGRAM OF CONNECTIONS
FOR THE
PEQUOT LIBRARY,
SOUTHPORT, CONN.

THE E.S.B.Co. PHILA, PA.

Fig. 8.

the second is done by cutting in and out the end cells. Both diagrams show the proper arrangement of all controlling and indicating appliances for a switchboard.

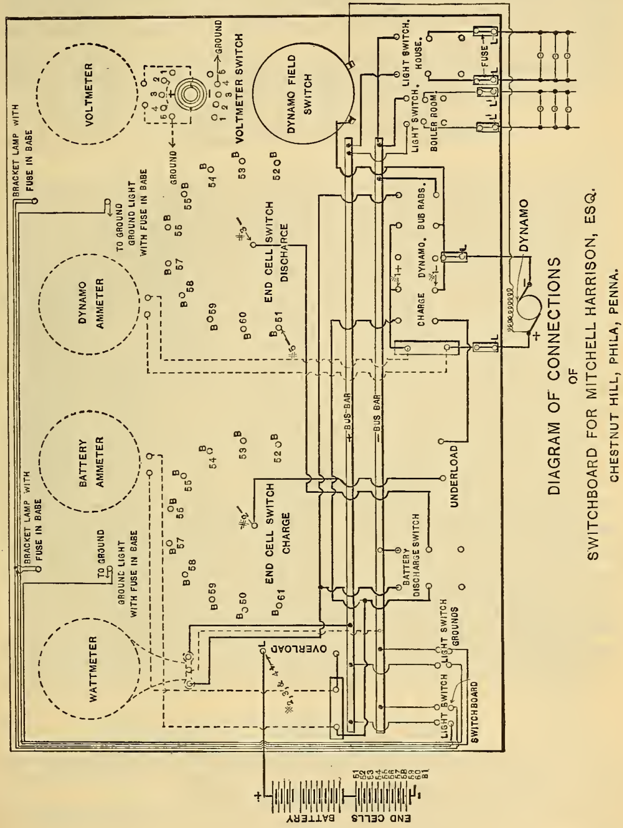


DIAGRAM OF CONNECTIONS
OF
SWITCHBOARD FOR MITCHELL HARRISON, ESQ.
CHESTNUT HILL, PHILA, PENNA.

Fig. 9.

The method of regulating by cutting in and out end cells is used only in plants large enough to afford an attendant, as the end cells are charged and discharged to different degrees, and need attention to keep in normal condition.

Useful appliances for isolated batteries are underload switches, for automatically cutting out the battery when it has discharged as low as is safe, and overload switches for preventing discharge at greater than a safe rate, say in case of a short-circuit on the line. Both devices open the main battery circuit and prevent trouble.

Storage Battery in Large Isolated Plants.

A large isolated plant, such as is now used in large office buildings, is practically a central station with a prescribed territory; and the battery is, in this case, an auxiliary, and used for furnishing the peak of the load, and in some cases all the load, during such periods of the run as it is within the capacity of the battery.

Experienced judgment is necessary in properly proportioning a storage battery to any plant; and it is necessary to know a number of points regarding its particular features, such as the following; viz.:—

1. Nature of load and duration.
2. Maximum, minimum, and average loads.
3. Size and type of generating units.

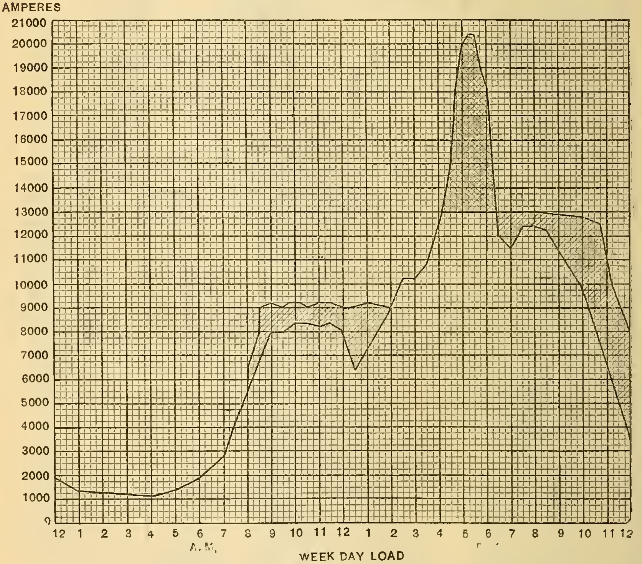


FIG. 10.

Where it is possible to do so, a load diagram constructed from actual records of output is in all ways the best, as it will include the information necessary, excepting data as to generators and voltage.

Even in new plants it is nearly always possible for the designing engineer to construct a load diagram that will serve well for proportioning the battery.

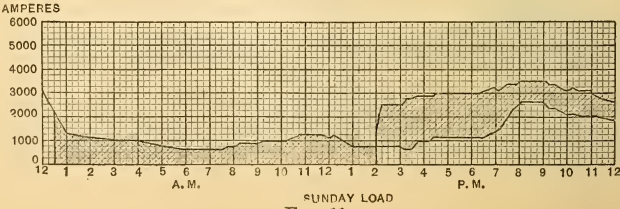


FIG. 11.

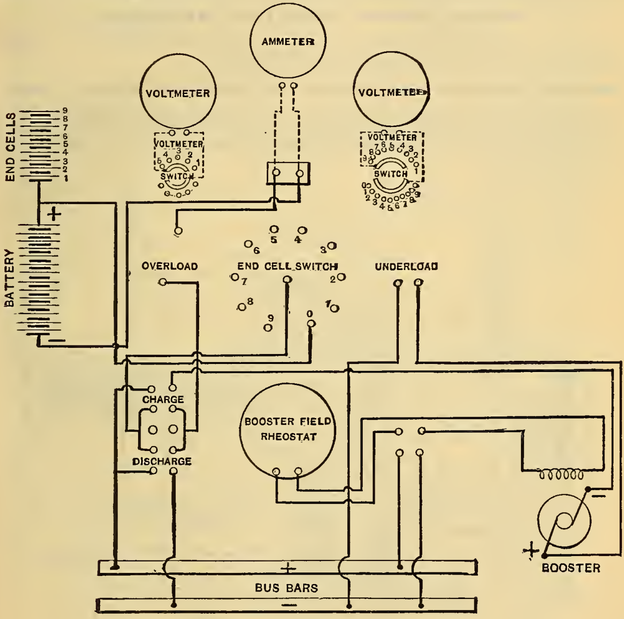
Advantages of a Battery in an Isolated Plant.

1. Generator capacity for the average load is all that is necessary, the battery taking the peak; and if the low load is within the capacity of the battery, the generating plant may be run at economical loads only, and shut down entirely during the time of low load, providing the battery is then fully charged, thus saving fuel.

2. Lamps may be run on the same lines with elevators or other variable load, the battery providing instantaneous regulation.

3. Greater reliability of plant, and provision for quick supply in case of storms and other sudden calls.

4. Possibility of reduction in pay-roll due to use of battery instead of steam plant and generators.



PROPOSED ARRANGEMENT
FOR BELTED BOOSTER,
WITH END CELL REGULATION

THE ELECTRIC STORAGE BATTERY CO.

FIG. 12.

Battery Charge and Control.

In the large isolated plant and in the central lighting station there are a number of methods in common use for operating the battery and controlling its output and pressure.

In such plants the dynamos are seldom designed with large enough range in voltage to permit of charging the battery direct to its full pressure, and recourse is then had to the "booster;" a belt or motor driven dynamo, with its armature in the battery-charging circuit, and its fields being excited from the bus bars, which may be used to supply the excess pressure necessary to produce the proper rise of voltage in the line to overcome the counter E.M.F. of the batteries.

The booster must have a capacity for the full charging current, and a range of pressure from ten to fifty volts.

Following are a number of diagrams of arrangements of batteries in actual use, the diagrams showing relative location of all appliances for switchboards and battery. These diagrams are furnished by the courtesy of the Electric Storage Battery Company of Philadelphia, Pa.

Belted Booster; End Cell Regulation.

The preceding diagram, Fig. 12, is one of the simplest forms for a plant with no special complications, and explains itself.

Belted Booster; Regulation by Counter E.M.F. Cells.

The following diagram shows the relative location and arrangement of all controlling and indicating appliances for a battery using a belted booster, and the regulation being accomplished by counter E. M. F. cells as previously described.

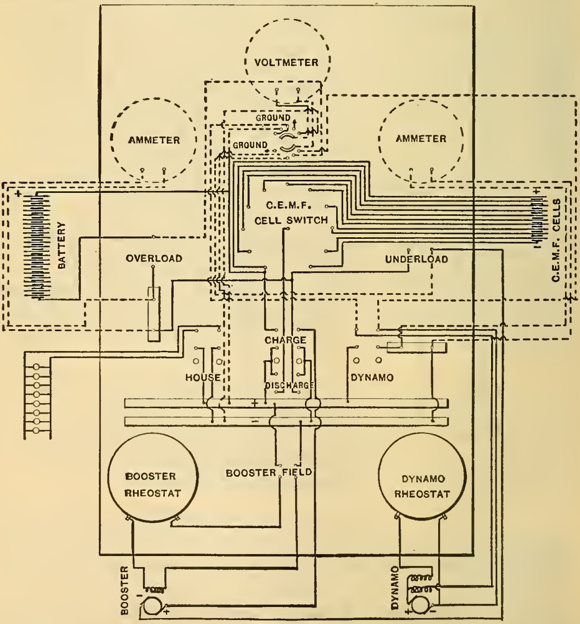
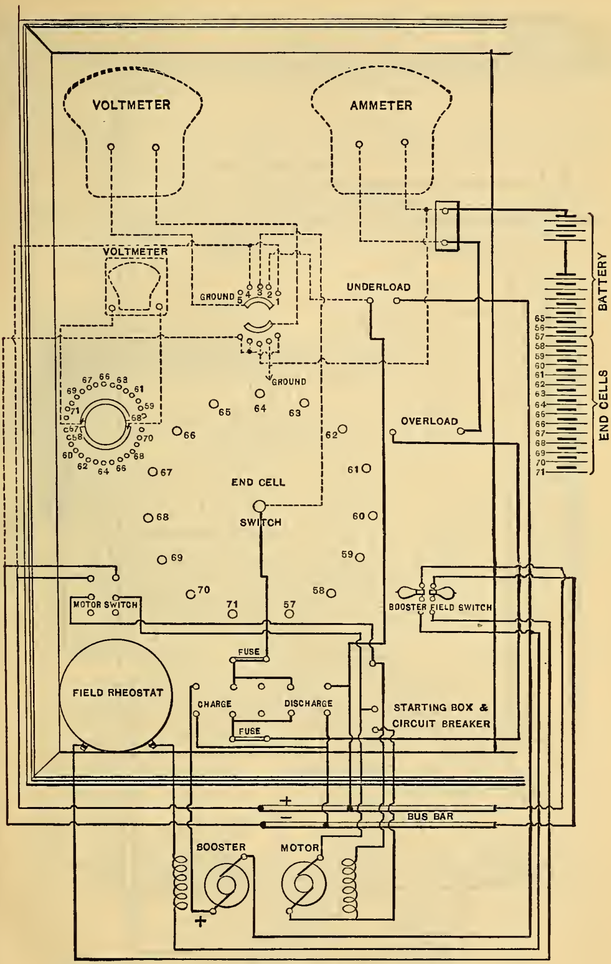


FIG. 13. Diagram of Connections for Plant consisting of Storage Battery, C.E.M.F. Cells, Compound Wound Dynamo and Belt-driven Booster. The E. S. B. Co.



SWITCH BOARD PANEL FOR MOTOR DRIVEN BOOSTER
WITH END CELL REGULATION,
FOR STORAGE BATTERY IN LARGE PUBLIC BUILDING

NOTE:-

ON FIFTEEN POINT VOLTMETER SWITCH POINTS NUMBERED 58, 59, 60, ETC. CONNECT WITH CORRESPONDINGLY NUMBERED POINTS OF END CELL SWITCH. ON END CELL SWITCH POINTS NUMBERED 57, 58, 59, ETC. CONNECT WITH CORRESPONDINGLY NUMBERED POINTS OF END CELLS.

FIG. 14.

Motor-Driven Booster; End Cell Regulation.

The preceding diagram (Fig. 14) gives the layout of the switchboard and all connections for a storage battery in a large public building.

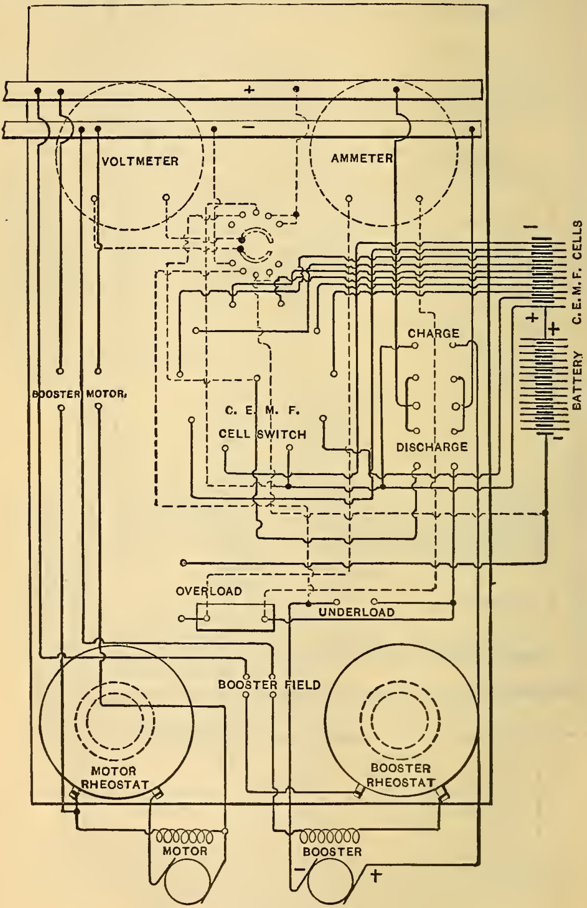


DIAGRAM OF CONNECTIONS

FOR BATTERY BOOSTER AND BOOSTER DYNAMO IN CONNECTION WITH C. E. M. F. CELLS AS AN AUXILIARY TO AN EXISTING SWITCHBOARD FOR COMPOUND WOUND DYNAMOS.

Fig. 15.

Motor-driven Booster; Counter E. M. F. Cell Regulation.

The preceding diagram shows connections and relative location of appliances for the switchboard for connection to an existing switchboard; counter E. M. F. cells being used for regulation, with a motor-driven booster for charging.

NOTE.—On Fifteen Point Voltmeter Switch Points numbered 58, 59, 60, etc., connect with correspondingly numbered Points of End Cell Switch. On End Cell Switch Points numbered 57, 58, 59, etc., connect with correspondingly numbered Points of End Cells.

Yacht Plant.

Yachts cannot carry any surplus weight of machinery; and in order to charge the battery it is often cut in two and the two halves charged in par-

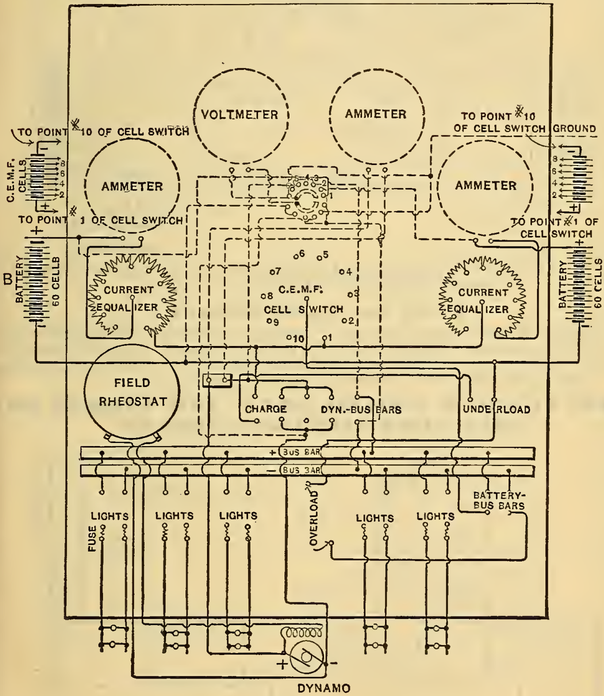


DIAGRAM OF CONNECTIONS OF SWITCHBOARD,
FOR PLANT CONSISTING OF STORAGE BATTERIES
WITH C. E. M. F. CELLS, AND SHUNT OR
COMPOUND GENERATOR. BATTERY IN TWO PARTS,
CHARGED AND DISCHARED IN PARALLEL.

NOTE: ON C. E. M. F. CELL SWITCH POINTS NUMBERED 1, 2, 3, 4, ETC. CONNECT CORRESPONDENTLY NUMBERED POINTS OF C. E. M. F. CELLS.

FIG. 16.

allel from the regular lighting dynamos, counter E. M. F. cells being inserted to take up the extra voltage of the dynamo, and to be used for regulation when in use on the bus bars. For discharge the cells are again all connected in series, and run as usual.

NOTE.—On C.E.M.F. Cell Switch Points numbered 1, 2, 3, 4, etc., connect with correspondingly numbered points of C.E.M.F. Cells.

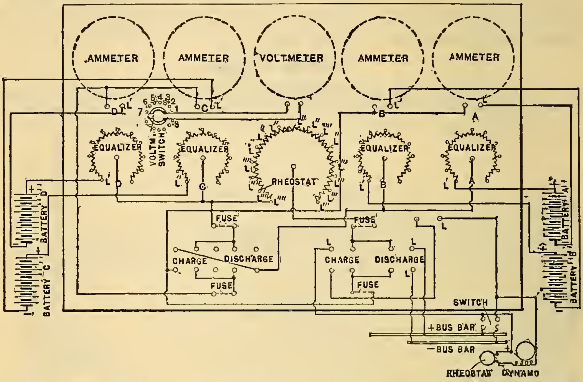


FIG. 17. Diagram of Connections of Storage Battery Switchboard Panel for Yacht "Niagara." The E.S.B. Co., Phila.

Plant for Yacht Niagara.

Preceding is the diagram for the connections of battery and switchboard for the above-named yacht. This battery is also charged in parallel and discharged in series, as was the last; but rheostats are here used for equalizing the charging current to the different legs of the battery.

FLUCTUATING POWER LOAD AND LIGHTS ON THE SAME DYNAMO CIRCUIT.

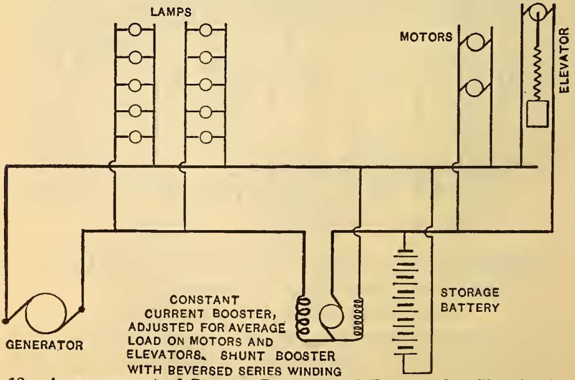
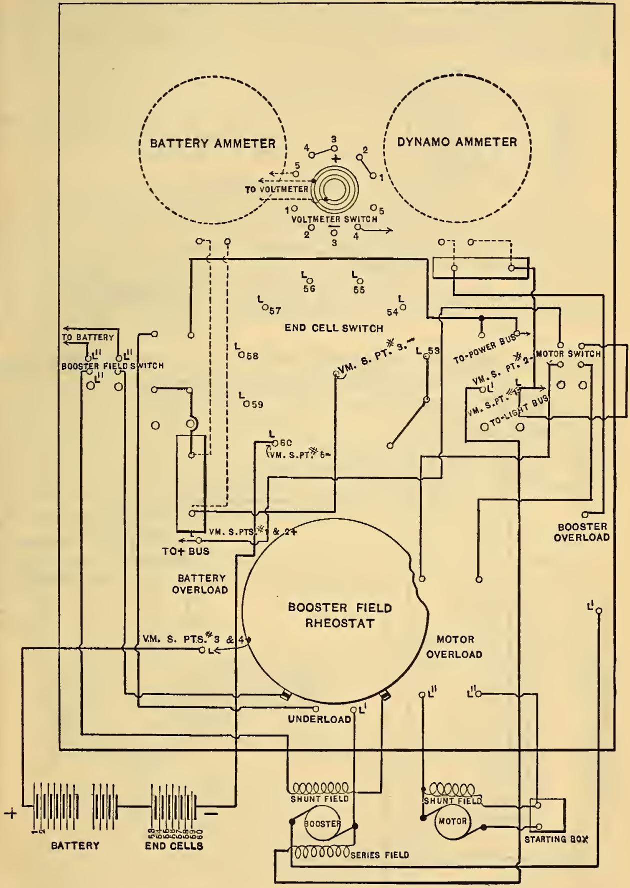


FIG. 18. Arrangement of Storage Battery and Booster for Circuits having a Widely Varying Power Load in Connection with Lighting.

When electric elevators or other appliances taking current intermittently are connected to circuits furnishing current for incandescent lamps, there



CONNECTIONS FOR
BATTERY, DYNAMO AND BOOSTER
FOR FLUCTUATING LOAD.

E.S.B.Co.
FIG. 19.

will be a very considerable fluctuation in the light unless means are furnished for preventing it. This does not permit of using one dynamo for both services unless a storage battery be connected as a regulator.

The diagram on p. 572 (Fig. 18) shows the scheme of such a connection of battery; and the more complete diagram following that gives the actual connections and diagram of panel board for an existing plant now being worked in this manner.

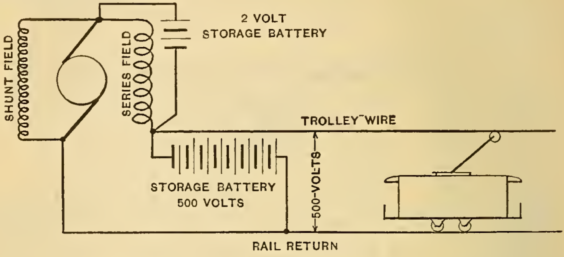


FIG. 20. Arrangement of Battery for Street Railway Circuits where Refinement of Regulation is not necessary.

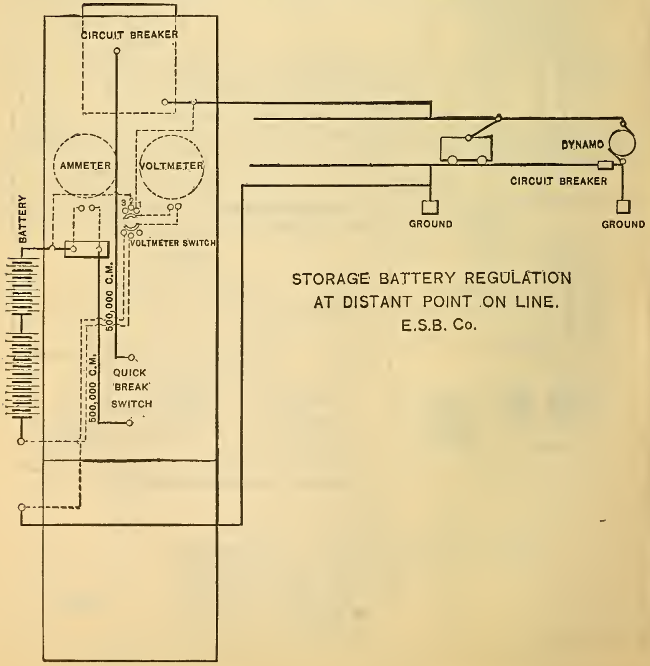


FIG. 21.

STORAGE BATTERY AS AUXILIARY FOR POWER PLANT FOR STREET RAILWAYS.

Owing to great fluctuations of load on the power-plant of street railways, a storage battery of the proper size and properly connected can be made to assist greatly in the economy of the station.

It will maintain a much evener pressure on the circuits.

Will take on all overload; and at the low demand between one and six o'clock A.M. will take all the load on all but special occasions, thus relieving the steam plant and attendant labor.

On such occasions, as it may be necessary to shut down the power-plant for a short time, the battery will take the entire load for a short period.

Battery used for Simple Regulation.

The two preceding diagrams illustrate the simplest form of application of a storage battery to street railway circuits. The first is when the battery is placed in the power-house, and in connection with a compound-wound generator; the two cells shown in shunt to the series winding are needed to prevent the main battery reacting on the generator.

The second diagram shows the use of a battery at some distant point on the line where it acts as a regulator of pressure, and at the same time a regulator of load on the engine.

Close Regulation, with Battery and Booster.

The following diagram is a sketch of an arrangment of a storage battery in connection with a differentially wound booster that will maintain a very close pressure on the lines at all times.

With this arrangement, when a heavy load comes on the circuit the current through the series field of the booster increases the pressure from the battery to the line, thus compelling the battery to assist. As the load decreases the series field is overbalanced by the shunt field, and the generator then feeds directly into the battery.

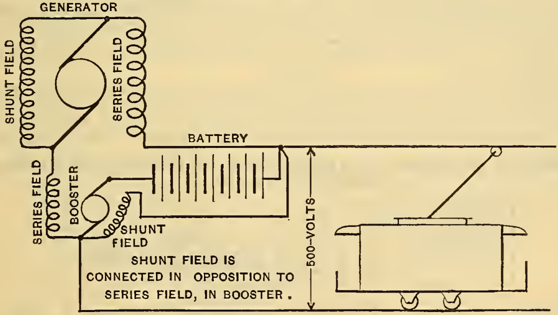


FIG. 22. Differential Booster for Maintaining Constant Voltage on Railway Circuits.

Battery for Regulation of Pressure at the End of a Long Railway Feeder.

The following diagram illustrates the use of a storage battery in maintaining a constant pressure at the end of a long railway line, as is done on one of the Philadelphia lines at Chestnut Hill. In this case the booster is located in the main power-house and charges the battery, which is located a number of miles away, through a special feeder at such times as the load is light and power is available at the power-house.

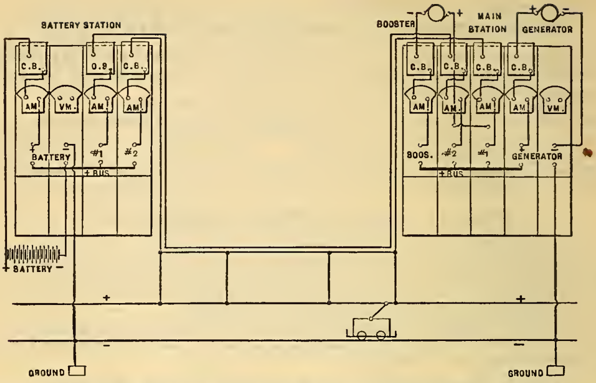


FIG. 23. Diagram Showing Application of Storage Battery to Electric Traction, Battery Located at a Distant Substation and Acting as a Load Regulator.

Generator and Battery can feed the system either separately or in combination through main feeder No. 1, a special feeder No. 2 with Booster being used as an adjunct to main feeder, or for independent charging of Battery. The E. S. B. Co., Philadelphia, Pa.

STORAGE BATTERY FOR CENTRAL-STATION USE.

All the advantages recited in the preceding paragraphs relating to the use of batteries in small and large isolated plants, and in street railway power, apply equally well to their use in central lighting stations; and with some refinements not necessary in railway work, they have been found to make for increased economy of working in every case where they have been intelligently applied.

The Edison Illuminating Companies were the first to develop their use on this side the Atlantic; and the growth of such use has been steady, and the capacity of batteries has increased to a very great extent since the first Tudor battery was installed in the station of the Boston Edison Company.

Different Methods of Application of Battery to Central Station Practice.

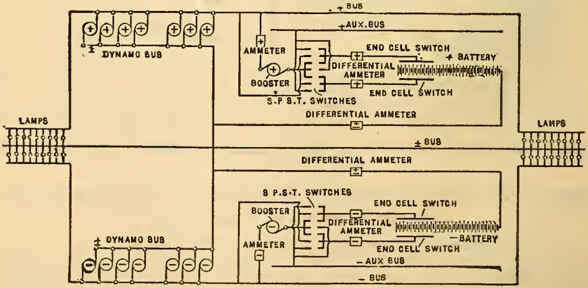


FIG. 24. Circuits of Storage Batteries in Connection with Three-Wire System, Philadelphia Edison Station.

The three diagrams, Figs. 24, 25, 26, illustrate the straight application of a storage battery to use in a central lighting station for all the regular uses of regulation of pressure and load, etc.

The first is the sketch of connections of the plant used in the station of the Philadelphia Edison Company; the second, that of the plant for the San Francisco Edison station; the third, that of the recently installed plant of the Chicago Edison Company, the largest by far yet constructed.

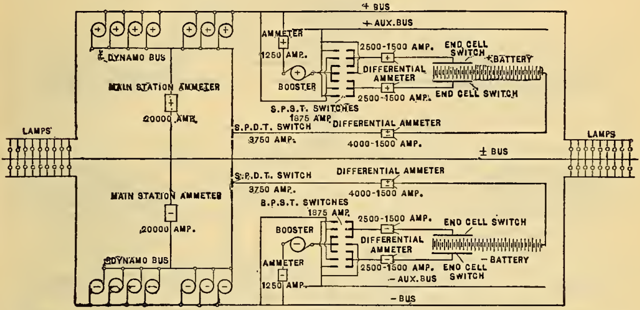


FIG. 25. Storage Batteries in Connection with Three-Wire System as used at San Francisco Gas and Electric Co., San Francisco, Cal. The E. S. B. Co., Phila.

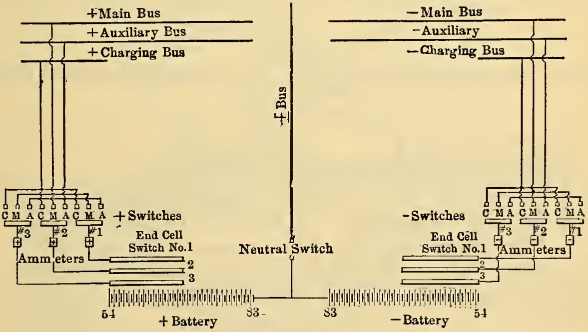


FIG. 26. Diagram of Connections of Storage Battery for Chicago Edison Co. E. S. B. Co.

The two diagrams, Figs. 27 and 28, show the circuits and connections of batteries in the two large substations of the New York Edison Company; the first is the station at Bowling Green, and the second at 12th Street.

The second of these substations is right in the heart of the city, and feeds in all directions into the heart of the network of conductors.

The first-mentioned station, that at Bowling Green, is in the lower part of the city, and feeds a large district occupied by the large office buildings, and keeps up pressure at what was practically the lower end of the network.

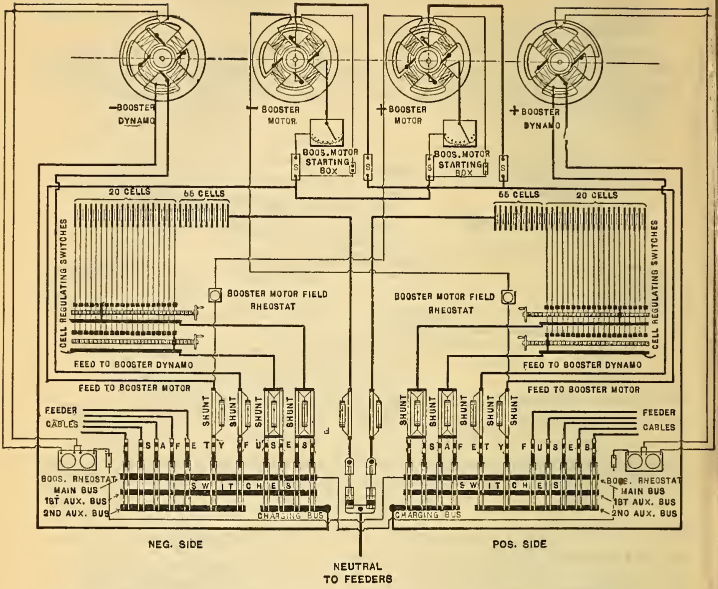


FIG. 27. Battery, Booster, and Feeder Connections, Bowling Green Storage Battery Station.

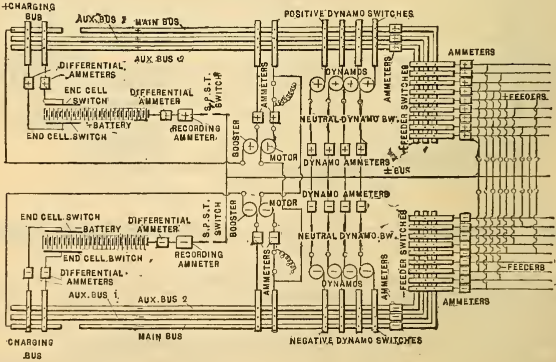


FIG. 28. Battery, Booster, and Line Connections of the 12th Street Station of the New York Edison Company.

The diagram, Fig. 29, illustrates the method of connecting a storage battery to a three-wire system with the dynamos of full pressure and connected directly across the outside conductors. This method has been in use abroad by the Siemens-Halske Company to some extent, and will make a satisfactory three-wire system from one dynamo or more.

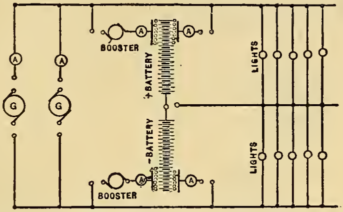


FIG. 29. Diagram of Connections Showing Application of Storage Battery to Three Wire System with Generators across Outside Wires Only. The E. S. B. Co., Phila., Pa.

The diagram, Fig. 30, shows one of the newer applications of the storage battery for use in connection with long-distance transmission, and it is quite similar to the preceding application with the exception that in this case a rotary converter is used in place of the regular generator.

The diagrams, Figs. 31, 32, of the Hartford Electric Lighting Company's plant, show a very clever method of using a rotary converter and storage battery on a three-wire direct current system.

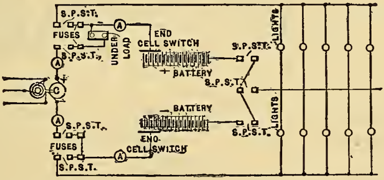


FIG. 30. Diagram of Connections for the General Electric Co.'s Exhibit, Omaha, Nebraska, Showing Applications of Storage Battery to Three Wire System with Generator across Outside Wires Only. The E. S. B. Co., Phila.

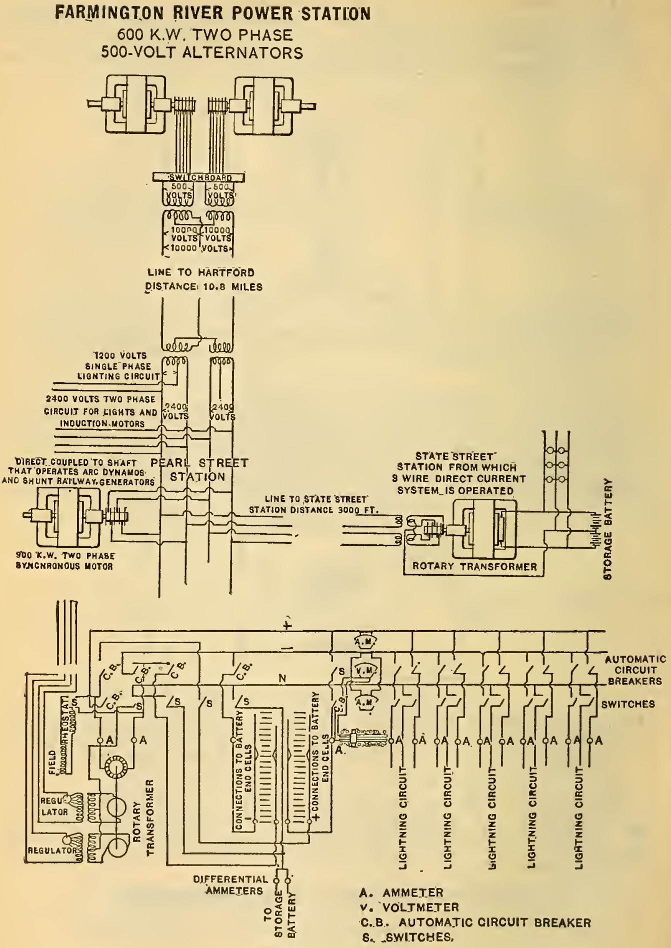
The terminals of the direct current side of the rotary are connected to the outside wires of the three-wire circuits, and the neutral is carried back of the rotary, and connected to the middle of the secondary on each of the two or three static transformers. This method works well whether the battery is connected or not.

TESTING STORAGE BATTERIES.

Condensed and rearranged from Article by Carl Hering in "Electrical World."

An intelligent test of storage batteries requires a considerable knowledge of such batteries, in addition to the mere capacity to make the proper connections and to read the instruments accurately. The conditions of the test are also highly important, and must be well understood if the results are to be reliable.

Storage battery tests may in general be separated into two classes; viz.:—



Figs. 31 and 32. Connections of Machines and Circuits of Hartford Electric Light Company, showing Special Connection of the Storage Battery to Rotary Converters.

a. To determine for a purchaser if the battery fulfills the specifications under which it was furnished.

b. To determine for a maker or prospective investor all the qualities of a battery, including its capacity, efficiency, maximum, minimum, and normal or best rate of working, both as to charge and discharge.

The first test should really be included in the second; or, when making it, it will be well to carry out as much of the routine of the second test as can be done without excessive cost to the client, and anyway as much as may be necessary to determine the prescribed results.

In the second test the operator will necessarily have to determine the conditions; and it is therefore highly important that he fully understand the peculiarities of storage batteries and their behavior and working, especially so where two batteries of different makes are to be compared.

Following are some of the points to be determined.

1. Whether the battery is for stationary or for portable purposes.
2. Weight of plates, of acid, of containing-cell, of one coupling.
3. Floor space, accessibility for inspection and repairs.
4. Size of plates.
5. Dimensions of containing-cell or box.
6. Rate of charge, — maximum, best, normal.
7. Rate of discharge, — maximum, best, normal.
8. Efficiency at all rates of charge and discharge.
9. Normal rate of charge per unit of plate surface.
10. Normal rate of charge per pound of plates, and per pound of cell total.
11. Normal rate of discharge per unit of plate surface.
12. Normal rate of discharge per pound of plates and per pound of cell total.
13. Curve of rise of voltage at different rates of charge.
14. Curve of fall of voltage at different rates of discharge.
15. Kilowatts capacity at different rates of charging.
16. Kilowatts capacity at different rates of discharge.
17. Curve of load value when charging at constant potential.
18. Curve of load value when charging at constant current.
19. Curve of specific gravity of acid by hydrometer during charge and discharge.

1. The specifications of the manufacturer will essentially determine whether the battery is for stationary or portable purposes, except in trials of new ones, in which case the person making the test will be in position to say from his trials for which purpose the battery may be best adapted.

Batteries for stationary purposes may, in general, be chosen regardless of weight and dimensions, but for portable purposes size and weight must, of a necessity, be the smallest commensurate with the service demanded.

2. A knowledge of the weight of plates, acid, containing-cell, and one coupling is useful in comparing output per unit of weight with other makes of battery.

3. The floor space required, and accessibility for repairs, often govern the selection of batteries for special purposes; and good practice would dictate that the cell occupying the least space per unit of output, and the one that was repaired with the least trouble, be selected.

4. The size of plates will determine the output per unit of surface.

5. Dimensions of the containing jar or box must be known, in order that proper space may be laid out for its installation.

6. In order to adapt a battery to the purposes of its use it is highly important that the maximum and normal rate of charge be known, as the battery is most frequently charged during the idle time, or time of lowest output of some operating electrical plant. It is sufficiently obvious that where a plant is available for but a short time, a battery admitting of a high rate of charging is desirable, although not always the most efficient in all ways; whereas, if there is plenty of time, during which the charging may be done, then the battery may be charged at a slower and more efficient rate.

7. A full knowledge of the maximum and normal rates of *discharge* is of the very highest importance, as on this depends the capacity and good working of the battery.

The capacity of all lead batteries is reduced by hastening the discharge, and this is especially so for batteries having the active material in thick masses, or so disposed that the acid has not free access to it. In batteries having the active material disposed in thin layers, and freely exposed to the action of the acid, the reduction of capacity is not so great.

While it may be true that a battery may be constructed for less cost if made for low rates of discharge, the capacity is so much reduced when discharged at high rates, that it seems better policy to construct for high rates of discharge, in which case the battery may be equally well used for discharges at low rates, but will not hold a charge quite so long as will the slow discharge battery. Treadwell says 8 amperes per square foot of positive plate is a good rate of discharge.

Theoretically, the capacity of a battery depends upon the amount of active material, while the rate of discharge depends upon the amount of surface acted upon by the acid.

In most installations where a storage battery is used, it is essential that the battery be capable of a high *rate* of *discharge* for a short time, say an hour or two, and it is this fact that governs the selection rather than its capacity, although this latter condition must receive due attention after the *rate* of discharge is settled.

In the United States it is now customary to designate the capacity of a storage battery by a time rate; viz., a given battery has a certain capacity, at a full discharge in three hours, and such a capacity at a discharge in five hours, etc., 8 to 19 inclusive. Nearly all these items are determined by calculations from the readings of the instruments in use, and need no further explanation here.

The following named readings may be taken as the routine of a test.

Charge.

Time.
Amperes input.
Volts of charging circuit.
Specific gravity of acid by hydrometer.
Temperature of room.
Temperature of acid.
Statement of gasing.

Discharge.

Time.
Amperes output.
Volts at cell terminals.
Specific gravity of acid by hydrometer.
Temperature of room.
Temperature of acid.
Statement of gasing.

General Conditions.

Insulation resistance of cell from ground.
Resistance of cell between terminals when fully charged and when fully discharged.

If there is a storage battery recording wattmeter available it will be useful in connection with the readings mentioned above.

SOURCES OF CURRENT FOR CHARGING.

Current from a battery of storage cells will be found by far the best for testing a cell or cells. Where one cell is under test, four others of similar size connected, two in multiple and two in series, will be found to give good results.

If current from public circuits, or from a dynamo, is to be used, it should be as steady as possible, of considerably higher voltage, and have a large resistance capable of carrying indefinitely the maximum current in series with the cell.

Before starting a test, it is necessary to decide the points at which the battery may be considered charged and discharged, as overcharging and undercharging and light and full discharge make much difference in the results.

It is difficult to predetermine a rate at which the battery will be fully discharged in a certain time, and the only way is by trial rates. Even then, no rate can be taken as reliable unless it can be repeated under the same conditions, any variation in result showing that the battery had not recovered from its previous discharge.

Charging too long at a high rate will injure the plates, but moderate overcharging with a small current is beneficial to the plates, though it, of course, reduces the efficiency.

Charging too little results in increased efficiency but less capacity.

Discharging too far increases the capacity, reduces the efficiency, and results in great variations in voltage and a tendency to increase the destructive action on the plates.

Discharging too little increases the efficiency but reduces the capacity.

Destructive action on the plates determines the limits of charge and discharge and inside the safe limits the points of stopping charge and discharge will depend on whether high efficiency or high capacity is deemed the most desirable under the special conditions. The proper stopping point is determined by a preliminary test for a curve of voltage, then the points may be selected between the points of rapid change in pressure.

Slow discharge will take out more of the charge than a rapid discharge, the latter condition leaving some of the charge in the battery, which may show in the next discharge, and make the results erroneous.

If a rapid discharge be followed by a slow one, the capacity for the second test will indicate higher than it ought, in some cases showing an efficiency exceeding 100 per cent.

If a slow discharge be followed by a rapid one, then the capacity of the second test will indicate lower than will be the correct result.

Destructive action on the plates can only be determined by inspection, which will show other than normal colors, sulphating, buckling, loosening of the active material, etc. A number of discharges may be necessary to determine if a certain rate is deleterious.

In stating the limiting voltages, it is most correct to state the rise or fall of voltage in percentage of the initial pressure, taking as such initial pressure the reading of voltage a short time after the start to charge or discharge, and when it has become constant. The percentage is not always the same for charge and discharge.

For the sake of uniformity, especially in comparing cells, it is best to make all tests with continuous discharge without stop.

It is considered best to *charge* with constant voltage, but is very difficult to do, as the current varies greatly, starting in at a large amount and reducing to a small amount at the end of the charge. The current may vary through wide limits without much effect on the charging voltage. Varying the charging current by steps will be found to result in more nearly constant voltage, reducing to a lower value when the voltage indicates a rapid rise. Take the time of charge at each rate in order to compute the capacity of charge.

It is best to make the *discharge* at constant current, as that more nearly approaches actual practice. If this is not practicable in the circumstances, then the best method is to discharge through a constant resistance.

Discharge at a constant current will require the use of a rheostat that can be changed by very small increments, such as a water box or carbon plate resistance. The readings will then be the voltage at the cell terminals and the constant amperes, and with a proper rheostat the test is very simple.

Discharge through a constant resistance, which, by the way, is seldom an actual condition, owing to heat variations, the calculations become tedious, as they have to be made for each reading, and a careful record kept of the time.

A discharge at constant watts would be the most correct method for batteries that were to be used for traction, but the calculations and adjustments are so troublesome and difficult as to add to the liability to error.

In comparing two cells connect them in series for charge or discharge, cutting out each one as its work is completed, measuring the voltage at the cell terminals.

In a comparison of different cells it is necessary to base the comparison on some common factor, such as the following items, the selection depending on the special conditions to be filled: —

Ampere-hours per pound.
Watt-hours per pound.
Charge and discharge rate in hours.

Discharge in watt-hours per pound.
Discharge in ampere-hours per dollar of cost.
Discharge in watt-hours per dollar of cost.

Readings of instruments will be governed as to time by the circumstances of the test and the quality of the apparatus. If the source of current or the rate of discharge is variable, many more readings will be necessary than if they are steady. If the instruments do not respond freely to changes of current many readings will also be necessary on that account. If all the conditions are favorable 15 to 25 readings will be sufficient to give a good average.

Before starting test, take the voltage of the cell on open circuit, as it is some indication of the condition of the cell.

During test take occasional readings of voltage from which to calculate the internal resistance of the cell, as follows: first take the voltage of the cell while connected in circuit and working, then take the cell out of circuit and take voltage on open circuit.

Connect voltmeter terminals to the lead terminals of the cell, not to the circuit or the couplers.

Connect the amperemeter as close as possible to one terminal of the cell, so as to include any leakage.

Leakage may be found by connecting one leg of the voltmeter to ground and the other to one terminal of the cell and then the other. The leak, if any, will be found nearest the terminal indicating the *least* deflection of the voltmeter.

Where the circuit is merely switched from the charging source to the discharging circuit, it is necessary to reverse the ammeter leads.

Calculate efficiencies for ampere-hours and watt-hours, and for mean volts, as follows:—

$$\text{Ampere-hour efficiency }\% = \frac{\text{Discharge in ampere-hours} \times 100}{\text{Charge in ampere-hours}}.$$

$$\text{Watt-hour efficiency }\% = \frac{\text{Discharge in watt-hours} \times 100}{\text{Charge in watt-hours}}.$$

$$\text{Efficiency of mean volts }\% = \frac{\text{Mean volts of discharge} \times 100}{\text{Mean volts of charge}}.$$

$$\text{Watt-hour efficiency }\% = \frac{\text{Mean volt efficiency} \times \text{ampere-hour efficiency}}{100}.$$

Comparing ampere-hour efficiency with mean-volt-efficiency will show whether loss in watt-hours is due to polarization and internal resistance, or to leakage and gasing or lack of retaining power of the active material.

SWITCHBOARDS.

For Light and Power.

THERE are two general types of modern switchboards for light and power:

(1) Those in which all the switching and indicating apparatus is mounted directly on switchboards.

(2) Those in which the main current carrying parts are separate or at a distance from the controlling and indicating apparatus. Both of these can be further divided into Direct Current and Alternating Current, and there are numerous and distinct classes under these.

Modern switchboards are made of slate or marble panels, each having a definite function.

LAYOUT OF SWITCHBOARDS.

In laying out buildings for central stations or isolated plants, the switchboard should be located in an accessible place, and have plenty of room both back and in front. In many cases the switchboard can be placed advantageously on a gallery overlooking the machinery. If due consideration be given to the location of switchboard with respect to the machines and feeders which it controls, unnecessary complications and expense can be avoided.

Switchboards are now standardized, covering a large range of D.C. and A.C. generators and feeders, although, of course, it is often necessary to meet special conditions, which, however, can be met usually by slight modifications of the standard.

Unnecessary complications and extra flexibility being at the expense of simplicity, are always to be avoided. It would seem unnecessary, for instance, in the great majority of cases to have more than one set of bus bars.

Plainness, combined with neatness, and symmetry, is much to be preferred, and nothing should be placed on a switchboard which has no other function than ornamentation.

If extensions to switchboards are expected, which is usually the case, panels controlling generators should be together at one end of the switchboard, and those controlling feeders at the other end. When total output panels are used, they are placed between the generator and feeder sections. Of course, where switches are controlled at a distance, this rule need not be followed; but, on the other hand, it is often advisable, in order to simplify station wiring, and to save copper in the busses, to intermingle the generator and feeder switches. Even in this case it is desirable to group the generator controlling and indicating devices together and likewise those for the feeders. For ordinary D.C. switchboards 4 feet is little enough behind the panel. In any case, there ought to be a clear space between connections on panels and wall, of 2½ to 3 feet. For large work and most A.C. work it is very often necessary to have 6 to 8 feet behind panels.

In the high-tension work of 5000 volts and above, the General Electric Company remove all high-tension apparatus from the face of the board; the switches being placed in fire-proof compartments of brick or soapstone, and operated mechanically through bell cranks and levers by means of a handle on the panel, or electrically by means of a controlling switch. The instruments are connected to secondaries of current or potential transformers, which are placed in some convenient place in connection with the high-tension wiring. This, of course, necessitates more room than the ordinary switchboards require. The main current carrying apparatus can be placed directly behind the controlling board, below in a basement, or under a gallery; or above in a gallery; or, if switches are electrically or electro-pneumatically controlled, they can be placed in any convenient place.

In locating switches and other appliances, it is usually assumed that dynamo leads come from below, and that feeder wires go out overhead, except in the case of underground feeders, which naturally go out below.

CONSTRUCTION.

Central station switchboards are usually composed of panels about 90″ high and 2″ thick, and varying in width from 16″ to 36″. The panels are generally in two sections; the top varying from 60″ to 65″, and the lower from 25″ to 30″. The General Electric Company's Standard is 62″ and 28″ respectively for top and lower part; the Westinghouse Standard is 65″ and 25″. The General Electric Company also makes panels 76″ high, $1\frac{1}{2}$″ thick for isolated plants. Each panel is beveled all around on the front edges with a $\frac{1}{4}$″ to $\frac{1}{2}$″ bevel.

Where a well finished switchboard is desired, black enameled slate is recommended for circuits of less than 1100 volts. The main current carrying parts are mounted directly on the panel. For higher voltages it is necessary to use marble on account of its higher insulating qualities. Plain slate can be used where a low-priced switchboard is desired for low voltages.

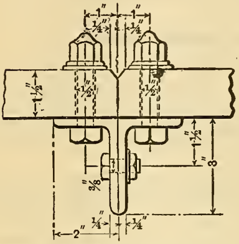


FIG. 1. Method of Joining Adjacent Panels.

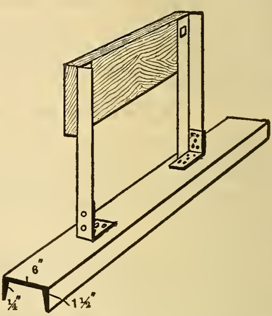


FIG. 2. Channel Foot for Switchboard Frame.

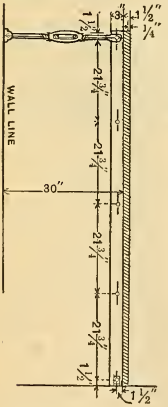


FIG. 3. Showing Method of Bracing Switchboard Panel to Wall.

There are several different varieties of marble used for switchboards, viz.: blue or white Vermont, pink or gray Tennessee, and white Italian. Marble being a natural product cannot always be matched in shade or markings. The colored marbles do not show so readily as white marbles the effect of oil or grease, and therefore are more suitable for switchboards. Of the colored varieties, the blue Vermont marble can be obtained in the most uniform color.

Steel angle bars varying from $2\frac{1}{4}$″ x $1\frac{1}{2}$″ x $\frac{1}{4}$″ to 3″ x 2″ x $\frac{1}{4}$″, are ordinarily used for supporting the panels, although in some cases for heavy work, steel channels, tees, or "I" beams are used. The angle bars stand on the floor, to which they are fastened by means of a small foot iron. The panels are bolted to the narrow web of angle bars, and adjacent angles are bolted together through their wide webs (Fig. 1).

The panels should be set up on a level strip, which can be of either hard wood, "I" beams, or an inverted channel.

The frame-work of all switchboards should be insulated from ground when used on circuits of 600 volts or less. In high tension A.C. systems it is necessary to ground all frame-work to carry off static discharge and in order to get rid of danger to the operator should he accidentally touch the frame-work. For securing the structure in a vertical position, rods with turn buckles for adjustment of length are run from the back wall to the angle frame, at or near the top. A "Y" connection can be made to straddle the two angles, and a bolt be put through the whole. The wall end can be secured by expansion bolts or other means.

Circuit breakers should be placed, if possible, near the top of the panel, so that there will be no apparatus above them. Instruments should be placed within convenient view of attendant, and switches and rheostat hand wheels should be located within easy reach.

It is recommended that illuminating lamps be left off of switchboards, and that instruments be illuminated from lights on the front of the switchboard.

The copper bus-bars and connections on the back of switchboards need careful laying out, with a view to carrying the current economically and without overheating, and above all, in order that there will be no undue crowding, and that they will present a neat and workmanlike appearance. The tendency has been of late to place the busses toward the top of panels, except in the case of small isolated plant switchboards. The switches, circuit breakers, and instruments are connected to busses by means of bare copper strips or insulated wire, bent in the most convenient shape to suit the case. It is *not* recommended, as a rule, to have long studs on the apparatus projecting out far enough to connect direct to busses, as the strain on the switch, due to weight of busses, is likely to affect the adjustment of switch contacts. Very often the connection strips are sufficient to rigidly support the busses, but in some cases it becomes necessary to provide insulated supports for carrying them. Copper bars, flat or round, are now practically universal on low-potential boards. Owing to the greater ease in making attachments and in adding capacity the flat bar is to be preferred, and a thickness of ⅛″, ¼″, and ½″, with width according to the current carrying capacity required, is convenient. The size of copper bus-bars and connection strips is usually figured on the basis of 1000 amperes per square inch of cross-section. By properly laminating the bars, it is safe to use this basis even for very heavy current. Contact surface should be figured anywhere from 100 to 200 amperes per square inch, according to the method of clamping, bolting, or soldering. In clamping or bolting, steel bolts should be used.

Herrick gives the following table as embodying the current practice for central stations, based upon a load factor not exceeding 50%. If figuring on a 100% load factor, the following amperes must be cut in half : —

COPPER BAR DATA.

From "Modern Switchboards," by A. B. Herrick.

Dimensions.	Amps.	Cir. Mils.	Sq. Mils.	Ohms per Foot.	Weight. per Foot.
1 × ¼″	433	318,310	250,000	.0000336	.97
1¼ × ¼″	530	397,290	312,000	.0000269	1.21
1½ × ¼″	626	477,465	375,000	.0000223	1.45
1¾ × ¼″	725	556,400	437,000	.0000192	1.70
1¼ × ⅜″	676	596,830	468,750	.0000179	1.82
1½ × ⅜″	798	716,200	562,500	.0000149	2.18
1¾ × ⅜″	916	835,600	656,250	.0000128	2.54
2 × ⅜″	1035	954,930	750,000	.0000112	2.92
2¼ × ⅜″	1154	1,074,300	843,750	.00000995	3.27
2 × ½″	1222	1,273,240	1,000,000	.00000840	3.89
2½ × ½″	1500	1,591,550	1,250,000	.00000672	4.86
2½ × ⅝″	1715	1,989,440	1,562,500	.00000537	6.07
0000 B. & S.	257	211,600		.0000505	.64
½″ round	305	250,000		.0000428	.76
⅝″ round	426	390,625		.0000273	1.18
¾″ round	560	562,500		.0000190	1.71
1″ round	861	1,000,000		.0000107	3.05

For the sake of securing the best conductivity, as far as possible, all switchboard connections should be worked out of rolled copper ; but it is occasionally necessary to use copper or brass castings, although their use should be avoided as far as possible, as the conductivity is always low, varying from 12% to 60% according to mixture. Where necessary to use castings, they should be made of new metal only, and care should be taken to insist upon a standard of conductivity in each piece if it is to be used where such a condition counts. A conductivity of 50% may be considered high and sufficient.

The following table from "Modern Switchboards," by A. B. Herrick, gives percentages of mixtures with resulting conductivity as compared with 100% copper: —

% Copper.	% Zinc.	Conductivity.	% Copper.	% Tin.	Conductivity.
98.44	1.56	46.88	98.59	1.41	62.46
94.49	5.51	33.32	93.98	6.02	19.68
88.89	11.11	25.50	90.30	9.70	12.19
86.67	13.33	30.90	89.70	10.30	10.21
82.54	17.50	29.20	88.39	11.61	12.10
75.00	25.00	22.08	87.65	12.35	10.15
73.30	36.70	22.27	85.09	14.91	8.82
67.74	32.26	25.40	16.40	83.60	12.76
	100.00	27.39		100.00	11.45

All minor connections to bus-bars such as switch leads, feeder ends, or in fact any attachments whatsoever, whether bolted to, clamped against, or soldered, should have ample surface contact, not less than ten (10) times (and twenty (20) times is better), the cross-section of the smaller of the two conductors connected, and where the sub-connection is of round-section it should be cup-soldered or "sweated" into a flat lug having the proper amount of surface contact for bolting or clamping to the bus-bar.

Cup-soldered conductors should enter the socket from two to three diameters. While all permanent joints of this nature should be soldered, it is sometimes necessary to make joints that can be easily disconnected, in which case the old-style socket with binding screws may be used, but the conductor should be entered from four (4) to ten (10) diameters to make a secure connection.

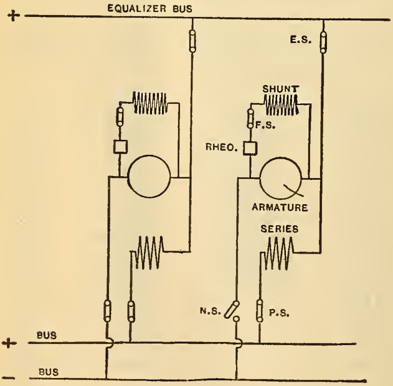


FIG. 4. Excitation of Generators.

BUS EXCITED DYNAMOS.

The diagram (Fig. 4) and text on a method of exciting dynamos from the bus-bars, in starting, was published by W. B. Potter, in the "Electrical Engineer." Besides being a very simple method of bus-connecting for excitation, if the equalizing switch, E.S., and positive switch, P.S., are left closed all the time, which can be done without harm excepting when some repairs or changes may be wanted in the dynamo, all equalizing connections are left in circuit all the time, and any dynamo that may be

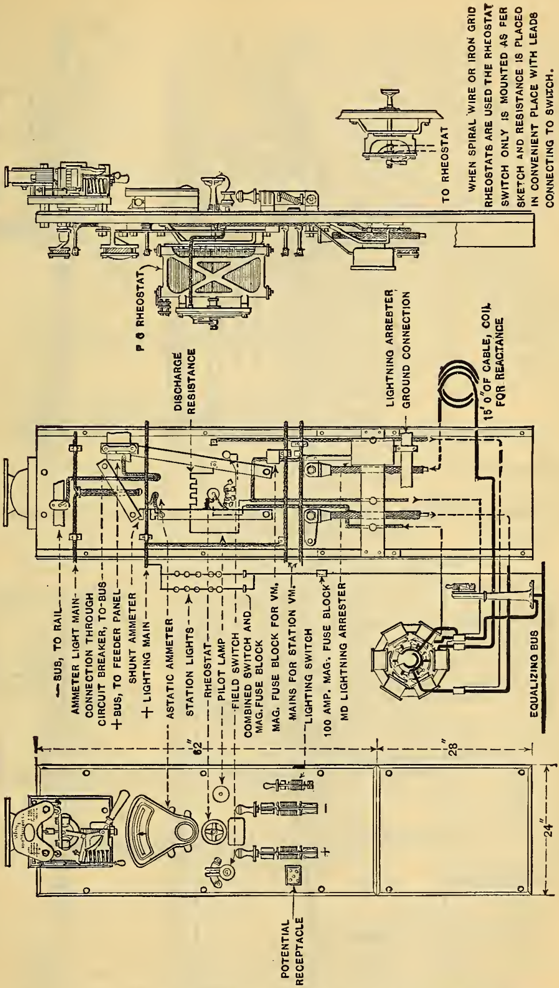


FIG. 5. Connections of Generator Panels for Direct Current. 300–1800 Amp. G. E. Co.

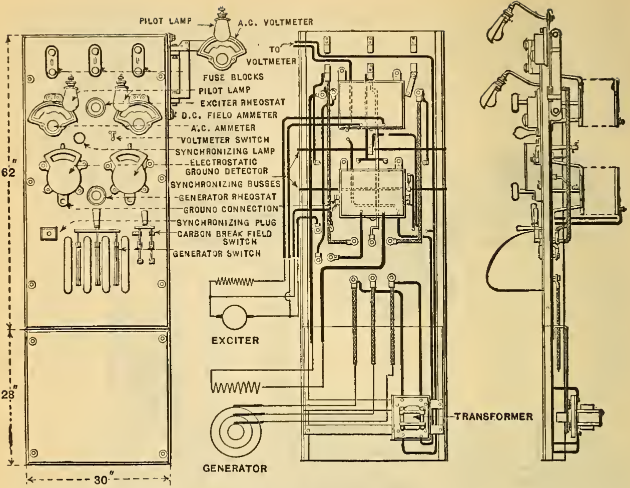


FIG. 6. Switchboard Panel for One Three-phase Alternating Current Generator, to 2500 volts. G. E. Co.

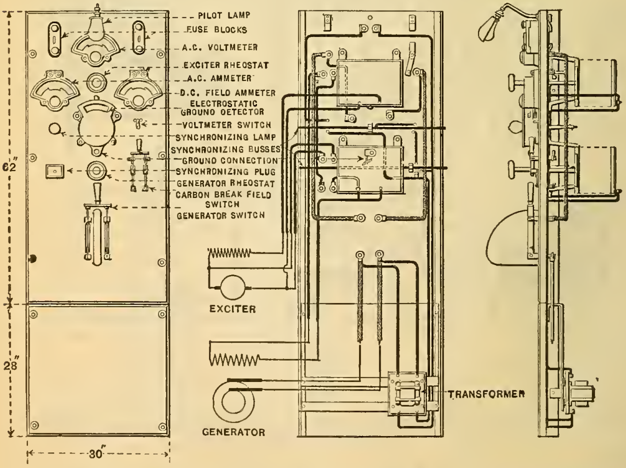


FIG. 7. Switchboard Panel for One Single-phase Alternating Current Generator, to 2500 volts. G. E. Co.

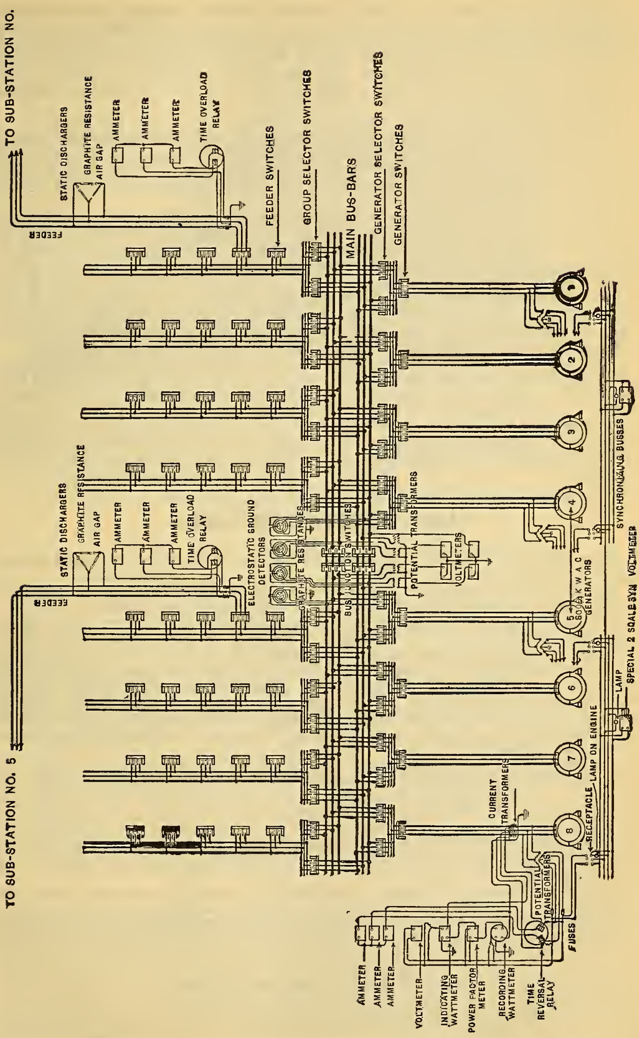


FIG. 8. Diagram of connections for switchboard of main power station Manhattan Railway Co., L. B. Stillwell, Cons. Engr.

running will then take its proper amount of current through its series coil, and will, therefore, compound more nearly as it was designed to do, than if all the load is on the series coil of the running dynamo. If greater simplicity is desired, the equalizing switch, E.S., and positive switch, P.S., can be one double-pole switch, and the negative switch, N.S., a single pole. Leave the double-pole switch closed all the time, and throw the machine in and out with N.S.

Mr. Potter says : —

By reference to the accompanying diagram, it will be seen that by closing the positive switch, P.S. (the equalizer switch, E.S., being closed), the series coil of the generator to be started is connected in parallel with the series coils of generators in operation, thus separately exciting the field of the generator to be started.

The field switch, F.S., being closed, the voltage is then adjusted by the field resistance to correspond with that of the bus, and the more easily so, as by this method there is secured a variation of voltage corresponding to that due to changes of load on the over-compounded generators in operation. This method also insures the polarity being at all times the same as the other generators. On closing the negative switch, N.S., and reducing the resistance in the shunt field, the generator takes up its load smoothly and without the violent fluctuation usually caused by connecting the series coils after the full potential has been developed by the shunt field only.

It is not necessary to show here all the standard forms of switchboard, or the appliances that are used with them, as changes take place so often that any article pictured or described is apt to be out of date in a very short time. A few diagrams of standard arrangements that are not subject to much change are shown. I have included the diagram of general arrangement of switchboard connections of the great plant of the Manhattan Elevated Railway of New York, as being very simple and of considerable interest.

ARC SWITCHBOARDS.

This line of switchboards represents an entirely different construction from that of ordinary switchboards.

Extra flexibility makes it desirable, and small currents make it possible, to use plug connections instead of the ordinary type of switches.

The function of arc switchboards is to enable the transfer of one or more arc light circuits to and from any of a number of generators. This transferring is sometimes accomplished by means of a pair of plugs connected with insulated flexible cable ; sometimes by plugs without cables, which bridge two contacts back of the board, or by a combination of cable plugs and plugs without cables. The type using plugs without cables is preferable, because danger is eliminated, which would otherwise be possible to attendant, due to contact with exposed or abraded cables carrying high-potential current.

The accompanying illustration (Fig. 9) shows an arc switchboard of the General Electric panel type, arranged for three machines and three circuits. The vertical rows of sockets are lettered and the horizontal numbered. The ends of the vertical bars are connected to the machines and circuits. Each of the bars is broken in three places, and the machine may be connected to its circuit by plugging across these breaks, thus making the bar continuous; by removing any pair of plugs the machine may be disconnected.

C11, E11 and G11 are ammeter jacks, and are used in connection with two plugs connected with a twin cable, for placing an ammeter in the circuit. The six horizontal bars are for the purpose of transferring a machine or a feeder to some circuit other than its own. Each horizontal bar is provided, at one side of the panel, with a socket (A3, A4, A5, A7, A8, and A9) by means of which it can be connected with the horizontal bar on the adjoining panel. All ordinary combinations can be made by means of the bars and plugs ; but cable plugs are provided with each panel, so that when necessary, machines and feeders can be transferred without the use of the bar. These plugs and cables are intended for use only in case of an emergency.

To run machine No. 1 on feeder No. 1, insert plugs in B10, C10, B6, C6, B2, and C2. To shut down machine No. 2, and run feeders Nos. 1 and 2 in series on machine No. 1, insert a plug at C5, D5, C7, and D7, and remove plugs at C6 and D6; this leaves two circuits and two machines in series.

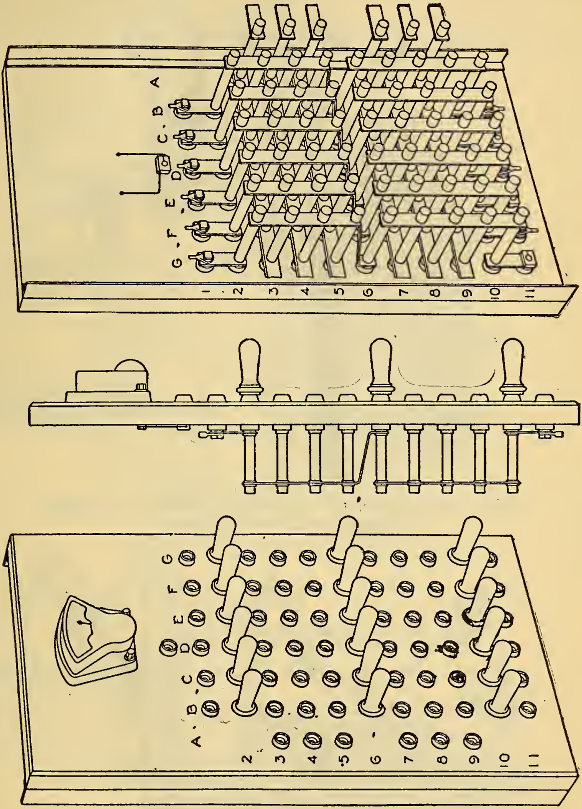


FIG. 9.

Short circuit machine No. 2 by inserting the plug at E7. Cut out machine No. 2 by removing the plug at D10 and E10. Take out plug at D7.

SWITCHING DEVICES.

Switching devices in connection with switchboards can be divided generally into two classes, viz.:

1. Switches.
2. Automatic circuit breakers.

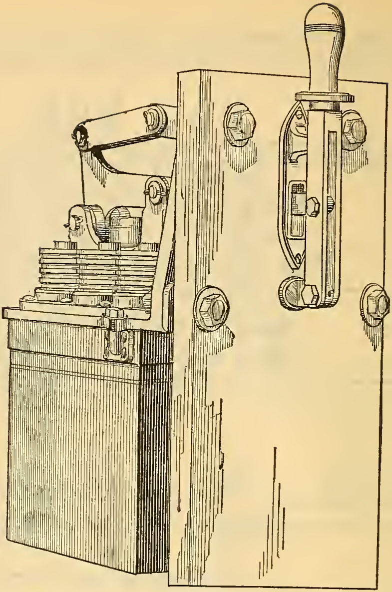


FIG. 10. Gen. Elec. Oil Break Switch, 5000 volts, 300 amps., Opened and Closed by Hand.

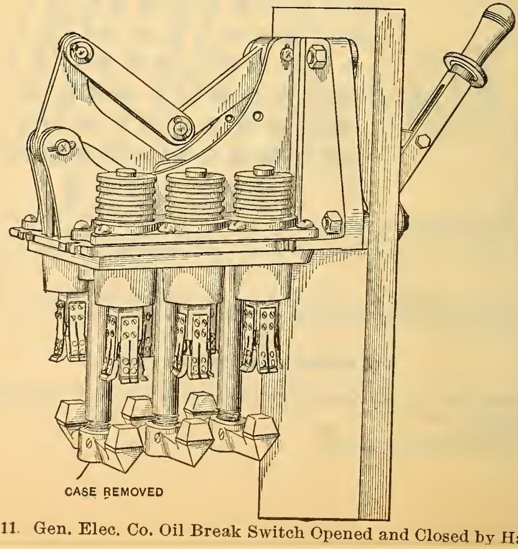


FIG. 11. Gen. Elec. Co. Oil Break Switch Opened and Closed by Hand.

Switches for low voltage and small current are of the same general form, though differing in details. In the main they consist of a blade of copper hinged at one end between two parallel clips, the other end of blade sliding into and out of two parallel clips. The clips are joined to copper or brass blocks to which the circuit is connected.

There seems to be little uniformity among manufacturers regarding the cross-section of metal and surface of contact to be used. Perhaps a cross-section of metal of one square inch per 1000 amperes of current capacity is as near to the common practice as any, and a contact surface of at least one inch per 100 amperes or ten times the cross-section of metal is also common practice, but will depend somewhat on the pressure between surfaces.

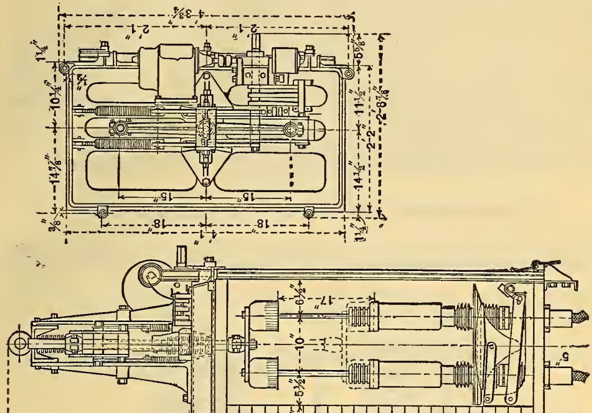


Fig. 12. Type of High Potential Oil Switch Adopted by Manhattan Ry. Co. and Niagara Falls Power Co. G. E. Co.

Auxiliary breaks are demanded by the National Code for currents exceeding 100 amperes at 300 volts, and "quick-break" switches are now quite common for pressure as low as 110 volts, although not in any way more necessary for that pressure than should be "quick-make" switches.

The rules on switch design issued by the National Code cover the requirements well, and they must be followed in order to obtain or retain low insurance rates; all switches must meet the requirements. See index for "National Code," and refer to section on "SWITCHES."

Blades, jaws, and contacts should be so constructed as to give an even and uniform pressure all over the surface, and no part of the surfaces in contact should cut, grind, or bind when the blade is moved. The workmanship should be such that the blade can be moved with a perfectly uniform motion and pressure, and the clips and jaws should be retained so perfectly in line that the blades will enter without the slightest stoppage.

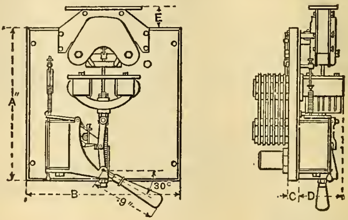
For pressures above 1000 volts, practice varies among the different manufacturers. The General Electric Company makes a switch in which the circuit is ruptured in oil. In the type designed by the Westinghouse Co. dependence is placed upon the arc being ruptured in open air by drawing it through a wide break. The Stanlay Co. has devised a switch which is designed to rupture the arc by means of a sliding shutter, which intercepts the arc when the contact is broken.

For non-inductive loads of small power and up to 2500 volts, any good form of quick-break switch can be satisfactorily used.

Two types of high-potential switches are shown on pages 594 and 595.

AUTOMATIC CIRCUIT BREAKERS.

Automatic circuit breakers are devices which have as an integral part an automatic trip which opens the circuit when the flow of current exceeds a predetermined limit. Many types are now made, some with carbon secondary breaks; but a very successful type is one early introduced by the G. E. Co., with the magnetic blow-out principle applied to extinguish the arc. Illustrations follow of one of the main sizes and a table for the various adjustments of the same.

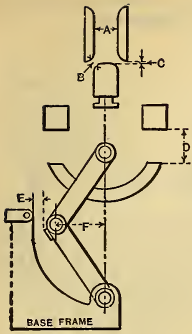


AMPERES	A	B	C	D	E
1800-3000	24	28	2	6¾	1⅝
2000-6000	28	28	2	7⅞	3¾
2000-10000	30	28	2½	8⅜	4⅛

FIG. 13. One Form of Circuit Breaker. 1800 to 10000 Amperes. G. E. Co.

For mean high potential circuits the Westinghouse Electric & Mfg. Co. has devised the instrument shown in the following cuts and diagrams (Figs. 15 and 16): —

The circuit-breaker consists of two hardwood poles, one being longer than the other, mounted upon a marble base, to which are secured the terminals to which the main leads or wires are connected. The poles are connected by a hinge, so that their extremities are in line at the upper end. On the upper end of each pole is mounted a copper sleeve supporting a round carbon contact block with a hole through its center. The longer pole is provided with spring jaws or clips so that it may be quickly and easily attached to, or detached from, the terminals on the marble base. The short pole has a flexible wire running through its interior; this wire is connected to the copper sleeve at the upper end of the short pole and to the lower clip terminal on the long pole. The sleeve at the upper end of the long pole is



Amperes.	Wide Open.					Closed.	When Sec. Contacts Touch.
	A	B	C	D	E	F	D
150– 2000	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{32}$	$\frac{5}{8}$ to $\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{8}$	$\frac{7}{16}$ to $\frac{1}{2}$
1800– 3000	$\frac{5}{8}$	$\frac{5}{16}$	$\frac{1}{4}$	$1\frac{1}{2}$		$\frac{3}{8}$ to $\frac{1}{2}$	1
2000– 6000	$\frac{5}{8}$	$\frac{5}{16}$	$\frac{1}{4}$	$1\frac{1}{2}$		$\frac{3}{8}$ to $\frac{1}{2}$	1
2000–10000	$\frac{5}{8}$	$\frac{5}{16}$	$\frac{1}{4}$	$1\frac{1}{2}$		$\frac{3}{8}$ to $\frac{1}{2}$	1

NOTE — B is dimension when parts are new.
First, Adjust E.
Second, Adjust Brush Tension.
Third, Adjust C.

FIG. 14. Dimensions for Adjusting MK Circuit Breakers.

connected to the upper clip terminal. Thus, these connections practically make the sleeves at the upper ends of the two poles the terminals of the apparatus.

The poles being removed from the base, a wire is inserted through the hole in the carbon tip at the upper end of the short pole, and secured to the

High Potential Circuit Breakers Made by Westinghouse Electric and Manufacturing Company.

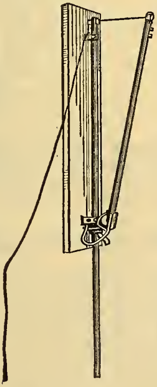


FIG. 15. 6000 to 15000 Volts.

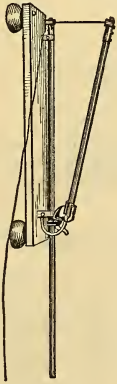
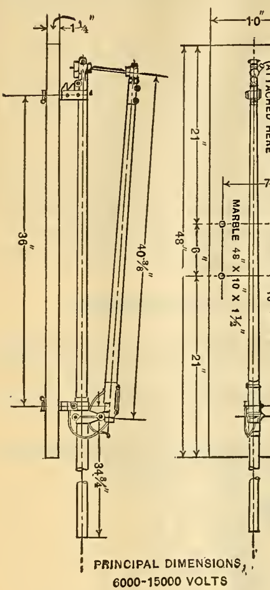


FIG. 16. 20000 to 40000 Volts.

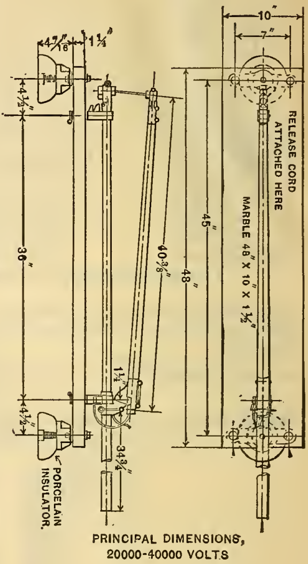
copper sleeve by a screw and washer. The other end of the fuse is passed through the carbon tip on the long pole, and secured to the copper sleeve by a cam-shaped lock. The length of the fuse should be from 6 to 10 inches.

The poles, after being fused, are placed in position by taking hold of the lower end of the long pole. When the fuse blows, the short pole is released by the action of the spring at the lower end, and falls away from the station-

High Potential Circuit Breakers, Made by Westinghouse Electric and Manufacturing Company.



FIGS. 17 and 18.



FIGS. 19 and 20.

ary pole, thus making a very long break. The lock cam has a long string attached to it, by means of which the fuse can be released if desired, thus causing the short pole to drop in the same manner as when the fuse blows. This feature permits the device to be used as a switch.

REVERSE CURRENT CIRCUIT BREAKERS.

For large installations of electrical transmission, where it is highly important that continuity of service shall be maintained, it is good engineering to use two separate lines of conductors. In such cases it is usual to keep both circuits connected so that in case of trouble on one of them its fuses or circuit breaking devices will cut it out, leaving the clear line to carry the load. An examination of the following diagram will explain the utility of the *reverse current circuit breaker*. Let a and a_1 be circuit breakers at the dynamo end of the two lines, and b and b_1 reverse current circuit breakers at the far end of the same. Should a short circuit occur as at x on the main line, it is plain that current will rush in both directions from the dynamo, by way of the main line and by way of the auxiliary line and the far end of the main line, in which portion the *direction* of the current will be the reverse of what it was ordinarily. Under this condition it is obvious that all the circuit opening devices would operate, and the auxiliary line would be of no effect in maintaining continuity of current. Now, if circuit breakers of such a design that they will open on a *reversal* of the *direction*

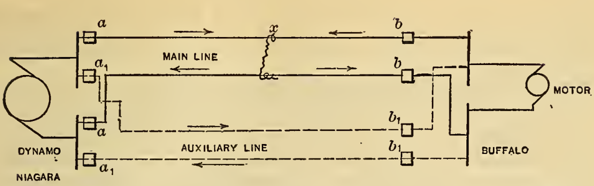


FIG. 21. Diagram Showing Use of Reverse Current Circuit Breaker.

of the current through them, be placed at the far end, as at b and b_1 then the main circuit breakers, a, a, will open, as will also the reverse current circuit breakers, b, b, thus leaving the auxiliary line intact. Of course a short circuit on the auxiliary line will operate in a similar manner.

The following diagram shows the connections of the reverse current circuit breaker at Buffalo as designed by the General Electric Co. An

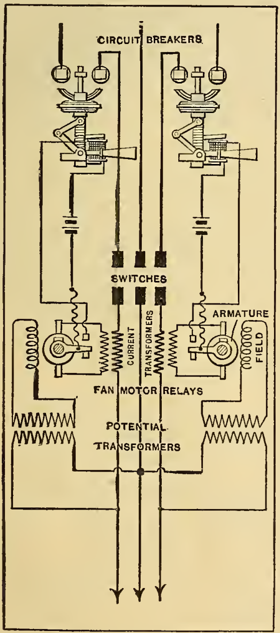


FIG. 22. The Circuits of a Reverse Current Circuit Breaker Set Showing How a Direct Current Motor is Used with Alternating Currents to Distinguish between Power Passing in One Direction and Power Passing in the Other Direction in the Line.

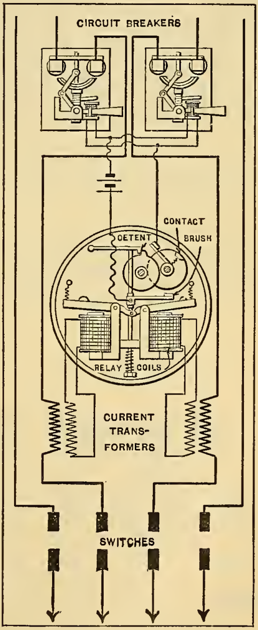


FIG. 23. The Circuits of a Time Element Relay Circuit-breaking Set.

ordinary fan motor is introduced by means of a transformer into the line, and acts to operate a relay on the shunted circuit breaker, a reversal of the current reversing the motion (or pull) of the fan motor armature, and closes the relay contacts as shown.

Time Element for Circuit Breakers. — Where circuits are loaded with large synchronous or induction motors and other devices liable to produce short circuits on the system when out of step or started too suddenly, it is not only necessary to protect the local or feeder circuit with circuit breakers, but in order to prevent the operation of all the protecting devices between the one in trouble and the dynamo itself, it is found advisable to introduce a time element or *adjustable delay* on all the main circuit breakers. This device must allow the circuit breakers farthest from the station to be adjusted so they will open first, and all the intermediate devices must have variable or graduated adjustments, say for opening after three seconds, and the main circuit breaker at the power house itself will open last of all, say in five seconds.

Mr. L. B. Stillwell devised an instrument for this purpose, and it has been widely adopted. Both the Westinghouse Co. and General Electric Co. have adapted this time element device to the circuit breakers in use at Niagara Falls, and cut No. 23 shows the arrangement by General Electric Co. diagramatically. The instrument is composed of a simple clock movement, the wheels of which are prevented from turning by a pawl which may be lifted out of place by either one of two relay magnets connected by transformer in the main line. The lifting of the pawl allows the clock wheels to revolve and close a relay circuit connected with the circuit breakers which promptly open. The clock movement can be adjusted to close the local circuit in any desired time; and in case the clock is started on a short circuit, which is off before the lapsing of the time period, the pawl drops, and the movement returns to its original position.

LIGHTNING ARRESTERS.

LIGHTNING ARRESTERS IN GENERAL.

(From pamphlet by Westinghouse Electric & Manufacturing Company.)

The Function of Lightning Arresters.—The function of a lightning arrester is two-fold. It should provide a path to earth offering the least possible resistance to the passage of static discharges, and it should avoid interruption of the service. The latter, though a negative function, is one of primary importance.

In the early days of electrical industry it was found that lightning discharges from overhead wires would pass more readily to ground over a small air gap than through coils or even long lengths of straight wire.

Numerous arresters based upon this principle were constructed and placed in practical use. The simplest form of these is the old saw-tooth spark-gap arrester which is still used for protecting telegraph and telephone lines. But a great difficulty arose with gap arresters when used on electric lighting, railway or power circuits, owing to the fact that the dynamo current followed the lightning discharge, establishing thereby a short circuit which would melt the dynamo fuses and thus interrupt the service.

With the object of overcoming this trouble various arresters were devised that would automatically interrupt the dynamo short circuit. At first this interruption was accomplished by simply placing fuses in the lightning arrester circuit, thus making it necessary to renew the fuses after each discharge. This method was obviously unsatisfactory. Arresters were then devised which would automatically interrupt the arc and then immediately adjust themselves for another discharge by means of moving parts; the latter, however, proved to be the cause of considerable annoyance, and experience demonstrated that the arc rupturing arresters were uncertain in action and hence unreliable.

Recognizing the importance of the problem the Westinghouse Electric & Manufacturing Company undertook a series of extensive theoretical and practical investigations, with the object of devising arresters which would offer a low resistance path to ground for disruptive discharges, and at the same time operate automatically and repeatedly without moving parts and without interrupting the service.

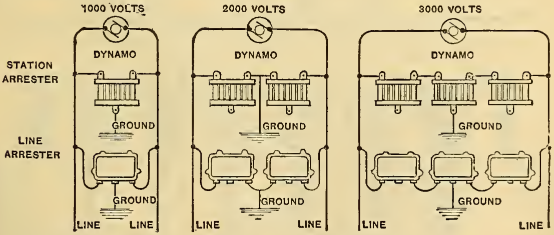


FIG. 1. Diagram Showing Electrical Connections for A. C. Lightning Arresters.

The results of these investigations, which extended over a period of several years, are embodied in the Wurts Non-arcing Lightning Arresters.

With a non-arcing arrester the dynamo current does not continue to follow the discharge; the apparatus is not left unprotected for an instant; the instrument does not deteriorate; it is entirely automatic in action, and will handle frequent and persistent discharges with perfect facility.

For systems of distribution, with their various motors, converters, and other appliances, a liberal allowance of line arresters judiciously distributed over the lines is essential for securing adequate protection. Much, however, depends upon the local conditions, such as the character of the soil with reference to the ground connections, and severity of lightning disturbances, the grade of insulation to be protected, the voltage of the circuit and the surroundings with reference to telegraph and telephone wires.

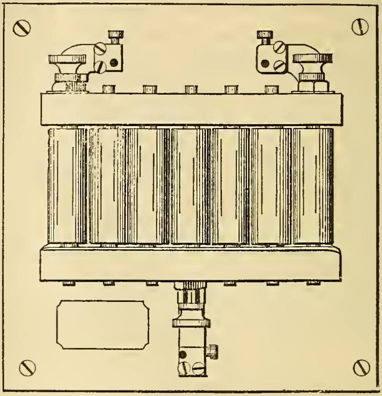


FIG. 2. Double-Pole Non-Arcing Metal Lightning Arrester. Type "A." (For Station Use.)

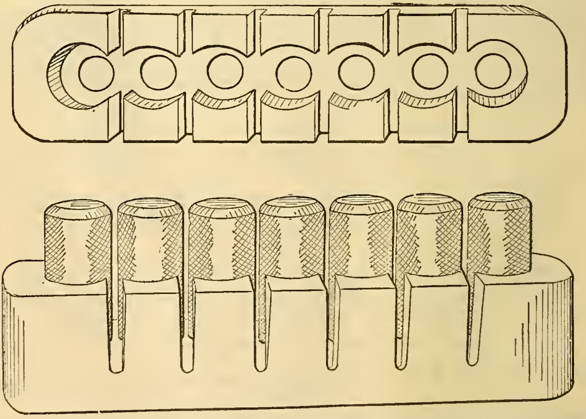


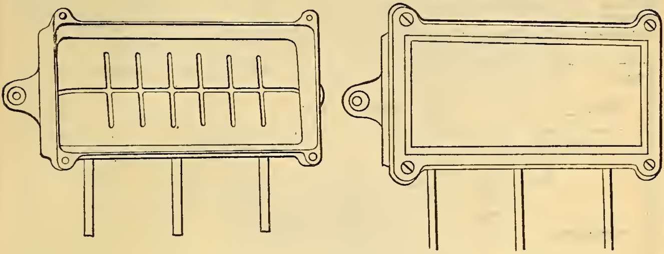
FIG. 3. Unit Lightning Arrester, Type "C," Showing Cylinders in Place.

THE NON-ARCING METAL LIGHTNING ARRESTER.

The non-arcing metal lightning arrester for alternating current circuits is based upon the discovery made by Mr. A. J. Wurts that an alternating current arc cannot be maintained over a short air-gap when the electrodes consist of certain metals and alloys thereof. Types "A" and "C" arresters, described below, are of the non-arcing metal type.

The Type "A" Arrester.—The construction of this arrester can be best understood by reference to Fig. 2.

It will be noted that there are seven independent cylinders of non-arcing metal placed side by side and separated by air-gaps. The cylinders, which are mounted on a marble base, are knurled, thus presenting hundreds of confronting points for the discharge. The dynamo terminals are connected to the end cylinders, and the middle cylinder is connected to the ground. The arrester is, therefore, double pole, that is, one arrester protects both sides of the circuit. When the lines become statically charged the discharge spark passes across between the cylinders from the line terminals to the ground. The non-arcing metal will not sustain an arc or become fused by it; hence with an arrester constructed of this material all possibility of vicious arcing and short circuits is avoided. There are no moving parts, no coils to impede the passage of the lightning discharge, and in fact nothing that requires either adjustment or inspection. These arresters are made in units for 1000 volts; for 2000 volts two units are connected in series, and for 3000 volts three are connected in series, all as indicated in the diagram, Fig. 7.



FIGS. 4, 5. Double-Pole Non-Arcing Metal Line Arrester—Type "C."

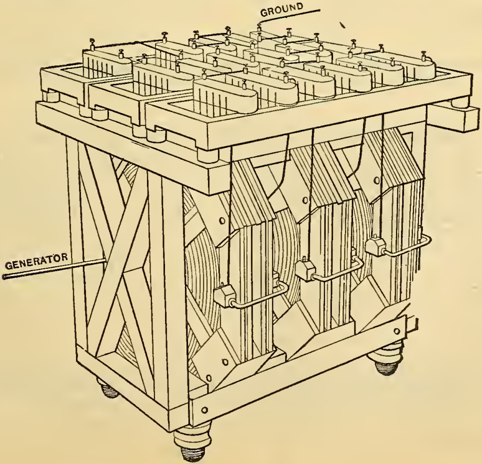


FIG. 6. Lightning Arrester for 15,000 Volt Circuit—Type "R."

The Type "C" Arrester.—This is similar to type "A," but instead of being mounted on marble it is inclosed in a weather-proof iron case for line use. The cylinders are placed in porcelain holders, as shown in Figs. 3 and 4. The arrester complete in the iron case is shown in Fig. 5. The method of connecting type "C" arresters to circuits of different voltage is also shown in Fig. 1.

The Type "R" Arrester.—A standard form of arresters for protecting alternating current high potential power transmission circuits is shown in Fig. 6. A diagram illustrating the method of connecting the arresters and choke coils for various voltages is given in Fig. 7.

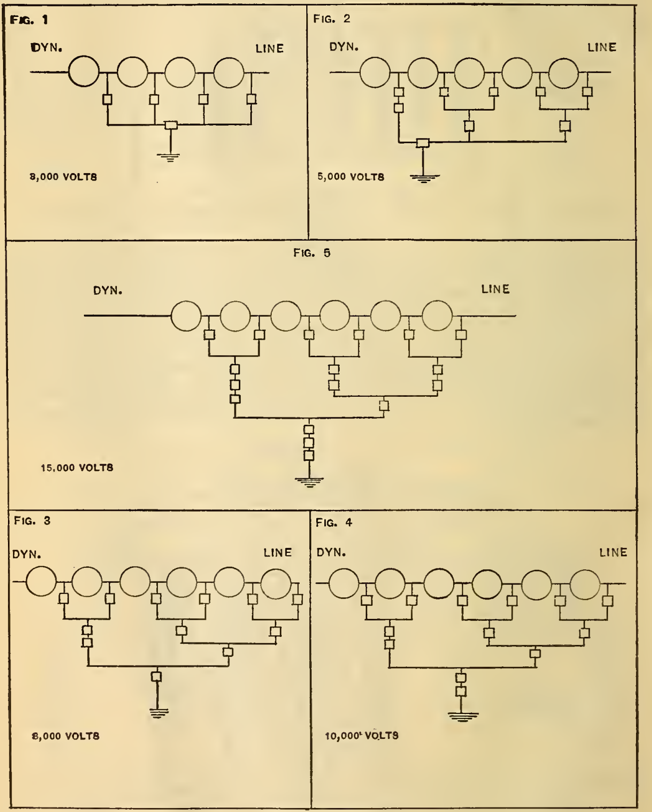


FIG. 7. Diagram Showing Pyramidal Form of Connecting Lightning Arresters and Choke Coils for Various Voltages.

EXPLANATORY NOTE.—Each circle represents a choke coil. Each rectangle represents one unit (type "C") non-arcing metal lightning arrester.

Sub-Fig. 1, four coils in series and one and one-half unit arresters between line and ground. Sub-Fig. 2, five coils in series and two and one-half unit arresters between line and ground. Sub-Fig. 3, six coils in series and four unit arresters between line and ground. Sub-Fig. 4, six coils in series and five unit arresters between line and ground. Sub-Fig. 5, six coils in series and seven unit arresters between line and ground.

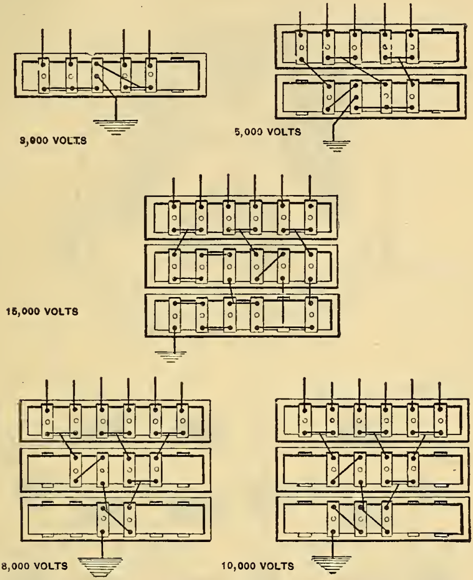


FIG. 8. Plan View of Lightning Arrester Racks, Showing Unit Lightning Arresters and the Connections for Each Voltage.

CHOKE COILS FOR A. C. CIRCUITS.

A lightning discharge is of an oscillatory character and possesses the property of self-induction ; it consequently passes with difficulty through coils of wire. Moreover, the frequency of oscillation of a lightning discharge being much greater than that of commercial alternating currents, a coil can readily be constructed which will offer a relatively high resistance to the passage of lightning and at the same time allow free passage to all ordinary electric currents.

Any coil will afford a certain amount of impedance to a disruptive discharge. Experience has shown, however, that there is one form which offers at once the maximum impedance to the discharge with the minimum resistance to the generator current.

Choke coils of this type connected in the circuit, when used in connection with non-arcing lightning arresters, offer a very reliable means of protecting well-insulated apparatus against lightning. This arrangement is particularly suited for protecting station apparatus in power transmission systems. Coils can, however, be used to advantage on the line for the protection of the more expensive translating devices.

Tests made under actual working conditions indicate that for ordinary commercial voltages effective protection is obtained with four choke coils in series in each wire, with four lightning arresters intervening, as shown in Fig. 10. This diagram also shows the method of connecting the coils and arresters to one end of a three-wire transmission system.

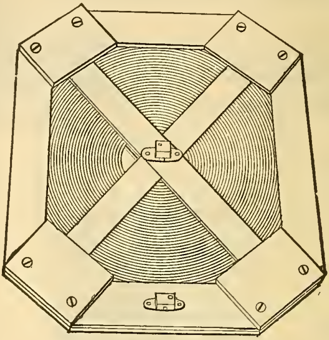


FIG. 9. A. C. Choke Coil.

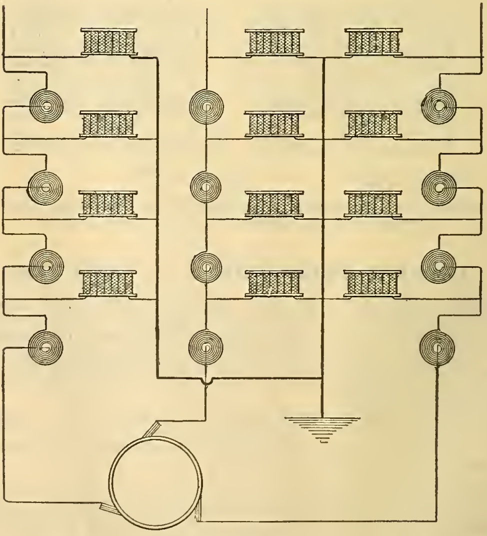


FIG. 10. One end of a 2000-Volt 3-Wire Power Transmission System Showing Bank of Choke Coils and Lightning Arresters.

ARRESTERS FOR D. C. CIRCUITS.

The non-arcing metal arresters described above are not suitable for use on D. C. circuits, but a non-arcing D. C. arrester has been devised by Mr. A. J. Wurts.

The principles upon which this arrester is designed are based upon the following facts: —

First. A discharge will pass over a non-conducting surface, such as glass or wood, more readily than through an equal air-gap.

Second. The discharge will take place still more readily if a pencil or carbon mark be drawn over the non-conducting surface.

Third. In order to maintain a dynamo arc, fumes or vapors of the electrodes must be present; consequently if means are provided to prevent the formation of these vapors there will be no arc.

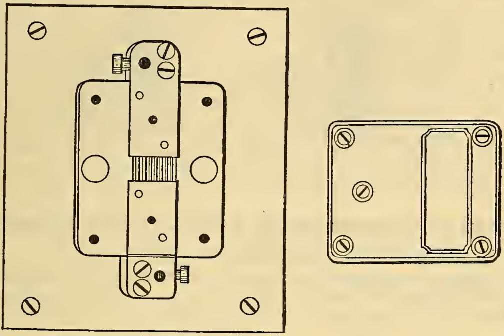


FIG. 11. Non-Arcing Railway Lightning Arrester, Type "K."
(For Station Use.)

The Type "K" Arrester. — The illustration, Fig. 11, shows the type "K" arrester for station use on D. C. circuits up to 700 volts. The instrument is single pole, and consists of two metal electrodes mounted upon a lignum-vitæ block, flush with its surface. Charred or carbonized grooves provide a ready path for the discharge. A second lignum-vitæ block fits closely upon the first block, completely covering the grooves and electrodes. Disruptive discharges will pass readily between the electrodes over the charred grooves, which act simply as an electrical crack through the air, providing an easy path.

The resistance between the electrodes is more than 50,000 ohms, so that there is, of course, no current leakage, but it should not be understood that the lightning discharge passes through this high resistance — it leaps over the surface of the charred grooves from one electrode to the other exactly as it would if there were but a simple air-gap. The presence of the charred grooves simply makes the path easier.

There being no room for vapor between the two tightly fitting blocks, no arc can be formed, hence the arrester is non-arcing.

GROUND CONNECTIONS FOR A. C. AND D. C. ARRESTERS.

Too much importance cannot be attached to the making of proper connections from the arrester to ground, which should be as short and straight as possible.

It is obvious that a poor ground connection will render inefficient every effort made with choke coils and lightning arresters to drive the static electricity into the earth. It is, therefore, important that we not only should understand how to construct a good ground connection, but also thoroughly appreciate the necessity of avoiding unfavorable natural conditions.

A good ground connection for a bank of station lightning arresters may be made in the following manner: First, dig a hole six feet square directly under the arrester until permanently damp earth has been reached; second, cover the bottom of this hole with two feet of crushed coke or charcoal (about pea size); third, over this lay 25 square feet of No. 16 tinned copper plate; fourth, solder the ground wire, preferably No. 0 copper, securely across the entire surface of the ground plate; fifth, cover the ground plate with two feet of crushed coke or charcoal; and sixth, fill in the hole with earth, using running water to settle.

The above method of making a ground connection is simple, and has been found to give excellent results, and yet, if not made in proper soil, it would prove of little value. Where a mountain stream is conveniently near, it is not uncommon to throw the ground plate into the bed of the stream. This, however, makes a poor ground connection, owing to the high resistance of the pure water and the rocky bottom of the stream. Clay, even when wet, rock sand, gravel, dry earth and pure water are not suitable materials in which to bury the ground plate of a bank of lightning arresters. Rich soil is the best. It is therefore advisable before installing a bank of choke coils and lightning arresters to select the best possible site for the lightning arrester installation, with reference to a good ground connection. This may often be at some little distance from the station, in which case it is of course necessary to construct a lightning arrester house. Where permanent dampness cannot be reached, it is recommended that water be supplied to the ground through a pipe from some convenient source.

LIGHTNING ARRESTERS FOR DIRECT CURRENT.

(From pamphlet by General Electric Company.)

Some years ago Prof. Elihu Thomson devised a lightning arrester based on the principle that an electric arc may be repelled by a magnetic field. In this device, the air-gap, across which the lightning discharges to reach

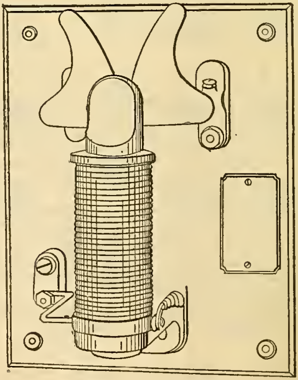


FIG. 12. Type "A" Arc Station Arrester.

the ground, is placed in the field of a strong electro-magnet. When the generator current attempts to follow the high potential discharge, it is instantly repelled to a position on the diverging contacts where it cannot be maintained by the generator.

The magnetic blow-out principle has been employed in the construction of a complete line of lightning arresters for all direct current installations, and in more than ten years of service magnetic blow-out arresters have always been effective in affording protection to electrical apparatus.

In designing lightning arresters for the protection of high-voltage alternating current circuits, however, different conditions have to be met, since high-voltage arcs are not readily extinguished by a magnetic blow-out. In a recently designed lightning arrester for alternating current circuits, metallic cylinders with large radiating surfaces are found to so lower the temperature of the arc that volatilization of the metal ceases and the arc is extinguished.

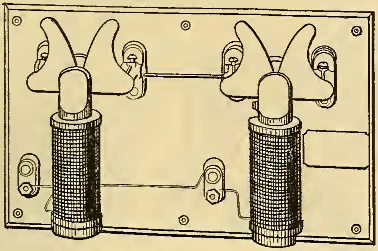


FIG. 13. Type "AA" Arc Station Arrester.

The variety of these lightning arresters provides for the protection of all forms of electrical apparatus and circuits.

The Type "A" Arrester is manufactured for the protection of arc lighting circuits, and is in extensive use throughout the world. Its construction includes a pair of diverging terminals mounted on a slate base with an electro-magnet connected in series with the line. The magnet windings are

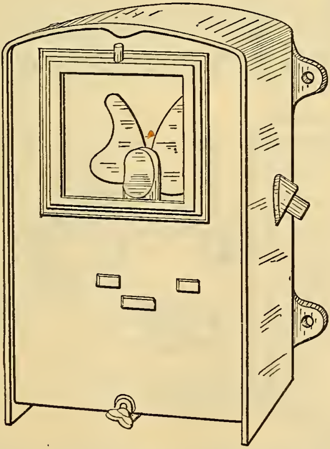


FIG. 14. Type "A," Form "C," Lightning Arrester, in Iron Box for Line Use

of low resistance, and therefore consume an inappreciable amount of energy with the small current used for arc lighting, although they are always in circuit.

The single Type "A" Arrester is suitable for circuits of any number of series arc lamps not exceeding seventy-five. For circuits of higher voltage, a double arrester known as the type "AA" is made by mounting two arresters on one base and connecting them in series. One arrester should be installed on each side of the circuit, as shown in the Diagram of Connections.

For use in places exposed to weather, the Type "A" Arrester is furnished inclosed in an iron case, and designated Type "A," Form "C."

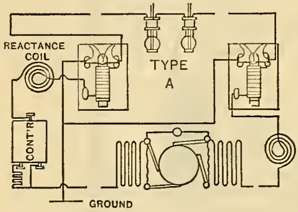


FIG. 15. Connections for Type "A" Arresters.

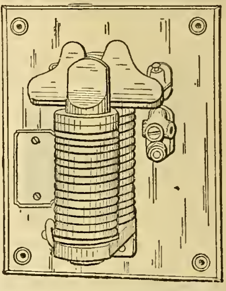


FIG. 16. Type "B" Incandescent Station Arrester 300 Volts or Less.

The construction of the Type "B" Arrester is similar to that of the Type "A," but its magnet windings are excited only when a discharge takes place across the air-gap. A supplementary gap is provided in the Type "B" Arrester, in shunt with the magnets, thus providing a relief for the coils from excessive static charge without affecting their action upon the main gap. The magnet coils, carrying current only momentarily, allow the same arrester to be used on circuits of large and small ampere capacity. The Type "B" can also be furnished with weatherproof case similar to that used with Type "A."

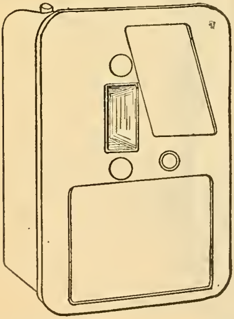


FIG. 17. Type "MD" for Direct Current Circuits up to 850 Volts.

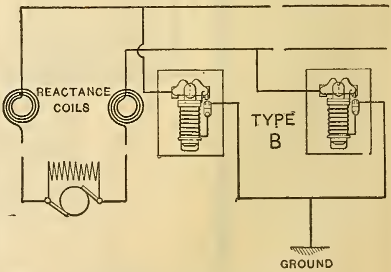


FIG. 18. Connections for Type "B" Arresters.

The Type "MD" Lightning Arrester has been designed for use on direct current circuits up to 850 volts. While similar to Type "M," Form "C" Arrester, it is considerably smaller, and is inclosed in a compact porcelain box measuring 7½ inches x 5 inches x 4⅛ inches. For street car and line use, the arrester is furnished in an additional box of iron or wood, as shown by Fig. 19.

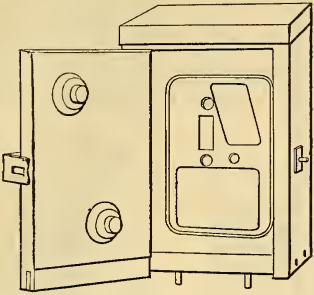


FIG. 19. "MD" Lightning Arrester in Wood Box.

This arrester has been adopted as standard for railway and all direct current 500-volt circuits. It has a short spark gap, a magnetic blow-out, and a non-inductive resistance.

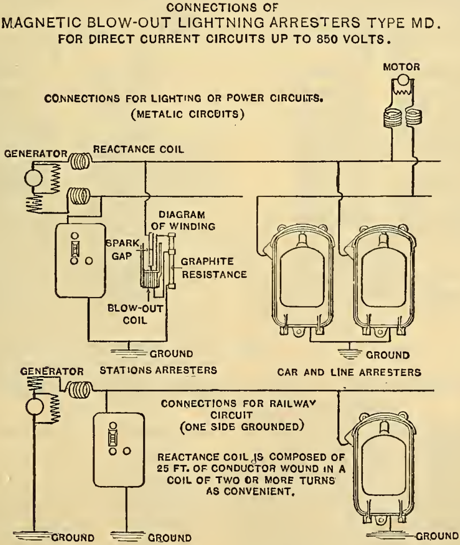
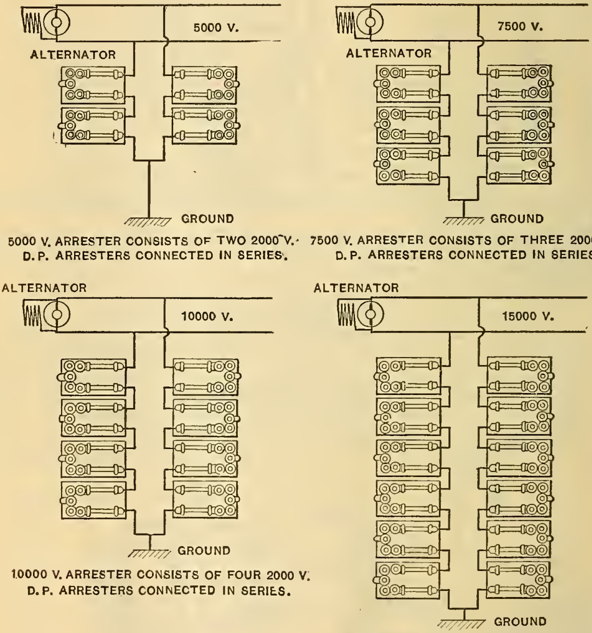


FIG. 20. Connections of Magnetic Blow-out Lightning Arresters, Type "MD" for Direct Current Circuits up to 850 Volts.

LIGHTNING ARRESTERS FOR ALTERNATING CURRENT.

The G. E. Alternating Current Arresters have been designed to operate properly with very small gap spaces. The arrester for 1000-volt circuits has two metal cylinders 2 inches in diameter and 2 inches long, separated by a spark gap of about $\frac{1}{32}$ inch. One cylinder is connected to the overhead line and the other cylinder to the ground, and a low non-inductive graphite resistance is placed in circuit. The large radiating surface of the metal cylinders combined with the effect of the non-inductive resistance prevents heating at the time the lightning discharge passes across the gap, and the formation of vapor which enables the current to maintain an arc is thus avoided.



5000 V. ARRESTER CONSISTS OF TWO 2000 V. D.P. ARRESTERS CONNECTED IN SERIES.

7500 V. ARRESTER CONSISTS OF THREE 2000 V. D.P. ARRESTERS CONNECTED IN SERIES.

10000 V. ARRESTER CONSISTS OF FOUR 2000 V. D.P. ARRESTERS CONNECTED IN SERIES.

15000 V. ARRESTER CONSISTS OF SIX 2000 V. D.P. ARRESTERS CONNECTED IN SERIES.

FIG. 21. Connections of Wirt or G. E. Alternating Current Short Gap Lightning Arresters, 5000 to 15,000 volts.

The arrester under normal action shows a small arc about as large as a pin-head between the cylinders.

The arrester for 2000-volt circuits is designed with two gaps of approximately $\frac{1}{32}$ inch each and a low non-inductive resistance.

The G. E. Arresters are now furnished by the General Electric Company for use on all alternating current circuits at practically any potential. For circuits above 2000 volts, the standard 2000-volt double-pole arrester has been adopted as a unit, and several of these are connected in series to give the necessary number of spark gaps.

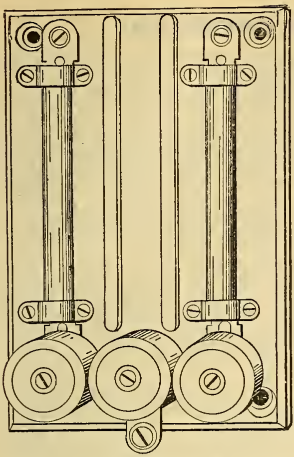


FIG. 22. G. E. Alternating Current Lightning Arresters.

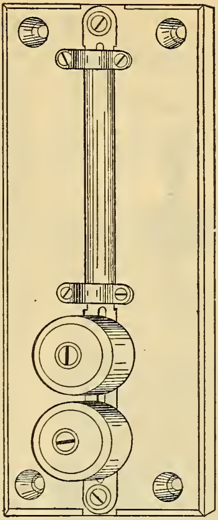
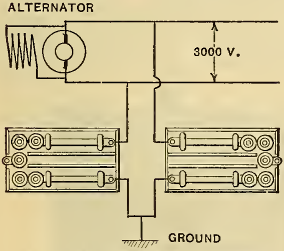


FIG. 23.



2000 V.D.P. ARRESTERS CONNECTED AS 3000 V.S.P. ARRESTERS.

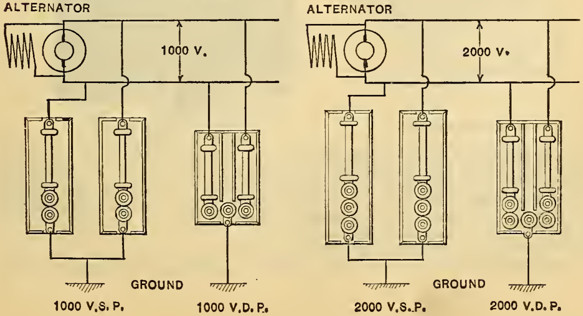


FIG. 24. Connections of Wirt or G. E. Alternating Current Short Gap Lightning Arresters, 1000 to 3000 Volts.

THE GARTON ARRESTER.

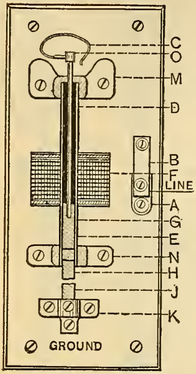


FIG. 25.

In Fig. 25 a cross-section view is shown of the Garton Arrester.

The discharge enters the Arrester by the binding post A, thence across non-inductive resistance B, which is in multiple with the coil F, through conductors imbedded in the base of the Arrester, to flexible cord C, to guide rod D and armature E, which is normally in contact with and resting upon carbon H, thence across the air-gap to lower carbon J, which is held in position by bracket K. This bracket also forms the ground connection through which the discharge reaches the earth.

We have noted that the discharge took its path through the non-inductive resistance in multiple with the coil. This path is, however, of high ohmic resistance, and the normal current is shunted through the coil F, which is thereby energized, drawing the iron armature E upward instantly. This forms an arc between the lower end of the armature and the upper carbon H. As this arc is formed inside the tube G, which is practically air-tight, the oxygen is consumed, the current ceases, and the coil loses its power, allowing the armature to drop of its own weight to its normal position on the upper carbon. The arrester is again ready for another discharge.

The S. K. C. Lightning Arrester Equipment, manufactured by the Stanley Electric Mfg. Company of Pittsfield, Mass., consists of three essential parts. The Lightning Arrester proper is two nests of concentric cylinders, with diverging ends held in relative position by porcelain caps, as shown in cross-section Fig. 26. To the innermost cylinder the line is connected; to the outer, the earth. The porcelain caps are provided with grooves so placed as to make all spark gaps one-sixteenth inch wide. Between these grooves are sufficient perforations to allow the free circulation of air between the cylinders. If, on the occasion of lightning, the dynamo current follows the lightning, a current of air is at once established through the perforations between the cyclinders, blowing the arc between the flaring ends where it is instantly ruptured.

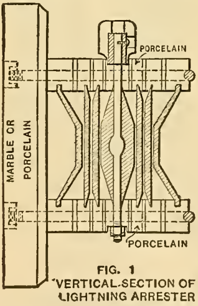


FIG. 26.

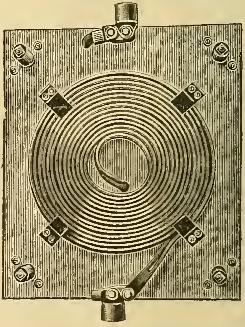


FIG. 27.

Between the line terminal and the ground connection there are three spark gaps, each one-sixteenth inch in width, making a total of three-sixteenth inch air-gap between either line-wire and the ground. At ordinary frequencies five thousand volts or over are required to jump the gaps of the arrester; but at the frequency of a lightning discharge the sparking potential is reduced to less than one-half of this. This phenomenon shows that the relative value of spark gaps cannot be expressed by "short" and "long," and their effectiveness as lightning protection cannot be measured by inches.

The spark gaps of the arrester described are about double the widths ordinarily used, yet the sparking potential at lightning frequencies is less. The concentric cylinders provide large discharge surface, enabling the arrester to take care of all the heavy discharges, relieving the line completely.

The second essential feature of the S. K. C. Lightning Arrester Equipment is a Choke Coil, so wound (Fig. 27) as to possess great opposition to the passage of lightning, yet practically no self-induction with currents of ordinary frequency. This coil is to be placed in the circuit between the lightning arrester and the apparatus to be protected. Introducing such a coil between the lightning arrester and the machine will offer practically no disturbing effect, either as to magnitude of the output or regulation of the system, and at the same time interposes enormous opposition to the passage of lightning discharges towards the machine to be protected.

To remove even the slightest static discharge from the line, an instrument similar to the one illustrated in Fig. 28, called a "Line Discharger," when used with the apparatus above described, discharges the line completely. The S. K. C. Line Discharger is a minute air-gap in series with a tube or tubes, filled with oxidized metallic particles, thus offering practically an infinite resistance to dynamic currents, yet allowing static discharges of extremely low potential to readily pass to earth. The Line Discharger is connected to the line as shown in Fig. 29. The number of tubes required is determined by the voltage. As the Line Discharger will remove even the small static charge, it prevents the accumulation of such charges on the line which might prove dangerous.

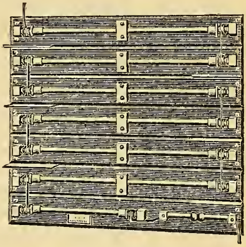


Fig. 28.

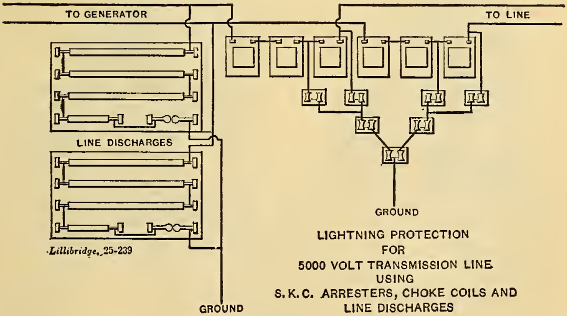


Fig. 29.

ELECTRICITY METERS.

Meters for measuring the amount of electrical energy furnished to customers are commercially called wattmeters or recording wattmeters, whereas they are really measurers or meters of watt-hours. The Edison chemical meter, in which a shunted definite portion of the current supplied to the customer is made to deposit zinc upon an electrode of an electrolytic cell, is properly a coulomb meter, or ampere hour meter, which becomes a watt-hour meter if the pressure be maintained constant.

This last meter is rapidly going out of use. The Thomson watt-hour meter, which is replacing it, can be used upon either direct or alternating circuits. It consists of a motor whose armature is connected in series with a resistance to the two mains, and whose field coils are in series with the supply circuit. The armature in rotating moves a recording mechanism. The rapidity of rotation is regulated by a copper disk connected to the armature shaft and moving between the poles of adjustable permanent magnets. It is made for use on two or three wire circuits, arc circuits, single phase or three phase a. c. circuits, and for recording input and output of storage batteries. The following diagrams show some of the principal uses to which it is put with the scheme of the connections to the circuits. There are many other purposes to which it is put, but the reader is referred to the instruction books accompanying the meters for further information on the subject.

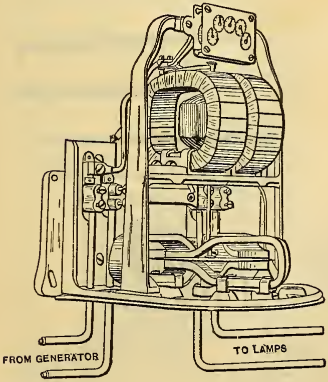


FIG. 1. Two-wire Meter.
(Small Capacity.)

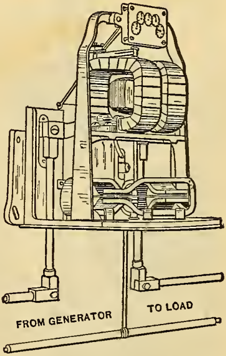


FIG. 2. Two-wire Meter.
(Large Capacity.)

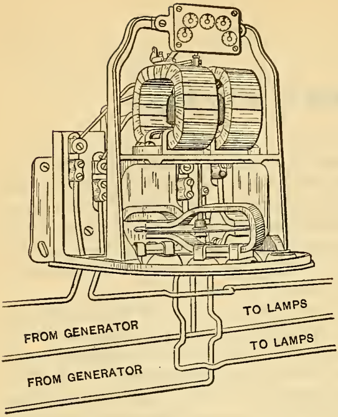


FIG. 3. Three-wire Meter. (High Efficiency Type).

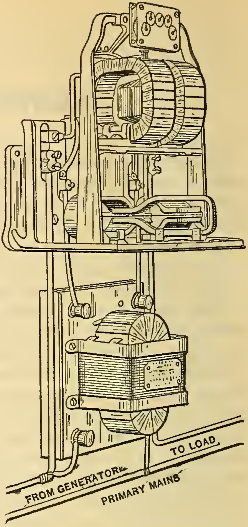


FIG. 4. Primary Meter.

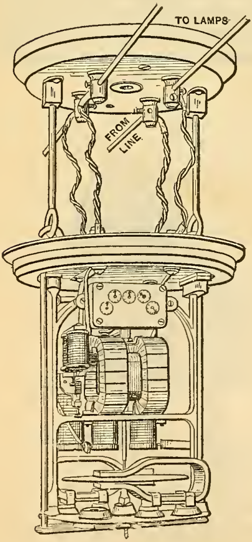


FIG. 5. Arc Circuit Meter.

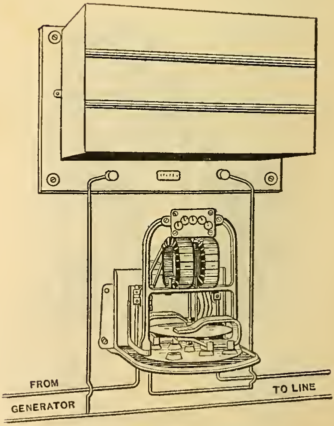


FIG. 6. Station Arc Meter.

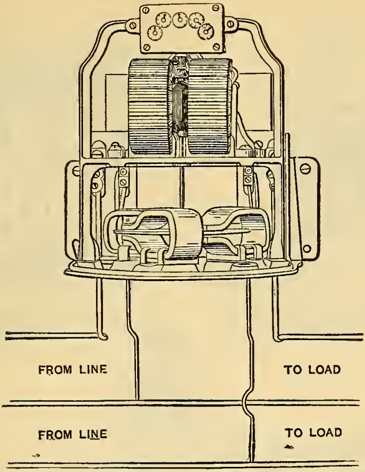


FIG. 7. Balanced Three-phase Secondary Meter.

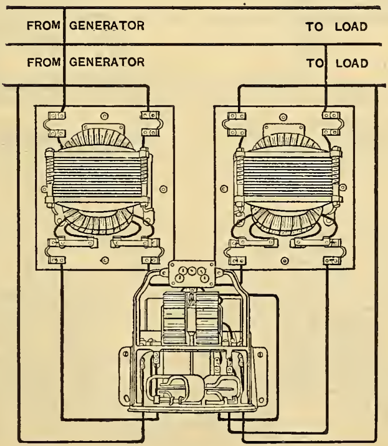


FIG. 8. Balanced Three-phase Primary Meter.

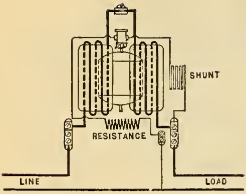


FIG. 9. Two-wire Meters from 75 Amperes to 1200 Amperes.

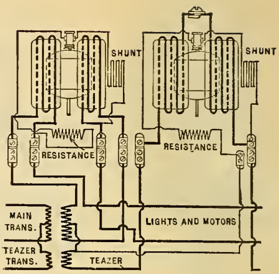


FIG. 10. Two Meters on Monocyclic System.

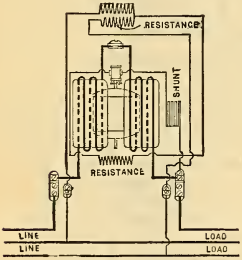


FIG. 11. Balanced Three-phase Meter.

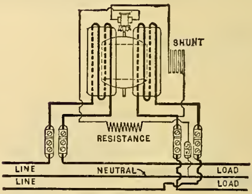


FIG. 12. Three-wire High Efficiency Meter.

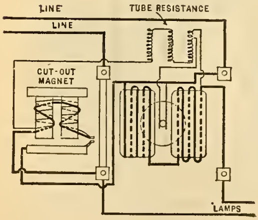


FIG. 13. Arc Circuit Meter.

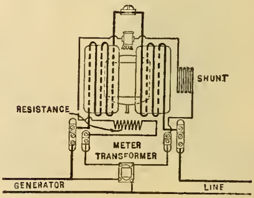


FIG. 14. Single-phase Primary Meter

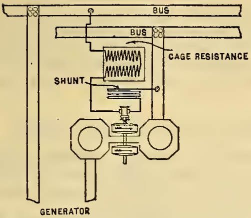


FIG. 15. Large Capacity Station Meter Form G_2.

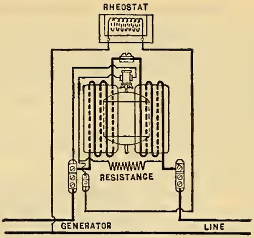


FIG. 16. Station Arc Meter.

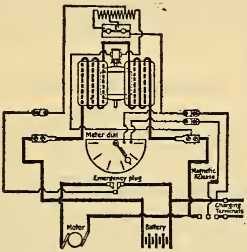


FIG. 16*a*. For Storage Battery 25 and 50 Amperes. 100 volts.

GENERAL NOTES CONCERNING THOMSON METERS.

In case a new jewel is inserted in the meter it is advisable to put in **a new shaft end**, as the point on the old one will probably be injured, more particularly if the meter has been running on the broken jewel.

Just before inserting a new jewel in a meter, it is well to place a drop of fine watch oil on the jewel.

Oil must not be used in the top bearing under any circumstances.

Oil or dirt on the commutator will cause the meter to register less than the correct number of watt hours.

If no "constant" is marked on the dial, the meter reads directly in watt hours.

See that the disk and armature move freely, and that no dirt collects on the magnets in such a way as to touch the disk.

Install the meter in a dry place, as far away from any heavy vibration as possible.

When it is necessary to install a meter near a railroad, or in any place where the vibration is sufficient to cause sparking at the brushes, the tension of the brushes upon the commutator should be slightly increased. This will do away with the sparking, and ensure greater accuracy.

In case of severe jar, it is advantageous to place a number of soft rubber washers under the heads of the screws which bind the meter to the wall and between the meter and the wall itself at each screw.

The disk will always rotate to the right when the meter is properly connected.

Testing of Thomson Recording Wattmeters.

Most companies find it desirable to test meters on their lines from time to time, not so much to check the accuracy of the meters as to be able to state to the customer how the meter is operating. If only a rough test be required, it can be made by turning on a specified number of lights, multiplying the number of lights by the average watts per lamp, and using the following standard formula: —

$$\frac{3600 \times \text{Constant (if meter has one)}}{\text{Watts in use}} = \text{Seconds per revolution of disk.}$$

By using a stop watch, meters can be tested in this way, and the only inaccuracy is the difference between the estimated and actual watts per lamp.

If a more accurate test be required, there are two methods, both of which are simple, and obviate the necessity of taking down the meter.

A portable indicating wattmeter may be connected in series with the meter to be measured. The portable instrument will read directly in watts, and with the above formula give an absolute test.

Another method is to have half a dozen high candle-power lamps, which have been tested at the station so that their wattage at all voltages is absolutely known. These lamps can be connected as the only load on the meter. By reading the voltage at the point of test with a portable voltmeter, and noting the watts recorded by the meter for the group of lamps, a direct comparison can be made.

Calibration of Thomson Recording Wattmeters.

Meters which have been neglected, misused, or very much worn, should be taken down, and brought into the station for repair and recalibration. In modern meters the speed can be increased or retarded about 16% by moving the magnets. On older meters having only one movable magnet, the variation obtainable by moving the magnet is considerably less. Meters which cannot be properly calibrated by moving the magnets can be roughly corrected by changing the resistance in series with the armature. Meters which are slow on light loads can be speeded without affecting the accuracy on high loads by increasing the shunt field coil, which is the fine winding. Meters which show a tendency to creep, that is, to move slightly without any load, have too many turns in the shunt field coil. Creeping is almost invariably traceable to vibration, which aids the meter to overcome friction on very light loads. It can be corrected by removing turns from the shunt field coil until the meter disk just barely fails to move on no load.

ALTERNATING CURRENT METERS.

In addition to the Thomson watt-hour meter, which is used on either a.c. or d.c. circuits there is a class of induction meters used only on the a.c. circuits. The Schallenberger meter is of this type, and is made by the Westinghouse Electric and Manufacturing Company in several designs, such as Watt-hour meters, ampere-hour meters, and the first mentioned are also made in two- and three-phase meters.

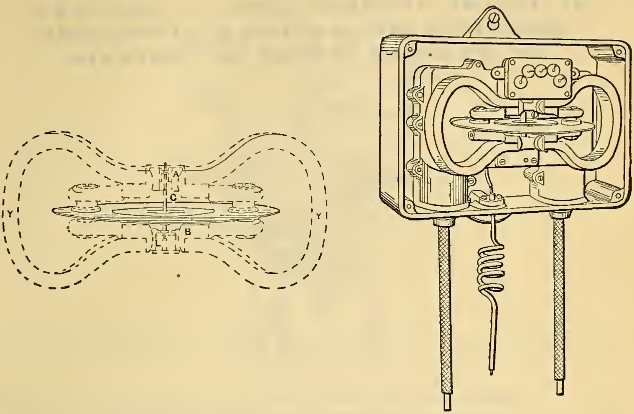
All of these meters depend in some way on the rotating of a disk or cylinder by means of induction coils properly placed in relation thereto.

The Duncan integrating meter is another of the class, and one formerly made by the Fort Wayne Electric Corporation was very similar to the Schallenberger ampere-hour meter. Some of these meters are regulated as to speed by small fans placed on the armature shaft, and are hardly as accurate as those having a retarding disk between magnets.

THE STANLEY METER.

The Stanley manufacturing Company has recently (January, 1899) brought out an a.c. meter that is sealed and warranted to remain accurate within a very small percent for a period of 3 years, provided it is properly installed and the seals are not broken. This meter is of the induction type, and the disk upon which the coils act is held in suspension, and at the same time retarded by two permanent magnets. The disk is so adjusted as to remain suspended midway between the poles of the magnets, and there is no other gearing for friction.

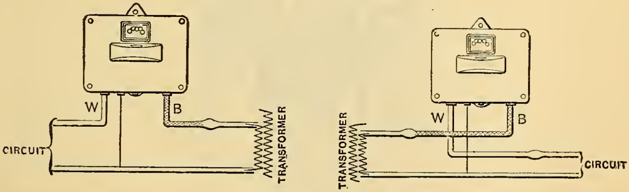
The following two cuts show its construction :—



Figs. 17 and 18.

Directions for Installing Stanley Meters.

Place the instrument on a secure support in as nearly a vertical position as can be judged by the eye. Open one of the mains in the circuit to be metered, and connect the heavy black terminal of the meter to the main leading to the transformer or current generator, and connect the white terminal toward the lamp circuit or current consuming device. Connect the small shunt wire directly across the mains to the opposite side of the circuit so that the shunt connection of the meter will receive the full working pressure of the circuit at approximately the voltage indicated on the case cover. See cuts No. 19 and No. 20 for diagrams of connections.



Figs. 19 and 20.

Directions for Reading.

Kilo-watt hours are recorded directly on the dial without the use of a constant, unless otherwise marked on the case cover. The first right-hand pointer on the dial indicates 1,000 Watt hours, or 1 K. W. H. for one complete revolution of the pointer, and each unit indicated by this pointer represents 100 Watt hours. The other pointers, taken in order from right to left, record successively 10 K. W. H., 100 K. W. H., 1,000 K. W. H., and 10,000 K. W. H. for one complete revolution of the pointer.

DIAGRAMS OF CONNECTIONS OF SHALLENBERGER INTEGRATING WATTMETERS TO VARIOUS STYLES OF CIRCUITS.

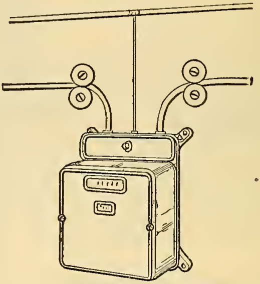


FIG. 21. Connections for Single-Phase Circuits; Current not exceeding 100 Amperes, Potential not exceeding 500 Volts.

The illustration above shows the method of connecting a meter to a single-phase circuit, carrying a current not exceeding 100 amperes and at a potential not exceeding 500 volts.

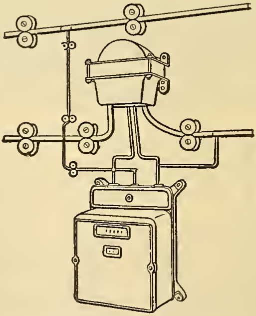


FIG. 22. Connections for Single-Phase Circuit; Current exceeding 100 Amperes, Potential not exceeding 500 Volts.

The illustration herewith shows the method of connection to a single-phase circuit carrying a current exceeding 100 amperes at a potential not exceeding 500 volts. In this case a series transformer is used, the current to be measured passing through the primary coil of the transformer, while the meter receives from the secondary coil of the transformer current bearing a fixed ratio to the primary current.

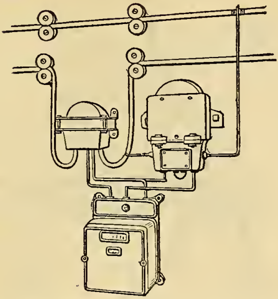


FIG. 23. Connections for Single-Phase Circuit; Potential exceeding 500 Volts.

The illustration shows the method of connecting the meter to a single-phase circuit carrying current at a potential exceeding 500 volts. To keep the high potential current out of the meter, both a series and a shunt transformer are used, even for currents not exceeding 100 amperes.

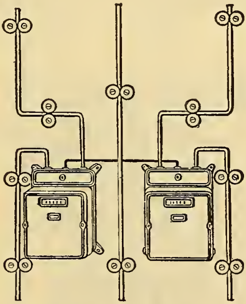


FIG. 24. Connections for Polyphase Circuits; Current not exceeding 100 Amperes, Potential not exceeding 500 Volts.

The illustration above shows the method of connecting two meters to a three-wire polyphase circuit, in which the current traversing each of the outside wires does not exceed 100 amperes, while the potential between either of the outside conductors and the middle conductor does not exceed 500 volts. This connection is correct for a three-wire, two-phase system, and also for a three-wire three-phase system.

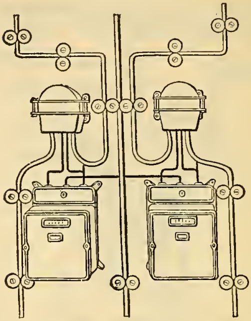


FIG. 25. Connections for Polyphase Circuits; Current exceeding 100 Amperes, Potential not exceeding 500 Volts.

The illustration herewith shows the method of connecting two of these meters to a three-wire polyphase circuit, where the current in each of the outside wires exceeds 100 amperes, while the potential between each of the outside wires and the middle wire does not exceed 500 volts. Series transformers are used to reduce the current to the meter. This arrangement is correct for either a three-wire two-phase or a three-wire three-phase system.

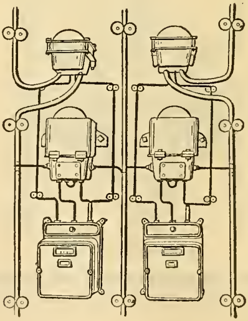


FIG. 26. Connections for Polyphase Circuit; Potential exceeding 500 Volts.

The illustration shows the method of connecting two meters to a polyphase three-wire system carrying currents at a potential exceeding 500 volts. It will be noted that both series transformers and shunt transformers are used. This connection is correct for either a three-wire two-phase or a three-wire three-phase system.

WESTINGHOUSE INTEGRATING WATTMETERS.

Two-Wire, Single-Phase. — The two-wire single-phase meter is rated for the average load of the installation, this being permissible on account of its ability to safely carry a load fifty per cent in excess of its rated capacity. It registers in *International Watts* the true energy delivered to the circuit, and it is said to be correct for all power factors. The counter reads directly in watts or kilowatt hours. Series transformers are used on all circuits carrying more than 80 amperes, and for voltages above 500 volts shunt transformers are also used. These meters are connected to two-wire, single-phase circuits, as shown in Figs. 21, 22 and 23.

Three-Wire, Single-Phase. — This meter is made to register the energy delivered by a three-wire circuit, through the medium of a specially designed series transformer, having two primary coils and one secondary coil.

One of these primary coils is connected in series with one of the outside wires of the three-wire circuit, and the other primary coil is connected in series with the other outside wire of the three-wire circuit. The secondary coil, in which the current is proportional to the sum of the currents in the two primary coils, is connected to the wattmeter. The shunt circuit of the wattmeter is connected between the neutral and one of the outside wires.

The current capacity, marked on the counter of the three-wire Westinghouse wattmeter, represents the current in each of the outside wires of the three-wire circuit. The voltage marked on the counter is that between one of the outside wires and the neutral wire.

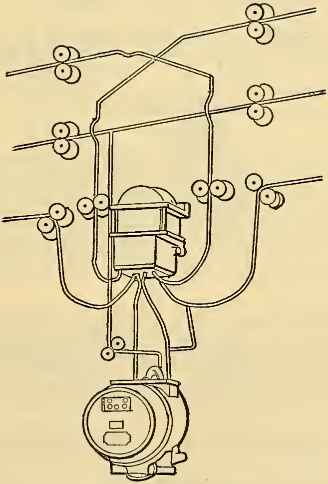


FIG. 27. Diagram of Connections of Westinghouse Three-Wire, Single-Phase Integrating Wattmeter.

The total current capacity of a three-wire wattmeter is, therefore, twice that marked on the counter, which represents the capacity of one side only.

The counter records, however, the total energy supplied to both sides of the three-wire installation; and the watt hours recorded on the counter in one hour, when the meter is running at full load, will be twice the product of the current and the voltage marked on the face of the counter.

Two- or Three-Phase Meters.

The Westinghouse polyphase meter records on a single dial the total energy delivered in all the phases of a two or three-phase circuit under all conditions of balance and of power factor.

The current capacity marked on the counter of the polyphase wattmeter is the current in each wire of the circuit; the voltage is that across a phase. No constant or factor is used.

Instructions for Checking and Testing Westinghouse Integrating Wattmeters.

Registration. — These meters as shipped are ready for use, and are accurate within the limits specified on the tag attached to them.

The disk revolves 50 times per minute at full load; the direction of rotation being from left to right. The unit of power is the international watt, and all wattmeters register directly in watts or kilowatt hours without the use of constants.

Methods of Checking. — One of the two methods mentioned below are recommended, circumstances dictating which of the two is the better. First method is to compare the instrument to be checked with a standard indicating wattmeter, and timing the disk.

Second method is by comparing with a standard integrating wattmeter.

First Method — Two-Wire, Single-Phase Wattmeter. — Connect the instrument to be compared in circuit with a standard indicating wattmeter, as shown in the following diagram.

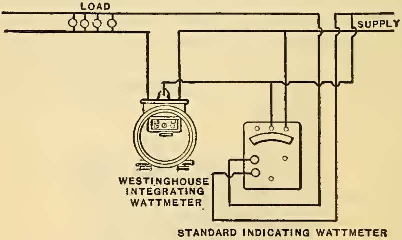


FIG. 28.

Load the circuit until the desired reading is obtained on the indicating wattmeter, and keep it at a constant value while the integrating wattmeter is being read. Time the revolutions of the disk with a stop-watch, commencing to count when the spot on the disk has made one revolution (after the watch has started), and counting the revolutions for at least a minute.

To arrive at the number of watts registered by the wattmeter, use the following formula:

Watts $= \frac{R}{T}K$. In this formula, $R =$ complete number of revolutions of the disk in time T.

$T =$ time in seconds of revolutions R.

$K =$ constant.

For wattmeters that are used without transformers, $K =$ volts multiplied by amperes (as marked on the counter), multiplied by 1.2. For wattmeters that are used with series transformers (but checked without them), $K =$ volts, as marked on the counter, multiplied by 6. For wattmeters that are used with both shunt and series transformers (but checked without them), $K = 600$.

In this way a wattmeter can be compared with a standard, and by varying the number of watts can be checked through its entire range.

All wattmeters for circuits exceeding 80 amperes are wound for 5 amperes, and are made to register the energy delivered by the main circuit by means of series transformers. The primary coils of these transformers, which are of heavy capacity, are connected in the main circuits, while the secondary coil, in which the current is proportional to the current in the primary windings, is connected to the wattmeter. These wattmeters can be tested without the series transformers, but should be connected as in Fig. 31 following, and the test made in the manner indicated. The full load is, however, the product of the voltage marked on the counter multiplied by 5, and not by the current indicated on the counter. K, in this case, = volts, as marked in the counter, × 6.

All wattmeters of voltages exceeding 400 volts are provided with 100-volt shunt-coils and 5 ampere series-coils, and are connected to the main circuit through shunt and series transformers of the proper ratio. In checking, connect without the series or shunt transformers to 100-volt circuit, as shown in Fig. 28, and proceed as indicated above, remembering that full load is 500 watts, and that in the formula $K = 600$.

Three-Wire, Single-Phase. — These wattmeters are all 5-ampere, single-phase instruments, and the method of connecting them for the first method of test is shown in Fig. 29.

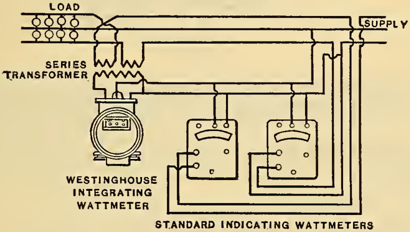


FIG. 29.

A. Connect two standard indicating wattmeters, one into each side of the three-wire circuit, being careful to have the connections of these standard wattmeters made on the supply side of the integrating wattmeter, as shown, so that it will not measure the energy used by them. Load the circuit until the desired readings are obtained on the indicating wattmeters, and keep at a constant value while the integrating wattmeter is being read. Time the number of revolutions of the disk as before. To arrive at the number of watts registered by the wattmeter, use the following formula:

$$\text{Watts} = \frac{R}{T} K.$$

R = number of complete revolutions in time T.
T = time in seconds required for revolutions R.
K = constant (volts times amperes, as marked on the counter, multiplied by 2.4).

The reading of the integrating wattmeter should equal the sum of the readings of the two standard indicating wattmeters.

B. A simpler method is to check the wattmeter without the series transformer. As previously mentioned, all these wattmeters are 5-ampere, 100-volt, single-phase, two-wire instruments. For purposes of test it is necessary only to connect them, as shown in Fig. 31, into a single-phase, two-wire circuit, with a standard indicating wattmeter, and proceed in the same manner as for two-wire wattmeters of this capacity.

Polyphase Wattmeter. — To compare a polyphase wattmeter with the standard, check each side separately on a single-phase circuit. Where transformers are not used in connection with the wattmeters, the full-load rating for each circuit of the wattmeter is the number of watts obtained by multiplying the current by the voltage marked upon the dial of the wattmeter.

If a series transformer is used with the wattmeter, full load in each circuit is the number of watts obtained by multiplying the voltage marked upon the dial by 5, as all wattmeters used with series transformers are wound for 5 amperes.

In testing, connect the polyphase wattmeter as shown in Fig. 30. Both shunt circuits of the integrating wattmeter are connected. The main current, however, is passed through only one series coil at a time, by connecting "C" to "A" or to "B." When one circuit of the wattmeter is fully loaded the rotating element makes 25 revolutions per minute, and 50 revolutions when both phases are fully loaded.

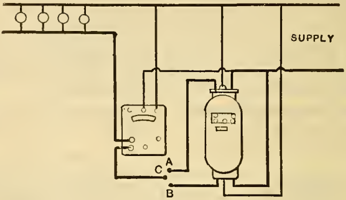


FIG. 30.

Load the circuit until the desired reading is obtained on the indicating wattmeter, and keep it at a constant value while the integrating wattmeter is being read. Time the revolutions of the aluminium disk for at least one minute.

To arrive at the number of watts registered by the wattmeter, use the following formula:

$$\text{Watts} = \frac{R}{T} K. \quad \text{Where}$$

$R =$ complete number of revolutions of the disk in time T.
$T =$ time in seconds of revolutions R.
$K =$ constant. (For wattmeters which are used with both series and shunt transformers, but checked without them, $K = 1200$.)

Always be sure to have both shunts connected when testing.

Second Method: With Standard Integrating Wattmeter.

Single-Phase Wattmeters. — When using integrating wattmeters as standards, use one of same capacity and voltage as those under test. Load the circuit into which the wattmeter is connected. If the disk of the instrument under test runs in synchronism with the standard wattmeter it is in correct calibration. Repeat for several different loads. Another method is to allow the instrument under test to run with the standard for several hours under full load. A comparison of the amount registered

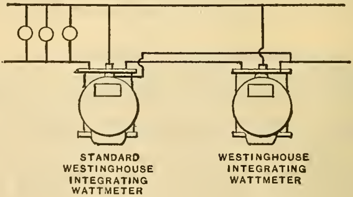


FIG. 31.

will show the difference between the two, or the error of the instrument tested.

When but a single wattmeter is to be checked against the standard, it should be connected as shown in Fig. 31.

When more than one wattmeter is to be checked against the standard, they should be connected as indicated in Fig. 32.

Referring to Fig. 32: If a short run is to be made, but one meter should be run with the standard at a time, otherwise the meter near the line connection will measure the energy taken by the shunts of those near the standard. If, however, the test is to be made by allowing the wattmeters to run with the standard for several hours they can all be run together, as the amount of energy used by the wattmeters themselves will be so small a percentage of the total readings that it will not be noticeable.

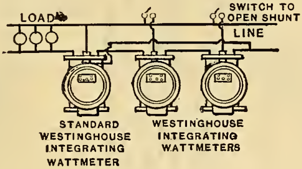


FIG. 32.

Polyphase Wattmeters. — Polyphase wattmeters should be checked against single-phase standards. The standard used, however, should be of twice the current capacity marked on the counters of the polyphase wattmeters. Connect as shown in Fig. 33.

The wire at "A" is connected first to the upper phase of the meter and then to the lower phase, proceeding in the same manner as with single-phase meters, noting, however, that the full-load speed of the disk will be 25 r.p.m., as only one phase will be on at a time.

Be sure to always have both shunts connected when making a test. In meters which do not use series transformers there is only one shunt terminal (the other wire of the shunt being connected to the right-hand series terminal inside the meter).

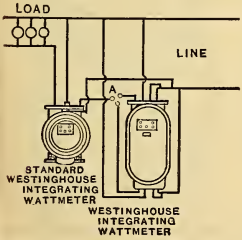


FIG. 33.

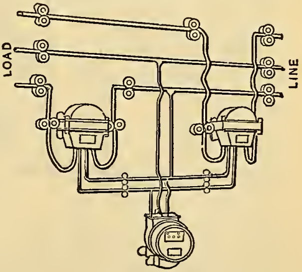


FIG. 34.

Fig. 34 shows the method of connecting three-wire, single-phase Westinghouse wattmeters to three-wire circuits.

All three-wire, single-phase Westinghouse wattmeters, for circuits exceeding 400 amperes per side, are connected in this manner.

Fig. 35 shows the method of connecting polyphase Westinghouse wattmeters to two-phase circuits.

All polyphase Westinghouse wattmeters for two-phase circuits of 400 volts or less, and of 80 amperes or less, are connected in this manner.

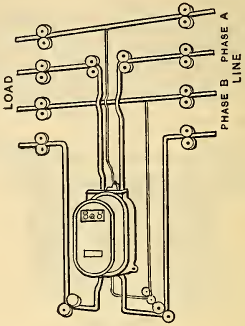


FIG. 35.

The following illustration shows the method of connecting polyphase Westinghouse wattmeters to three-phase circuits.

All polyphase Westinghouse wattmeters for three-wire, three-phase circuits of 400 volts or less, and of 80 amperes or less, are connected in this manner.

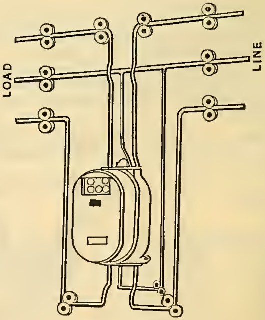


FIG. 36.

The following illustration, Fig. 37, shows the method of connecting polyphase Westinghouse wattmeters to two-phase circuits.

All polyphase Westinghouse wattmeters for two-phase circuits of 400 volts or less, and greater than 80 amperes capacity, are connected with series transformers in this manner.

Fig. 38 shows the method of connecting polyphase Westinghouse wattmeters to three-phase circuits.

All polyphase Westinghouse wattmeters for three-phase circuits of 400 volts or less, and of greater than 80 amperes capacity, are connected with series transformers in this manner.

Fig. 39 shows the method of connecting polyphase Westinghouse wattmeters to two-phase circuits.

All polyphase Westinghouse wattmeters for two-phase circuits of all current capacities, and for more than 400 volts, are connected with shunt and series transformers in this manner.

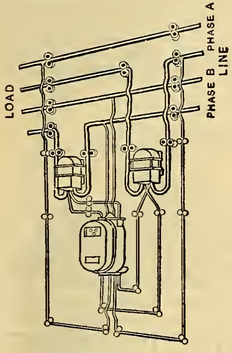


FIG. 37.

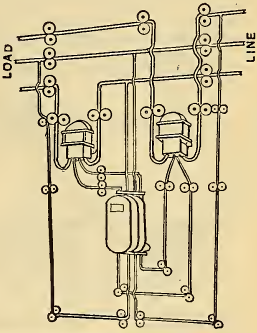


FIG. 38.

Fig. 40 shows the method of connecting polyphase Westinghouse wattmeters to three-phase circuits.

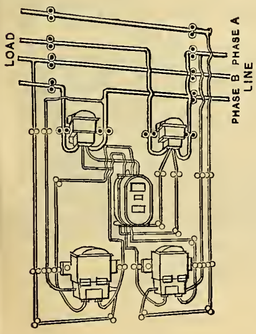


FIG. 39.

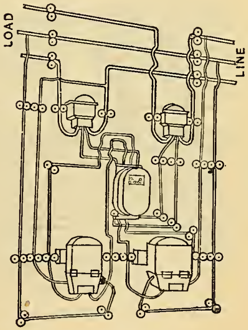


FIG. 40.

All polyphase Westinghouse wattmeters for three-phase circuits of all current capacities, and for more than 400 volts, are connected with shunt and series transformers in this manner.

To Tell the Exact Current Flowing at Any Time in a Schallenberger Meter.

Note the number of revolutions made by the small "tell-tale" index on the top of the movement, in a number of seconds equal to the constant of the meter. The number of revolutions noted will correspond to the number of amperes passing through the meter. For example: the 20 ampere meter constant is 63.3; if the index makes ten revolutions in 63.3 seconds, 10 amperes are passing through the meter. In order to avoid errors in reading, it is customary to take the number of revolutions during a longer time, say 120 seconds; then as a formula, we have:

$$\frac{\text{Number of revolutions} \times \text{meter constant}}{\text{Number of seconds}} = \text{Current.}$$

0000 Ampere-hours.

0030 Ampere-hours.

00930 Ampere-hours.

07930 Ampere-hours.

57930 Ampere-hours

00890 Ampere-hours.

21810 Ampere-hours.

37120 Ampere-hours

FIG. 41. Dials showing Sample Readings.

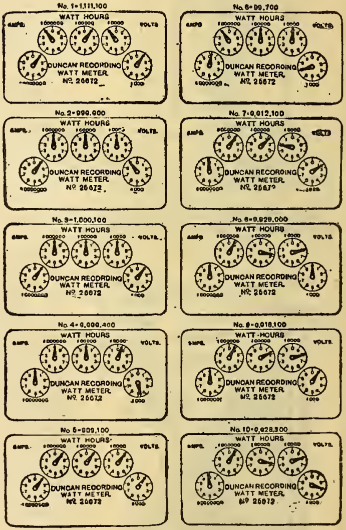


FIG. 42. Difficult Meter Readings.

THE SCHEEFFER WATT-METER.

This meter, made by the Diamond Meter Co., Peoria, Ill., is another of the induction type, used for alternating currents, and has some special features. The two following cuts illustrate its latest development.

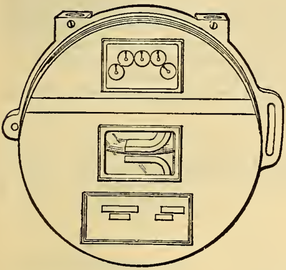


FIG. 43. Round Pattern, Type *D*. Scheeffer Watt-Meter Closed.

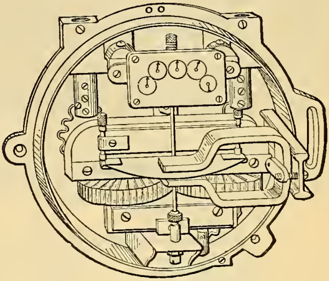


FIG. 44. Round Pattern, Type *D*. Scheeffer Watt-meter Open.

A very ingenious device is used for sensitive adjustment, and the following cut and description taken from the Company's catalogue is sufficiently clear to indicate its use.

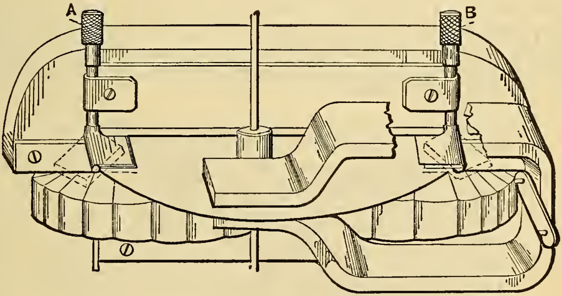


FIG. 45. Meter Core. Showing Shields for Sensitive Adjustment.

There are two knurled posts, *A* and *B*, secured to the meter core by screw clamps as shown in the cut. These posts carry iron shields that can be made to embrace more or less of the disk by turning the posts.

"When the iron piece or shield embraces the disk it exerts an influence inductively on the disks so as to give it a torque, and will cause it to revolve slightly. The left-hand piece (looking at the meter in front) will cause a torque towards the right, and the right hand piece toward the left. If the two pieces equally embrace the disk they will balance each other, and no movement will result. By throwing one out the other will prevail, and cause it to revolve. Thus the two pieces can be adjusted towards each other so that the meter is always balanced and just on the point of turning, and is highly sensitive to extremely small loads. Great care must be taken so the balance is perfect, as otherwise the meter will be overcompensated, and will slowly run on pressure, and record when no load is on. When this adjustment is made, a good way to establish a balance is to keep tapping the meter when adjustment is made, as this will give a better adjustment for the meter, as a meter will often not run on pressure when quiet, but run slowly when subjected to vibrations. A very good way to calibrate a meter is to adjust the full load, and then adjust the knurled brass posts, so that by tapping a balance of the meter is effected so as not to run on pressure. This condition will leave the meter highly sensitive and correct, as it is not necessary that the lower loads be calibrated by a Watt-meter. When the posts have been properly adjusted, they must then be fastened securely by screwing the clamp which holds them tight, so that they will not be distured."

In testing or calibrating "Scheeffer" meters, use a stop-watch for timing and the following formulae for determinations.

METER CALCULATIONS.

R = revolutions.
W = watts.
C = constant on meter dial.
S = second.

$$R = \frac{W \times S}{3{,}600 \times C}.$$

$$W = \frac{R \times 3{,}600 \times C}{S}.$$

$$S = \frac{R \times 3{,}600 \times C}{W}.$$

METER PRICE CHART.

The General Electric Company furnishes a large price-chart for facilitating the making of bills from meter readings. The above cut is a reduced facsimile of the chart. The figures at the bottom are kilowatt-hours; those at the left are the amounts of bills in dollars and cents. The diagonals are different rates per kilowatt-hour. Selecting the diagonal having the rate at which charges are to be made, a point is found on it directly over the number of kilowatt hours shown by the meter; in the column at the left, on a horizontal line from the same point, will be found the amount of bill. For example, take 50 kilowatt hours at 10 cents per kilowatt hour, the amount of bill shown at the left is $5.00.

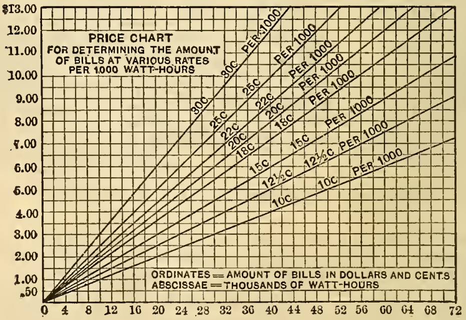


FIG. 49. Meter Price Chart.

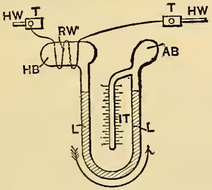
WRIGHT DISCOUNT METER.

This instrument is for use in connection with a watt hour meter for determing the maximum use of current during any given period; or may be used without the watt-hour meter in connection with any electrical device for which it is desired to know the maximum use of current, either direct or alternating.

It is slow acting so as to take no account of momentary spurts, such as starting an elevator or street car, and is rated to record as follows:

If the maximum load lasts 5 minutes, 80 % will register;
If the maximum load lasts 10 minutes, 95 % will register;
If the maximum load lasts 30 minutes, 100 % will register.

The following figure shows the working parts in theory, which, being of glass and liquid, are placed in a cast-iron case, with a glass front to permit reading. As shown, one leg of the circuit passes around a glass bulb which is hermetically sealed, and connected to a glass tube holding a suitable liquid.



T, Terminals.
H W, House wires.
R W, Resistance wire.
H B, Heated bulb.

A B, Air Bulb.
I T, Indicating tube.
L, Liquid.
⟶ Direction.

FIG. 47. Wright Discount Meter.

The heat due to the current passing in the circuit expands the air in the bulb, which forces the liquid down in the left column and up in the right. Should the quantity of heat be such as to force some of the liquid high enough, it will fall over into the central tube, where it must stay until the instrument is readjusted. The scale back of the central tube is calibrated in amperes on the left and in watts on the right. After reading and recording the indication for any period of time, the liquid is returned to the outer tubes by simply tipping up the tubes, etc., which are hinged at the top connections for the purpose.

The readings of the *demand meter* or *discount meter*, either of which names are used, together with those of the watt-hour recording meter, furnish a basis for a more rational system of charging for electricity than has been customary. This subject is being taken up by many of the larger electricity supply companies.

The instrument is handy to use in circuit with a transformer to show how the *maximum demand* compares with the transformer capacity; also on feeders and mains to show how heavily they may be loaded.

TELEGRAPHY.

In this chapter only the instruments used in telegraphy will be noticed; and these, with their connections, in theoretical diagrams only. For the various details, whose presentation would defeat the purpose of clearness in this compilation, readers are referred to various works on telegraphy. Lines, batteries, etc., are each treated in other chapters.

AMERICAN, or CLOSED CIRCUIT METHOD.

The following diagram shows the connections of the Morse system of single telegraphy, as used in the United States. The terminal stations only are shown, and in one case the local circuit is omitted. Several intermediate stations (in practice 25 is not unusual) may be cut in on one circuit; all the instruments working in unison, in response to one key only.

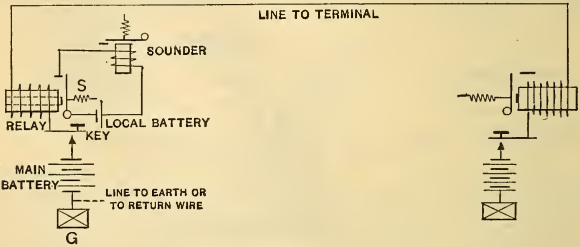


Fig. 1.

In Fig. 1 at either end is a key which, when open, allows the now unattracted armatures to be withdrawn by the retractile spring, S. Closing the key restores the current to the relays, attracts the armatures to the front stop; the local circuit through the relay points is closed, and the signal is heard on the sounder. The attracting force of spring, S, is less than that of the relay cores as energized by the current from the battery used for a given circuit. It can, by "pulling up" on the spring, be made greater; in which case the given current is ineffective to close the relays, and if the tension of spring, S, is maintained, battery must be added to close the relays. It is possible, therefore, by means of spring, S, to make a comparatively weak current ineffective to close the relay points. The significance of this will appear later in connection with the quadruplex.

EUROPEAN, or OPEN CIRCUIT METHOD.

The following diagram shows the connections of one terminal station with the line connecting to the next. The ground plates may be dispensed with if a return wire from the next station is used, thus forming a metallic circuit.

This method of connecting Morse apparatus is used mostly in Europe, and has two advantages over the American method .

a. The battery is not in circuit except when signals are being sent.

b. When the key is closed and the current admitted to line, the coils of the relay are cut out of the circuit, thus lessening the hindrance to the flow of current.

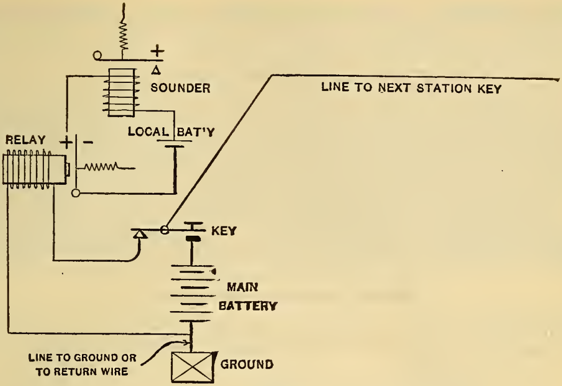


Fig. 2.

REPEATERS.

In practical telegraphy, the high resistance of the line wire between the terminal stations, and imperfect insulation permitting leakage in damp weather, make it inexpedient to attempt to transmit signals over circuits whose lengths have not well-defined limits. But a circuit may be extended, and messages exchanged over longer distances by making the receiving instrument at the distant terminal of one circuit do the work of a transmitting key in the next. The apparatus used for this purpose is called a repeater, and is usually automatic, in a sense which will appear later on.

From among the scores of repeaters, selection must be made of representative types, — the two in most general use.

Milliken Repeater.

The following diagram illustrates the theory of the Milliken repeater, which is in general use in the United States and Canada. The essential feature of every form of automatic repeater is some device by which the circuit into which the sender is repeating not only opens when he opens, but closes when he closes.

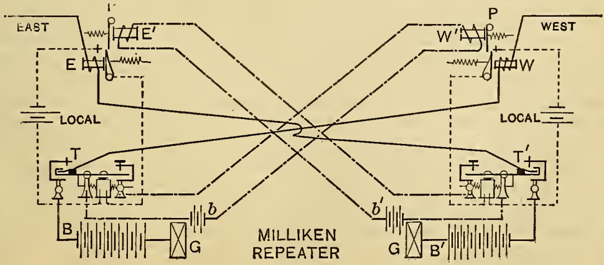


Fig. 3.

In the diagram is represented the apparatus of a repeating station in which appear the instruments and three distinct circuits in duplicate, viz.: the east and west main line; east and west local (dotted); east and west extra local (dash and dot). Starting with both "east" and "west" keys closed and the line at rest, battery *b′*, whose circuit (dash and dot) is complete through transmitter, T′, energizes extra magnet, E′, attracts the pendent armature, P′, leaving the upright armature free, the pendent armature, P, being similarly held by battery, *b*. In operation, the distant east opens his key, relay, E, opens, then transmitter, T, through whose tongue and post passes the west line, which opens, and would open relay, W, and therefore transmitter, T′; but at the moment transmitter, T, opens, the extra local circuit (dash and dot) opens, releasing pendent armature, P, which is drawn by its spring against the upright armature holding closed the points of relay, W, and transmitter, T′, and therefore the east line, which passes through its tongue and post. When the distant west breaks and sends, the action begins with the west relay instead of east, and follows the same course.

Weiny-Phillips Repeater.

A theoretical diagram of the Weiny-Phillips repeater is given herewith. It is in general use by one of the principal telegraph companies, and is introduced here because it involves the principle of differentiation in magnet coils, which plays so important a part in duplex telegraphy. As in the Milliken, there are three distinct circuits in duplicate; and in the diagrams the parts performing like functions in the two types of repeaters are similarly lettered. The connections and functions of the main line (solid black) circuits and of local (dotted) circuits, are identical with those of the Milliken. But instead of the extra magnets and pendent armature of the latter, we have a tubular iron shell inclosing a straight iron core and its windings, the combination of shell and straight core performing the same functions as the usual horse-shoe core. The turns of wire around the core of the extra magnet are equally divided, and the current traverses the two halves in opposite directions. Such a core is said to be differentially wound, because the core is energized by the *difference* in strength of the currents in the coils; but when the coils are equal in resistance, the equal currents, passing in opposite directions around the core, neutralize each other. If one of the coils is opened, the core at once becomes a magnet capable of holding the armature at the moment when, the repeater in operation, the "east" station opens his key, opening relay, E; then transmitter, T; then opening the "west" wire, which would open relay, W, transmitter, T′, and therefore the east wire; but the opening of transmitter, T′, is prevented by the energizing at the critical moment of core W′ one coil of which is opened

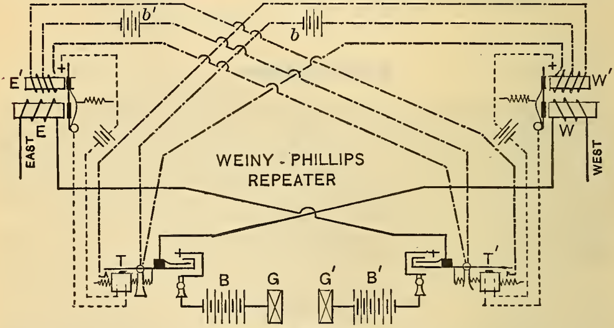
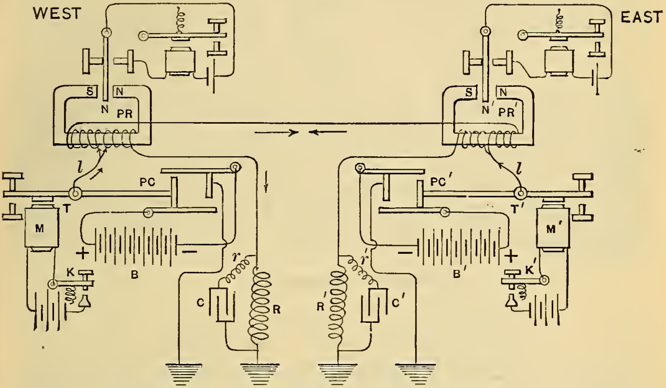


FIG. 4.

when transmitter, T, opens. When the distant west breaks and sends, the action begins with the west relay instead of the east, and follows the same course.

DUPLEX TELEGRAPHY.

That method of telegraphy by which messages can be sent and received over one wire at the same time is called duplex; and the system in general use, known as the polar duplex, is illustrated in the accompanying diagram. In single telegraphy all the relays in the circuit, including the home one, respond to the movements of the key; the duplex system implies a home relay and sounder unresponsive, but a distant relay responsive to the movements of the home key; and this result is effected by a differential arrangement of magnet coils, of which the extra magnet coils in the Weiny-Phillips repeater furnished an example. A current dividing between two coils and their connecting wires of equal resistance will divide equally, and passing round the cores, will produce no magnetic effect in them. This condition is established when the resistance of the wire marked —> <— in the diagram is balanced by the resistance of a set of adjustable coils in a rheostat marked R. This is called the ohmic balance (from ohm, the unit of resistance); and the static balance is effected by neutralizing the static discharge on long lines by means of an adjustable condenser, C, and retardation coil, r, shunting the rheostat as shown. In the single line relay the movement of the armature is effected by the help of a retractile spring in combination with alternating conditions of current and no current on the line. In the polar relay the spring is dispensed with, and the backward movement of the armature is effected, not by a spring, but by means of a current in a direction opposite to that which determined the forward movement. This reversal of the direction of the current is effected by means of a pole-changer, PC, whose lever, T, connected with the main and artificial lines, makes contact, by means of a local circuit and key, K, with the zinc (—) and copper (+) terminal of a battery alternately. The usage in practice is zinc to the line when the key is closed; copper, when open. The law for the production of magnetic poles by a current is this: When a core is looked at "end on" a current passing round it in the direction of the hands of a clock produces south-seeking magnetism, S; in the opposite direction, north-seeking magnetism, marked N. A springless armature, permanently magnetized and



THEORETICAL DIAGRAM OF POLAR DUPLEX
BALANCING SWITCH OMITTED
FIG. 5.

pivoted, as shown in the drawing, will, if its free end is placed between S and N magnetic poles, be moved in obedience to the well-known law that like poles repel, while unlike poles attract each other. The "east" and "west" terminal is each a duplicate of the other in every respect; and a description of the operation at one terminal will answer for both.

Under the conditions shown, the keys are open; and the batteries, which have the same E.M.F., oppose their copper (+) poles to each other, so that no current flows in the main line. But in the artificial line the current flows round the core in such direction as, according to the rule just given, to produce N and S polarities as marked, opening the sounder circuits at both terminals. If, by means of key, K′, the pole-changer, PC′, of "east" station is closed, the connections of battery, B′, are changed; it is said to be reversed; and it now adds its E.M.F. to that of battery B, the current flowing in a direction from "west" to "east"; i.e., from copper to zinc. But the current in the main line is to that in the artificial as 2 to 1; and if the relative strength of the resultant magnetic poles is represented by small type for that produced by the current in the artificial line, and by large type for the main, the magnetic conditions can be graphically shown, as they are produced on each side of the permanently magnetized armatures marked (N) and (N′). In relay, PR′, it is Sn (N′) sN, causing it to remain open; in relay PR it has changed to Ns (N) nS — just the reverse of that shown in the diagram — the relay therefore closes, and the sounder also. If key, K, of the west station is closed at the same time, the batteries are again placed in opposition, but with zinc (—) poles to the line, instead of, as in the first instance, copper (+) poles. The result is no current on the main line; but the current in the artificial lines, flowing in the direction from the ground (whose potential is 0) to the zinc (—) of the batteries, the magnetic condition at "east" station is represented by n (N′) s, which closes relay, PR′; and at "west" station by n (N) s, which closes relay PR. The conditions necessary to duplex work, viz., that the movement of key, K′, should have no effect on relay, PR′, but should operate the distant relay, PR, are thus fulfilled, and the transmission of messages in opposite directions at the same time is made practicable. In the case of the Wheatstone Automatic duplex this exchange goes on at high rate of speed, the maximum rate being 250 words a minute.

Duplex Repeater.

In wires worked in the duplex or quadruplex system, the static capacity of the wire, which plays little if any part in the operation of circuits by the single method, places a limit on the length of the continuous circuit. But the distance between working stations can be greatly extended by the use of repeaters in which, by an arrangement perfectly simple, the pole-changer of a second circuit is controlled by the relay points of the first. The longest regular circuit in the United States is that worked between New York and San Francisco, with six repeaters.

QUADRUPLEX.

The *quadruplex* system of telegraphy allows of two messages being sent in either direction, over the same wire, and at the same time. In theory it is an arrangement of two duplexes, so different in principle as to permit of their combination for the purpose designated. If the accompanying diagram of the quadruplex is examined, there will be noticed in it the pole-changer, polar relay, and all the apparatus of the polar duplex. The polar relay at the "east" station (not shown) will respond to signals sent by the pole-changer, PC, at the "west" in the manner described in the paragraph on the Polar Duplex, so long as the working minimum of current is maintained. This working minimum can be doubled, trebled, or quadrupled without appreciable difference to the polar relays. In the paragraph on Single Telegraphy, the operation of the single relay, fitted with a retractile spring, was effected by opening and closing the key; or, in other words, by alternating periods of "no current" and "current" on the wire. It was further stated, in anticipation of its introduction at this point, that the spring could be so adjusted that a weak current, though flowing all the time through the coils, would not close it. To effect the closing an increase of battery, and therefore of current strength is necessary, so that the relay, instead of, as in the first instance, responding to alternating periods of "no current" and "current" could be operated by alternating periods of "weak current" and "strong." In the diagram, transmitter T, when its key is open, admits to the line a current sufficient to operate the polar side; and

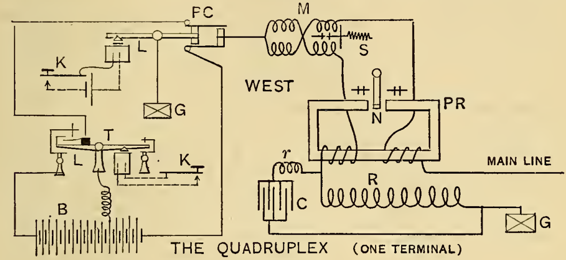


FIG. 6.

at the "east" station (not shown) there is a differentially wound relay, M′, the duplicate of relay M in the diagram, the tension of whose spring makes it unresponsive. But when all the battery is on, a condition which obtains when the key closes transmitter, T, the distant relay, M′, is closed. In short, there is in the quadruplex a pair of polar relays which respond to changes in the *direction*, not in the strength of the current; and a pair of neutral relays, which respond to changes in the *strength*, not to the direction of the current. The diagram shows the apparatus in its simplest form; there are a number of details in connection with its operation, the complete connections for which are rather too complicated for this book. On page 199 of Mavers's *American Telegraphy* will be found a diagram embodying the full scheme of connections; and Thom and Jones' *Telegraphic Connections* contains diagrams and detailed descriptions of the systems in general use.

THE STEARNS DUPLEX.

The operation of differential relays like M in the diagram of the quadruplex, by alternations of "no battery" and "battery," is the principle of the Stearns duplex which, as the first condenser-using, and therefore static-eliminating duplex in the world, has a certain historic interest. In February, 1868, there were in use by the Franklin Telegraph Company a duplex, set New York to Philadelphia, and another to Boston; and in August, 1871,

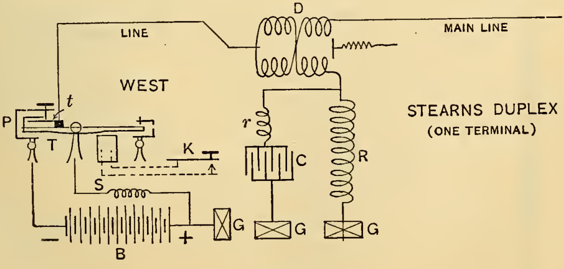


FIG. 7.

by the Western Union Telegraph Company, a duplex, New York to Albany —all without condensers. In March, 1872, the Stearns Duplex, with condenser, went into operation between New York and Chicago, but it has been superseded by the polar system.

Reverting to the diagram, the pole-changer with its adjuncts, and the polar relay of the quadruplex, are omitted; one pole of the battery is grounded, and the lever of transmitter, T, is grounded through a resistance equal to that of battery, B. This grounds the line through tongue, T, and leaves the battery open at the post, P. The "east" station (not shown) is a duplicate of the "west," and the control of relay, D, by the distant transmitter, T′, may be traced as follows. Suppose distant transmitter, T′, sends copper to the line when closed, the current dividing equally between the main and artificial lines in distant relay, D′, has no effect upon it; but at the west station there is no current in the artificial line in relay, D, so that the current in the main line closes it. Open the key, K′, and the line is grounded through the lever of transmitter, T′; battery B′ is open, and there being no current on the wire, relay, D, is open in response to the opening of distant key, K′. Let transmitter, T, now be closed, and trace the control of relay, D, by the distant key, K′. The current, which now flows from the ground through the lever of open transmitter, T′, to the zinc pole of battery, B, is neutralized in relay, D, by an *equal* current flowing from the ground through its artificial line in the opposite direction around its cores, so that relay, D, remains open. Now close distant transmitter, T′, and the current in the artificial line (i.e., through the rheostat, R) of relay D is overpowered as to its effects by a current on the main line of twice its strength, and relay D is closed. It is thus shown to be controlled by the distant key, K′, irrespective of the position of home key, K, and the conditions necessary to duplex telegraphy are met.

TELEGRAPH CODES.

Morse, used in the United States and Canada.
Continental, used in Europe and elsewhere.
Phillips, used in the United States for "press" work.

Dash = 2 dots.
Long dash = 4 dots.
Space between elements of a letter = 1 dot.
Space between letters of a word = 2 dots.
Interval in spaced letters = 2 dots.
Space between words = 3 dots

Letters.

	Morse.	*Continental.*
A	– ——	– ——
B	—— – – –	—— – – –
C	– – –	—— – —— –
D	—— – –	—— – –
E	–	–
F	– —— –	– – —— –
G	—— —— –	—— —— –
H	– – – –	– – – –
I	– –	– –
J	—— – —— –	– —— —— ——
K	—— – ——	—— – ——
L	———	– —— – –
M	—— ——	—— ——
N	—— –	—— –
O	– –	—— —— ——
P	– – – – –	– —— —— –
Q	– – —— –	—— —— – ——
R	– – –	– —— –
S	– – –	– – –

	Morse.	*Continental.*
T	—	—
U	- - —	- - —
V	- - - —	- - - —
W	- — —	- — —
X	- — - -	— - - —
Y	- - - -	— - — —
Z	- - - -	— — - -
&	- - - -	

Numerals.

	Morse.	*Continental.*
1	- — — -	- — — — —
2	- - — - -	- - — — —
3	- - - — -	- - - — —
4	- - - - —	- - - - —
5	— — —	- - - - -
6	- - - - - -	— - - - -
7	— — - -	— — - - -
8	— - - - -	— — — -
9	— - - —	— — — — -
0	——	— — — — —

Punctuations, etc.

	Morse.	*Continental.*
. Period	- - — — - -	- - - - - -
: Colon	— - — - - -	— — — - - -
:— Colon dash		
; Semi-colon	- — - — -	— - — - — -
, Comma	- — - —	- — - — - —
? Interrogation	— - - — -	- - — — - -
! Exclamation	— — — -	— — - - — —
Fraction line	-	
— Dash		
- Hyphen		— - - - - —
’ Apostrophe		- — — — — -
£ Pound Sterling		— - — - -
/ Shilling mark		
$ Dollar mark		
d pence		
Capitalized letter		
Colon followed by quotation :“		
c cents		
. Decimal point		
¶ Paragraph	— — — —	
Italics or underline		- - — — - —
( ) Parentheses	- — - - —	— - — — - —
[ ] Brackets		
“ ” Quotation marks.		- — - — - — - —
Quotation within a quotation “‘ ’”		

	Phillips.
. Period	- - — — - -
: Colon	— - — - -
: — Colon dash	— - — - — - -
; Semi-colon	- - - - -
, Comma	- — - —
? Interrogation	— - - — -

! Exclamation	— — — -
Fraction line	-
— Dash	— - - - — - -
- Hyphen	- - - - - — - -
’ Apostrophe	
£ Pound Sterling	- - - - - - — - -
/ Shilling mark	- - — —
$ Dollar mark	- - - - — - -
d Pence	— - -
Capitalized letter	- - - - — - -
Colon followed by quotation : “	— - — - - — -
c cents	- - -
. Decimal point	— - — —
¶ Paragraph	— — — —
Italics or underline	- - — - — - -
( ) Parentheses	- - - - - — - - - - - - - — -
[ ] Brackets	— - - - - - — - - - — - - - - - — - - -
“ ” Quotation marks	- - — - — - - - — - — -
Quotation within a quotation “ ‘ ’ ”	- - — - - — - - - - - — - - — - - -

Abbreviations in Common Use.

Min.	Minute.	*Bn.*	Been.
Msgr.	Messenger.	*Bat.*	Battery.
Msk.	Mistake.	*Bbl.*	Barrel.
No.	Number.	*Col.*	Collect.
Ntg.	Nothing.	*Ck.*	Check.
N.M.	No more.	*Co.*	Company.
O.K.	All right.	*D.H.*	Free.
Ofs.	Office.	*Ex.*	Express.
Opr.	Operator.	*Frt.*	Freight.
Sig.	Signature.	*Fr.*	From.
Pd.	Paid.	*G.A.*	Go ahead.
Qk.	Quick.	*P.O.*	Post Office.
G.B.A.	Give better address.	*R.R.*	Repeat.

TELEPHONY.

THEORY OF THE MAGNET TELEPHONE.

The Receiver. — The following cut is meant to illustrate in a simple manner about all that is known of the theory of the *magnet* or *Bell telephone*. It is well known that the lines of force in a bar magnet curve backward and around from one end or pole to the other. If a piece of iron, or say a diaphragm, be placed across one end of the bar, but not touching it, many of the lines will traverse the diaphragm, as the path so provided is magnetically easier than air. Now, if the diaphragm be moved backward and forward, or to and from the end of the bar, a change will take place in the position and condition of the lines of force surrounding that end of the magnet; and if a coil of fine wire be placed on the end of the bar close up to the diaphragm, then the changes produced in the lines of force will react on the coil of wire (as in a dynamo when the armature is moved across the lines of force), and an E.M.F. will be produced in the coil. This is the exact condition illustrated in the cut below.

Now, if the ends of the wire of the coil be extended, and connected to the terminals of an exactly similar instrument, any movement of the diaphragm of one will be exactly reproduced in the other instrument; and, therefore, if one talks against and so vibrates one diaphragm, the other will be vibrated, and speech will thus be repeated. While authorities seem to think that this simple theory is scarcely enough to account for all the results found in a telephone receiver, yet it apparently covers the greater part.

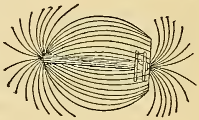


FIG. 1.
Field of Bell Telephone.

Based on the above theory, good transmission of sound needs:

A powerful magnet and magnetic field.

A diaphragm that will vibrate freely.

A wide, shallow coil, in order to take in as many lines of force as possible. The permanent magnet is essential to reproduce the pitch.

The Transmitter. — Although the Bell receiver proved to be an instrument of the most extraordinary sensitiveness, and as a receiver has never been superseded, yet as a transmitter its range is extremely limited, and much time has been spent by many minds in developing instruments to extend the range of telephonic transmission.

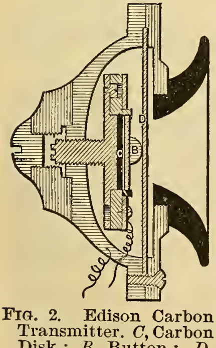


FIG. 2. Edison Carbon Transmitter. *C*, Carbon Disk; *B*, Button; *D*, Diaphragm.

While many inventors have tried to design a transmitter in which the circuit is broken at each and every vibration of the receiving diaphragm, yet none have succeeded; and successful telephones are based in principle on the change of resistance in a circuit, which produces undulatory curents, and that is exactly the point patented by Professor Bell.

Edison, taking up the principle, devised the transmitter known by his name, in which, to produce the undulatory currents, he utilized the change in resistance of carbon under varying pressure.

The cut herewith shows the design of the Edison Carbon Transmitter, which was quite a success as a loud-speaking instrument, and was doubtless the forerunner of the modern transmitters. The instrument consists of a button of lamp-black, compressed between two metal plates to which the conductors are connected, with a battery in circuit. An ivory button presses against the cake of lamp-black, or carbon, and is in turn pressed by the diaphragm.

Hughes next determined, by his experiments with the *microphone*, that the maximum effect is produced when the contact with or between the particles of the carbon is a *loose* one. He showed many beautiful experiments with that crudely made instrument which is shown in principle and as used in the following cuts.

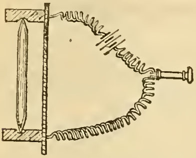


FIG. 3. Hughes Carbon Microphone.

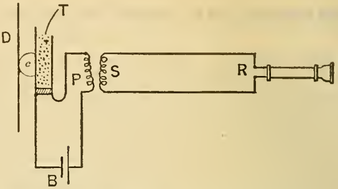


FIG. 4. Diagram of simple telephone circuit for transmitting in one direction. *C*, pressure button ; *D*, diaphragm ; *T*, loose carbon contacts ; *B*, battery ; *P*, primary of induction coil ; *S*, secondary ; *R*, bell receiver.

The well known principle of the induction coil was then utilized to magnify the effects of the undulations ; and thus were devised all the essential features of the modern telephone transmitter, which are in use to-day in every commercial instrument. The following cuts show the simple form in which all the above mentioned principles are connected to form a practical telephone.

The principles are :

The diaphragm, operated by sound vibrations, varying the pressure on loose carbon contacts, and varying the resistance in the local circuit so as to produce undulatory currents, which are reproduced in the secondary circuit of the induction coil, transmitted over the line circuit to the receiver, where the undulatory currents cut the lines of force surrounding the coil, and produce exactly similar vibrations in the diaphragm adjacent to it, thus vibrating the surrounding air, and producing sound waves identical with those directed at the diaphragm of the transmitter.

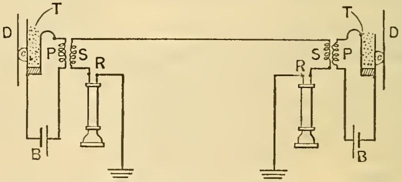


FIG. 5. Diagram of simple telephone circuit for conversing, or transmitting in both directions. Letters all the same as in previous cut.

Receivers. — The Bell receiver is almost universally used to-day. It varies in its construction only in using a single-pole magnet for ordinary work, a double-pole magnet for long-distance circuits, and the watch-case receiver for desk, speaking-tube and operators' sets. All are shown in the accompanying cuts.

It has been found that a very narrow air-chamber between the diaphragm and mouth-piece produces the best results, and that a small hole through the rubber of the cap helps also.

Few if any improvements have been made excepting in the use of better quality of materials and better construction.

The reader is referred to the "Telephone Hand Book" by Herbert Laws Webb (Electrician Publishing Co., Chicago), for description of foreign and other instruments.

FIG. 6. Magnet of Single Pole Receiver.

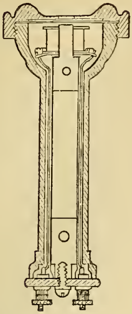


FIG. 7. Single Pole Receiver.

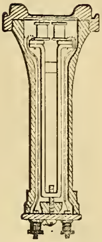


FIG. 8. Double Pole Receiver.

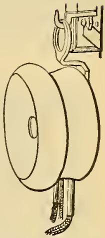


Fig. 9. Watch Receiver.

Transmitters. — After Edison designed his carbon transmitter, and Hughes made the microphone experiments, the Bell receiver was no longer used for transmitting purposes, and numerous forms of battery transmitters were designed. To-day they are legion, and differ, generally speaking, only in inessential details. Only those forms mostly in use will be described here, as they illustrate in principle nearly all others.

None but carbon transmitters are used to-day, and these are in three principal forms or classes; the first using single contacts, of carbon for varying the resistance, as in the Blake; the second using several contacts; and the third class, known as the Hunning type, using granulated carbon. Granular carbon transmitters are more used than any other type.

Transmitters of the second class are not used to any great extent in the United States. The Blake, of the first class, and the "solid back," of the third class, are the forms most used by American companies, the latter largely predominating since the extensive adoption of metallic circuits.

I can do no better than quote, in describing these instruments, from Webb's "Telephone Hand-Book."

Blake Transmitter. — For lines of moderate length, the *Blake transmitter* will give good service if kept in good adjustment. It is of simple construction, low first cost, and requires but little battery power. It has the disadvantage of needing careful adjustment when set up, and frequent inspection and adjustment while in service.

Each of the parts has an important function to perform, and on all being in good condition depends the efficient working of the instrument. See Figs. 10 and 11.

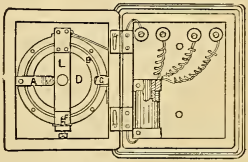


FIG. 10. Blake transmitter. *D*, Diaphragm; *B*, rubber band; *C*, clip; *A*, damper; *L*, iron bracket; *F*, adjusting-screw.

The variable resistance is made in the following way: A slender spring, carrying a platinum contact point, bears on the centre of the diaphragm. A second spring carries a button of compressed carbon let into a rather heavy socket of brass. The face of the carbon button presses lightly on the platinum contact point of the first spring. The vibrations of the diaphragm cause the pressure of the platinum point on the carbon button to vary, resulting in a variation of the resistance at the contact. The secret of the good working of the instrument is that the two sides of the contact have no rigid bearing. In Edison's first transmitter he made one carbon contact solid with the case, and the other solid with the diaphragm. Consequently, the variable contact was not sufficiently "sympathetic," as it were, with the vibrations of the diaphragm, and the instrument did not work well. Blake discovered the reason of the defect, and applied the remedy.

In the Blake transmitter the carbon button "stands up" to the platinum contact, securing the full effect of the variations in pressure, because of the weight of the brass socket; that is, because of its *inertia*, or resistance to be set in motion. The platinum contact is held against the diaphragm by the carbon button, but the normal set of its spring is *toward* the button and *away* from the diaphragm. Consequently we have a delicately balanced arrangement, susceptible to change by the least vibration communicated by the diaphragm to the platinum point.

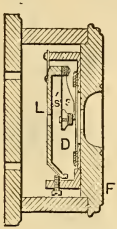


FIG. 11. Section of Blake transmitter. D, diaphragm; S, carbon spring; S', platinum spring; L, iron bracket; F, adjusting-screw.

The arrangement of the parts to allow of proper adjustment of the springs is very ingenious. An iron ring is attached to the inside of the case, this ring having a bracket, or projection, top and bottom. To the top bracket is attached a piece of angle iron bent at its upper part to a right angle, at the lower part to an obtuse angle. The lower bracket serves as a bearing for the screw by which the iron support may be adjusted. The top part of the support carries the two springs, which are insulated from each other by hard-rubber washers. The carbon spring is sheathed with a rubber sleeve, the diaphragm (generally of iron) is clamped over a rubber gasket, and is provided with a damper, consisting of a metal spring screwed to the inside of the case. This damper is rubber-covered, and has a little cloth pad that presses on the diaphragm near its centre. The damper checks the vibrations of the diaphragm as quickly as they have done their work, preventing continued vibrations that would interfere with those following. The adjustment of the springs is effected by means of the screw bearing on the obtuse angle of the iron support. Turning the screw upward forces the support, and consequently the carbon button, toward the diaphragm, increasing the pressure between the button and the platinum contact. A reverse action of the screw allows the support to come away, by reason of the outward set of the spring by which it is attached to the iron frame, resulting in a decrease of the pressure between the button and the platinum contact. The normal set of the spring with the platinum contact gives it a tendency to follow the carbon button, and, if the button is pulled back, the platinum contact should follow it nearly half an inch. The best adjustment is when the pressure of the carbon button on the platinum contact just holds it lightly against the diaphragm, not so lightly as to allow of any separation or break when the diaphragm is vibrated by the voice. The two springs of the transmitter are, of course, connected in circuit with the primary wire of the induction coil and with the battery. The induction coil generally used in the Blake transmitter has a resistance in the primary of half an ohm and in the secondary of about 250 ohms.

The "Solid-Back" Transmitter.—The transmitter case is of metal, and has much the form of the gong of an electric bell; it is enclosed by a perforated metal lid or cover, to which is attached the mouthpiece. The cover carries the entire transmitter, which consists of two small carbon disks enclosed in a metal chamber having an insulating lining; between the disks is a layer of finely granulated carbon, and the disks being slightly smaller than the containing chamber, the surrounding space between the edges of the disks and the side of the chamber is also filled with carbon granules. The back electrode is in metallic connection with the containing chamber, a little pin in the brass backing of the carbon disk fitting into a recess in the chamber, and holding it firmly seated. The front electrode is insulated from the chamber by the insulating lining of varnished paper and by a mica disk or washer, which encloses the chamber when the front electrode is placed in position. The front electrode is secured to the vibrating diaphragm of the transmitter by means of a pin, which extends from its brass backing through a hole in the centre of the diaphragm. This pin has two threads, one for a nut that clamps the mica washer over the end of the chamber containing the two electrodes, and a finer one for two small nuts that clamp the electrode to the diaphragm.

The mica washer is held against the little chamber by a brass collar, which screws on the brass chamber itself, and secures the mica washer to it around its edge. The mica washer being clamped to the chamber at its periphery, and to the front electrode at the centre, has sufficient elasticity to allow of the electrode responding to the vibrations of the diaphragm, and at the same time the transmitter chamber is effectually closed. The chamber has a projecting stud at the back which fits into a hole in a stout brass bridge, and is there secured by a set screw. The metal bridge is screwed to the cover of the transmitter case. The diaphragm, which is of metal, is secured to the cover, and is provided with the usual clip and padded dampening spring. One end of the brass bridge carries a block of insulating material, and to a small binding-post on this block a fine wire, attached to the front electrode, is connected. The rear electrode, being in metallic contact with the bridge and through it with the case of the transmitter and the supporting arm, needs no special connection, one side of the primary circuit being connected to the arm of the transmitter. The other side is connected by a cord, which passes through a hole in the bell-shaped transmitter-case to the binding-post on the insulating block.

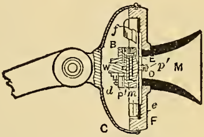


Fig. 12. Section of Solid-Back Transmitter. *M*, mouthpiece; *D*, diaphragm; *E*, front electrode; *B*, back electrode; *W*, electrode chamber; *P*, metal bridge piece; *d*, set screw; *m*, mica washer; *p*, threaded pin on front electrode; *e*, rubber band; *f*, damper; *C*, case; *F*, cover.

The vibrations of the diaphragm are communicated to the front electrode by the pin, which forms a rigid connection between them. The electrode, having a certain freedom of movement within the little chamber, varies the pressure on the layer of carbon granules between it and the back electrode, thereby setting up the usual variation of resistance required in a carbon transmitter. The design of the instrument is very good. The two electrodes, being of carbon, make excellent contact with the carbon granules, thus affording the best opportunity for wide variation of resistance under vibration, while the carbon electrodes, being soldered to brass disks, good metallic contact is obtained with the two sides of the primary circuit. The "packing" difficulty is, to a considerable extent, obviated by this form of transmitter. The space in the chamber around the edges of the electrodes contains a certain quantity of granulated carbon, which is not directly in the circuit, and does not become heated up rapidly by the current; and any expansion of the granules immediately between the electrodes through heating causes a displacement of part of the heated carbon into the cooler. When the transmitter is out of circuit and cools off, the granules tend to resettle into their original position.

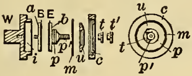


Fig. 13. Details of Solid-Back Transmitter. *W*, electrode chamber; *i*, insulating lining; *B*, back electrode; *a*, brass backing; *E*, front electrode; *b*, brass backing; *p*, thread for nut *U*; *m*, mica washer; *u*, nut for clamping *m* in place; *p′*, thread for *t* and *t′*; *c*, cover of *W*; *TT*, nuts for clamping front electrode to diaphragm.

The chamber containing the working-parts of the instrument is extremely small, and forms a sort of button attached to the front cover of the case. By unfastening the screws which hold the cover, the entire transmitter can be withdrawn, the connecting cord joined to the insulated binding-post having first been disconnected. On account of the smallness and delicacy of the parts, great care is required in handling the transmitter when assembling or taking apart. When properly set up, it needs no adjustment; and indeed there is nothing that can be adjusted unless some radical defect exists. Figs. 12 and 13 show the details of construction by means of a section of the transmitter mounted, and a section of the various parts of the chamber, and a front view of the chamber

Magneto Generator and Bell.—The magneto generator has, in the United States, displaced every other device for a calling signal for use with telephones.

It is simply a crude form of alternating-current dynamo having permanent magnet fields, and but one armature coil with its terminals led out through the shaft, and one contact. To this dynamo circuit is joined a polarized bell or ringer. It is made up of a small electro-magnet that is connected in circuit with the wires from the small dynamo; and when that instrument is brought into action by revolving its armature, current is sent through the coils of the electro-magnet, thus energizing it alternately, first in one direction, then in the other, and throwing its armature, or keeper, which is pivoted opposite the poles, back and forth, and so vibrating the hammer attached to the armature between the two gongs mounted above. The *polarized* bell has a small permanent magnet fixed to the frame carrying the electro-magnet, which tends to keep the armature pressed over in one direction. Owing to the high resistance of the generator armature, this, when not in use, is cut out of circuit, and only the bell coils left connected to the line. There are many ways of effecting this change in the circuits automatically, but the devices employed are so varied that no description will be attempted here. The cuts shown embody the theories and general methods of connection.

An extension bell should only be connected in the ringing-circuit, as shown in the cut. An extension bell is simply the ringing-portion of a magneto separated from the dynamo part, in order that it may be placed in some distant location, where it is necessary to get a signal from the telephone.

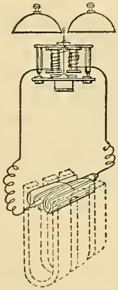


FIG. 14. Magneto-Generator and Bell.

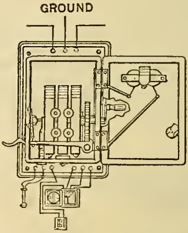


FIG. 15. Complete Magneto-Bell. Post Pattern.

Automatic Switches.—In a complete telephone set or instrument there are several circuits, or parts of circuits, each having its own application.

The *ringing*-circuit consists of the magneto-bell and generator, the armature of the latter being individually controlled by an automatic device.

The *talking*-circuit, consisting of the secondary of the induction coil, and the receiver.

The *primary* circuit, consisting of the battery, the variable resistance of the transmitter, and the primary of the induction coil.

The automatic switch must be so designed as to connect the ringing-circuit to the line when the instrument is not in use, so that signals may be received from other telephones or from the exchange, and to cut out the *ringing*-circuit, and connect the line to the *talking*-circuit, and close the *primary* circuit when one wishes to talk.

This is almost always done by using the weight of the receiver to hold down a switch that will make all the necessary contacts for cutting the *ringing* circuit in when the instrument is not in use. When the weight of the receiver is removed, a spring lifts the switch to an upper position, in which it closes another set of contacts through the *talking* and *primary* circuits, and leaves the *ringing* circuit either open or short-circuited.

There are so many of these switches that only a diagram of a standard plan can be included here. A second diagram shows the proper connection for an extension bell.

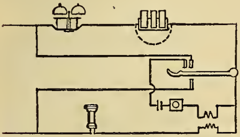


FIG. 16. Diagram of Connections of Series Magneto Bell and Telephone Set.

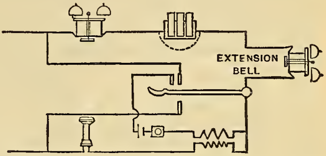


FIG. 17. Diagram showing proper Connections of Extension Bell.

Requirements of Metallic Circuits. — Metallic circuit telephone lines must fulfil the following conditions: —

a. Both wires of the circuit must have substantially the same *resistance.*

b. Both wires must have substantially the same *electrostatic capacity.*

c. Both wires must have substantially the same *insulation resistance.*

Overhead Circuits on Poles. — The above three requirements mean practically that both wires must be of the same material, the same length, have the same methods of insulation, be carried on the same poles (or in the same cable), and in most cases should be on the same cross-arm, and always adjacent to each other.

Electrostatic capacity is treated in the chapter on conductors.

Mutual- and self-induction are also treated in the chapter on conductors, but there are some points applying especially to telephone circuits that will be mentioned here.

The telephone is so sensitive that unless care be taken to prevent it, the induction from neighboring lines will produce noise and "cross-talk." Therefore, both lines of the circuit must be balanced in relation to adjacent lines, so that induction from them may be neutralized.

This is usually accomplished by transposing the two wires of a circuit at certain intervals along the line, the frequency of such transposition varying according to the number of circuits on the line and the length of line. On the main long-distance lines it is usually done every quarter of a mile.

The following cuts show the methods of transposition used in the United States and in England.

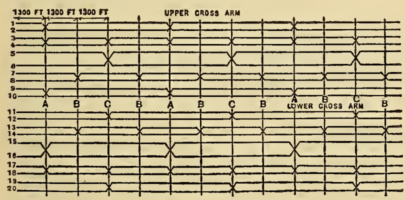


FIG. 18.

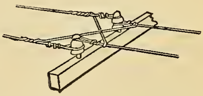


FIG. 19. Transposition of Metallic Circuit.

In American practice if more than two cross-arms are used, odd-numbered arms are transposed as the upper arm in Fig. 18, and even-numbered arms are transposed as the lower arm in Fig. 19.

In England it is sometimes the practice to change the position of the wires at each cross-arm, so that in four spans two wires of a circuit make a complete twist about each other.

Aërial cables for telephone circuits are generally made up of No. 18 B. and S. copper wire, insulated with rubber to $\frac{3}{32}''$.

The wires are twisted in pairs, and laid up into a cable containing the number of wires required. Each layer is taped, and the whole is wrapped with two strong tapes impregnated with a preservative compound, and laid on in reverse layers.

In modern practice lead-covered dry-core cable is frequently used for aërial cable with very successful results. The lower cost and improved electrical conditions are substantial arguments in its favor. The chief disadvantage is the weight of lead-covered cable as compared with rubber.'

Underground Circuits.—For many years after the introduction of the telephone the difficulties of working through underground wires seemed insurmountable. The electrostatic capacity of the underground wires of early days was so much greater than that of overhead circuits as to materially interfere with telephonic transmission. In late years, however, the methods of insulation have been so much improved that many thousands of miles of telephone wire are now under ground; and it may be said that underground construction of telephone circuits is the general rule in large cities, and is rapidly being adopted even in small towns.

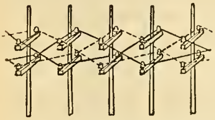


FIG. 20. English method of of Transposing Metallic Circuit.

The electrostatic capacity of a submarine conductor is twenty times that of an overhead copper wire of equal resistance; and the etectrostatic capacity of the early forms of paraffined-cotton insulated cable was about twelve times as high as that of an overhead copper conductor, 104 mils diameter; but the underground conductor, being of much smaller cross-section, has a higher resistance, about seven times that of the overhead wire in the case above cited.

Underground Cables.—The standard type of cables for telephone work contains four hundred insulated wires, twisted in pairs with about three-inch lay; and the pairs are cabled in reversed layers, forming a cable about 2 inches diameter. The cable is always enclosed in a lead pipe with walls ⅛ inch thick, and for the size here under consideration about 2¼ to 2½ inches diameter. 100-pair and 50-pair cable, and various smaller sizes, are used for distribution. Originally 50-pair was the standard size; it was later replaced by 100-pair, and now 200-pair has practically become the standard cable for main routes.

Cables are often made of other sizes, sometimes of 500 and even of 600 wires; but such large cables are difficult to handle, and 100-pair is the size most generally used in large cities.

The insulation of cables is now mostly of dry paper loosely wound on the wire. This method of construction secures a low capacity and a high insulation as long as the lead covering remains intact, preserving the dryness of the paper.

The standard size of copper wire for telephone cables is now No. 19 B. and S., which has a resistance of about forty-five ohms per mile.

The average mutual electrostatic capacity is about .085 microfarad per mile, and runs as low as .07 microfarad per mile.

The insulation resistance of all conductors should exceed five hundred megohms per mile, after being laid and connected to the cable heads; and in practice this resistance is nearly always much higher, often several thousand megohms per mile.

The lead covering of underground cables is nearly always alloyed with three per cent of tin; and in many cities where the gases are destructive to the lead, a covering of asphalted jute is served outside the lead.

Submarine telephone cables are usually made up of stranded conductors, seven No. 22 B. and S. wires, insulated with rubber compound to $\frac{3}{32}$ inch.

The cores are twisted in pairs the same as the paper insulated underground conductors, and cabled together much in the same way. Ten pairs of conductors is the usual limit for a submarine telephone cable. The cable formed by the cores is served with hemp, and armored with galvanized iron wires, the iron being protected by a layer of hemp soaked in a pitch compound. In situations where the risk of damage by anchors, etc., is not great dry core cables are now used for river crossing. The cable is iron-armored over the lead sheathing.

Lightning and Current Arresters.—Telephone lines need protection from :

a. Lightning.

b. Crossing with heavy currents that will immediately burn out the instruments.

c. Crossing with "sneak" currents, or currents feeble enough not to burn out at once, but by gradual or slow heating cause the destruction of the instruments or parts of them.

A simple fuse wire would afford ample protection in most cases but for the danger that it will be replaced, when blown, by a copper wire.

The fuse at the outer terminal of an underground cable is usually set to blow at eight amperes.

A style of protector now extensively used, especially to protect the central-station instruments, is the one shown in the following cut. It has an air-space cut-out that blows if pressure on the circuit reaches 300 volts ; and a "sneak" current arrester that will ground the line within thirty seconds, under a steady current of .3 ampere.

The air-space cut-out consists of two blocks of carbon, separated by a thin strip of mica, with a perforation in the centre. The upper carbon block has a drop of fuse-metal let into its lower face, which completes the short circuit when the current sparks across the space.

The lower block rests on a metal strip that is grounded, and the upper carbon block is held in position by a spring connected to the line.

The sneak current-arrester is a small spool of fine German-silver wire, having a resistance of 28 ohms.

In the centre of this spool is a metal pin, which is normally prevented from passing clear through by a drop of fuse-metal, but which is released when the drop of fuse is melted by the heating of the coil by a foreign current, and allows the lower spring connected with line to fly up, and make contact with a ground strip.

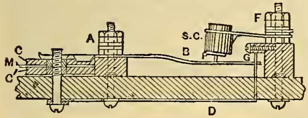


FIG. 21. Combination protector. A, line-post ; F, instrument post ; B, German-silver spring ; CC, carbon blocks ; M, mica sheet ; S C, sneak coil ; P, releasing-pin ; G, grounding-strip ; D, ground wire.

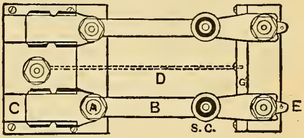


FIG. 22. Plan of Combination Protector.

Notes on the Installation and Maintenance of Telephones.—The subscriber's telephone should be placed in some location out of the usual route of office traffic, and on a solid wall or where it may be free from vibration.

Use No. 18 B. and S. rubber-covered wire for connection to outer circuits, unless wires are to be much exposed, when it is better to use No. 16 B. and S. The rubber on No. 18 should be at least $\frac{3}{32}$ thick, and on No. 16 at least $\frac{5}{32}$.

Following the rules of the National Conference of Underwriters (see index for insurance rules) will insure a good job ; and as they must be followed, it is hardly necessary to give other directions.

Instruments should be periodically inspected, and all parts should be kept clean and bright.

Go over all connections and binding-posts and see that all are tight, also that all screws are tight.

Dirty contacts and frayed cords often cause much trouble.

Examine the receiver by unscrewing the ear-piece. The diaphragm should not be bent or dirty or rusty ; the pole-piece should be clean, and the top should be $\frac{1}{32}$ inch from the diaphragm, no more, no less ; if it is farther away from the diaphragm, the field will be too weak, whereas if much nearer, the diaphragm is liable to stick. A good test for strength of magnet is to see if it will hold up the diaphragm by its edge.

In the *magneto bell* keep all contacts clean and bright, especial attention being given to those of the automatic switch and shunt.

Gearing and armature bearings should work freely and be occasionally oiled.

The bells should ring clearly, and when ringing dull are probably loose at centre.

Short circuit the bell binding-posts and turn the crank; the bell should ring. Place a resistance of several thousand ohms between bell and generator, and the bell should then ring when crank is turned. A generator may be strong enough to ring its own bell on short circuit, and yet not do it through resistance.

It is, however, of the most importance that the generator be capable of ringing the distant bell, or of throwing the drop at the central station.

If the bell is known to be all right, and will not ring on short circuit, then the fault will be in the generator armature, and may be caused by a broken wire or a bad contact. If its contacts are platinized, clean with unglazed writing-paper; if not platinized, use emery paper.

Short circuit the binding-posts of the transmitter, then tap on the mouthpiece or diaphragm of the transmitter, and notice quality of the "side-tone," which will enable the inspector with some practice to judge of the condition of the transmitter and battery.

In the *Blake transmitter*, the rubber band under the diaphragm, the pad, and the sleeve must be soft and elastic, and the rubber ring encircling the diaphragm must not stick to the casting.

The platinum spring should touch the diaphragm only with its point.

The platinum spring and that carrying the carbon should both be tightly clamped to the support.

The contact between the platinum point and the carbon button must be clean; and, as the platinum tends to dig into the carbon and to roughen itself, it is highly important that the platinum point be smoothed and burnished, and that the carbon be rubbed down with emery paper, giving the final polish with a clean piece of paper. The platinum point, if not too rough, can be polished with unglazed writing-paper.

Make final adjustment with the bottom screw on the iron support. Test results with side tone until the talk is clear.

If the talk has a hollow sound, weaken the damper and slip.

If the volume is poor, loosen the adjusting-screw, stiffen the damper, and see that the platinum point rests well against the diaphragm.

If the sound is broken and confused, give the platinum spring more "follow" to the carbon button, and see that the diaphragm is firmly clamped on the rubber ring, and that there are no inequalities in the ring. If the sound is scratchy, clean the platinum and carbon, and see that the platinum spring is not twisted.

A weak battery will give a weak transmission, as will also a high resistance in the primary circuit.

Frying and buzzing sounds may be caused by loose battery connections or dirt on the carbon button.

A bent diaphragm will give a metallic sound to the transmission.

There is no adjustment to the *solid-back;* and its efficiency depends on its having been properly set up at first, and on the condition of the battery and its circuit.

The good working of granular-carbon transmitters depends mainly on the battery. If the battery power be too low, the transmission will, of course, be weak; but if it be too high, the transmitter may be overheated, which will injure it.

Two cells of Fuller battery giving about 4.2 volts, or two cells of storage battery giving about 4 volts, are generally used with the solid-back instruments.

The resistance of the primary circuit is very low when the transmitter is at rest, being for the transmitter itself about 1 ohm; the current may then be 2½ to 3 amperes, and the heating may produce packing.

When the transmitter is spoken into, the resistance immediately rises to about 10 ohms, and the current decreases to .6 amperes or less.

Below is quoted from "Webb" the methods of locating trouble in a telephone.

"When a telephone will not work, the trouble may be either in the line, the inside wiring, or in the instrument and its connections. If, on short-circuiting the instrument at the top binding-posts the bell rings and side tone is obtained, the instrument is all right. The inside wiring should then be tested by short-circuiting the wires if a metallic circuit, or attaching a temporary ground if a grounded circuit, at the point where the line enters the building; if the bell then rings, the trouble is in the line, and must be found in the ordinary way. If the bell does not ring, the fault is in the inside wiring, and can soon be traced out. If no side-tone is obtained at the first test, the instrument is at fault. Either the receiver or a detector galvanometer may be used in locating the defect. The receiver is most convenient, and it should be tested first by connecting it directly to the battery; if a good click is heard, it is all right; if not, there may be a broken wire in the receiver, or the diaphragm may be out of order. If the receiver is good, the primary circuit should be tested by opening it at one of the connections, the automatic switch being up, and trying for current either with the receiver or by testing. If no current is found, the trouble may be a broken or disconnected wire, loose binding-post, corroded connection, battery dry or zinc eaten off; the automatic switch may have a bad contact through rust or dirt, or bent or loose springs, or broken wire; the transmitter may have a broken wire or cord, or may be open at the variable resistance through bad adjustment or lack of carbon. All the various paths for the current in the primary circuit should be traced out from one pole of the battery back to the other, and the trouble will quickly be found. If the primary circuit tests O.K., the trouble must be in the secondary circuit; and this can be tested by connecting one terminal of the battery to one binding-post of the telephone and touching the end of a wire joined to the other terminal to various points in the secondary circuit, beginning with the second binding-post of the telephone. When a click is heard in the receiver, the trouble lies between the point just touched with the wire and the second binding-post of the instrument.

The inspector's kit should contain the following tools and material:

Pair cutting pliers,
Pair long-nose pliers,
Warner Battery gauge,
Tack-hammer,
Screw-driver,
Soldering lamp and iron,
File,
Dusting brush,
Coil of insulated wire,
Rubber tape for covering joints,
Candle for examining instruments,
Solder and soldering fluid,
Small bottle of oil,
Trimming-knife,
Box containing screws, staples, washers, nuts, etc.,
Chamois skin, cloth, and polishing paste,

Spare parts of instruments, such as transmitter and receiver diaphragms, cords, hinges, bell-cranks, gongs, rubber bands, dampers, clips and springs, carbon buttons, and granulated carbon.

The small articles are conveniently carried and kept in good order by using small round tin boxes to contain them. A separate stout bag should be used for battery material, and should contain a number of spare zincs and carbon plates or porous cups complete, a supply of sal-ammoniac, etc., a strong knife, a sponge, and a quantity of cotton rags or waste.

The author feels it is necessary to offer some apology for having confined the foregoing text so largely to telephone instruments used by the Bell Company only; but principles only are meant to be treated, and there is little available data that would serve to make those principles plainer. Many of the so-called independent instruments are well designed and constructed, and are gradually making headway. The same methods of test and connection in general apply to one as well as to the other.

TELEPHONE SWITCHBOARDS.

The subject of switchboards will be treated only as to diagrams showing the general principles on which they are constructed. They differ much in details, and one company at least is carrying on a quite extensive business with an automatic switchboard having no operator whatever. No description is at this time available which does justice to the exceedingly ingenious instrument that makes the connections automatically between any two subscribers.

Many improvements in detail have been introduced, and are continually being brought out, such as self-restoring drops, luminous indicators in place of drops, and various other devices which cannot be mentioned here.

Multiple Switchboard.—The multiple switchboard is in use in most of the large offices, and, while very complicated in practice, is simple in theory, and is designed to enable the operator to be independent of other operators, and to reach each subscriber's line without excessively long cords. The board is divided into sections, each being of such a size that an operator can reach either end, and yet three operators may work at the board without inconvenience.

Every subscriber's line has a spring-jack at every section, but the drop or other visual signal is on one section only. There are usually 200 drops on a section; therefore when a subscriber calls "central," the operator inserts her plug in the spring-jack of the subscriber, learns with what number he wants to be connected, then connects one end of a cord from the calling subscriber's jack to the one he called, as the number called for has a jack on every section. The following diagram shows in simple form the connections for three subscribers' circuits for three sections of a multiple circuit board. This diagram (Fig. 22*a*), as are those following, is from an article in the *American Electrician* by Kempster B. Miller.

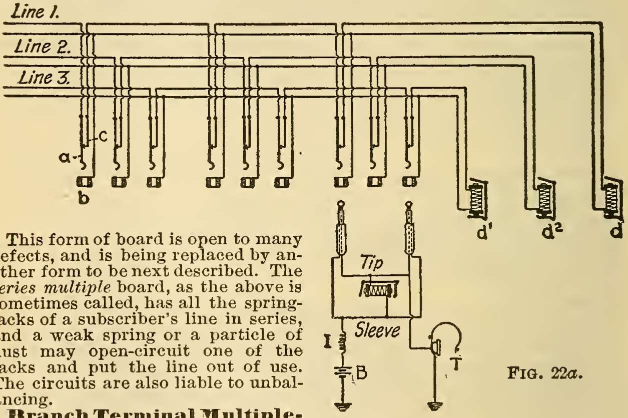


FIG. 22*a*.

This form of board is open to many defects, and is being replaced by another form to be next described. The *series multiple* board, as the above is sometimes called, has all the spring-jacks of a subscriber's line in series, and a weak spring or a particle of dust may open-circuit one of the jacks and put the line out of use. The circuits are also liable to unbalancing.

Branch Terminal Multiple-Board.— This is a multiple-board devised to overcome the defects of the *series multiple*-board previously described. The general distribution of circuits is the same, but the spring-jacks are connected to the subscriber's line in *multiple* instead of in *series*. There is a common ground-wire for all sections, and there is also a third wire through each section for each circuit of a subscriber. This line is so connected through the drop magnet as to automatically restore the shutter when connection is made to the calling subscriber's jack.

The following diagrams (Figs. 22*b*, 22*c*) give the scheme of the connections.

Express System.—As the number of subscribers increases, the multiplicity of circuits, jacks, and connections increase as the square of the number on all multiple-boards.

Messrs. Sabin & Hampton of San Francisco devised a system that has been in use several years in the San Francisco office. It is much simpler than the multiple system, but not so handy to operate. Each subscriber's line has one line-jack, which is on a section of board which may be termed "B" boards. The "B" boards are divided into sections of 100 lines each, with an operator for each section. Another set of boards, called "A" boards, are used as a sort of clearing-house, through which all connections from subscriber to subscriber are made. Trunk-lines lead from the "B" boards to the "A" boards, and an order-wire connects the "A" board operator with the "B" board operators. When a subscriber calls, the "B" operator on the section on which the calling subscriber's line-drop happens to be situated merely plugs a trunk-line into the subscriber's spring-jack. The "A" operator inserts her listening-plug in the trunk-line just connected, and asks what number is wanted. She then calls through the order-wire to the "B" section on which the required number is situated, asking that operator to plug a trunk-line in on the number required, which she does, and answers back giving the number of the trunk-line she proposes to use; and the "A" operator then connects the ends of the two trunk-lines by a multiple cord, as on the multiple-board. The process would seem to be complicated, but is said not to cause unusual delays.

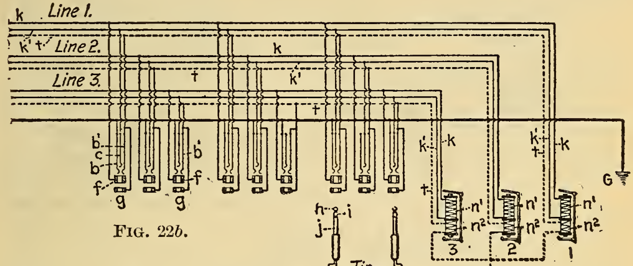


FIG. 22b.

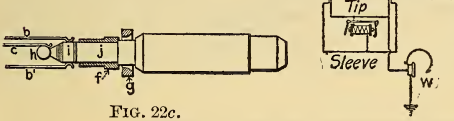


FIG. 22c.

No magneto bell is used; the subscriber merely removing his telephone from its hook operates the calling drop, which immediately restores itself when the trunk-line is plugged in or the subscriber hangs up his telephone. The drop signal also operates at once, should the "B" operator pull the trunk-line plug before the subscriber has finished. One small storage battery is sufficient for a large exchange; and the entire plant, — boards, subscribers' instruments, and all, — is much less expensive than those of the ordinary multiple type.

The diagrams (Figs. 22d, 22e) show the scheme of connections in the *Express System;* the first one showing the subscribers' lines and their connections to the "B" boards, while the second diagram shows the "central" connections.

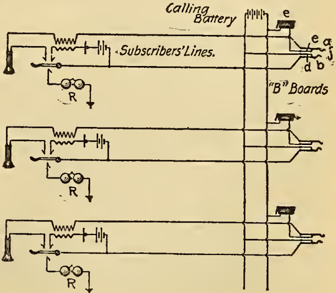


FIG. 22d.

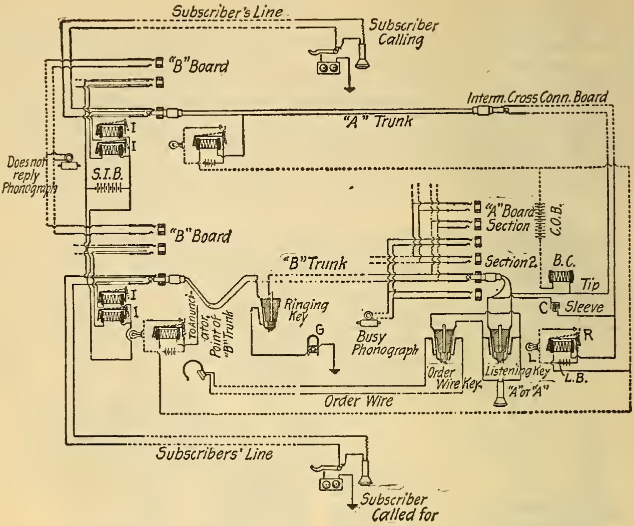


FIG. 22e.

COMMON-BATTERY SYSTEM.

The common-battery system, as its name implies, is a centralized energy system; i.e., the transmitter and signalling batteries, or sources of energy, are all located at the central office or exchange. This centralization has numerous advantages: batteries at each station are done away with, thus lessening the inspection and maintenance charges; hand generators are not required at each station, thus decreasing the investment; and the apparatus at stations is made much more compact and neater. The power-plant at the central office is, however, more expensive to instal and maintain than in the magneto system. The service is quickened, and the labor on the part of the subscriber is diminished.

The underlying principle of the common-battery system is the insertion of a battery into the line connecting two stations, the battery being a part of the cord circuit completing the connection, between the stations, at the exchange.

The line from the station enters the exchange, passes through the contacts of a cut-off relay, then one side of the line passes directly to ground, while the other side passes through a line relay, and battery to ground. A line lamp signal, an auxiliary relay and battery, are connected through the contacts of the line relay, the auxiliary relay controlling a pilot lamp signal. The cord circuit contains a repeating coil and battery. Supervisory relays, controlling lamp signals, are placed in both the answering and the calling sides of the cord circuit at the exchange. The calling side also contains a combined ringing and listening key, or separate keys.

The operation of this system is briefly as follows: Nominally the receivers are on the hooks, and the line-circuits are open. Removing the receiver from the hooks closes the line circuits through the contact of the hook-switch, current then flowing through the line from the central office. This flow of current energizes the line relay, closes its contact, thus lighting the line lamp signal, and closing the contacts of the auxiliary relay which in turn lights the pilot lamp. The pilot lamp acts as a safeguard in case the line lamp is broken, and also gives the supervising operator an indication as to the line operators' punctuality in answering calls. The lighting of the line lamp indicates that a station is calling. The operator takes the answering plug of the cord circuit and inserts it into the jack of the calling line. This introduces grounded battery through the sleeve of the plug, energizes the cut-off relay, opens the circuit of the line relay, and thus extinguishes the line and pilot lamp signals. Having ascertained the number called for, the operator inserts the calling-plug into the proper jack, and rings the called for station. As long as the receiver at the called-for station remains on the hook the supervisory relay in the calling side of the cord circuit is not energized, and the supervisory lamp is lighted. As soon as the receiver is removed from the hook the supervisory relay is energized, and the lamp is shunted out by a low resistance, and thus extinguished.

When neither of the supervisory lamp signals in the cord circuit glows, the operator knows that both receivers are off the hooks. The operator can supervise the conversation, if necessary, by means of the listening-key. If neither station hangs up its receiver, the supervisory relay armature is released, and the corresponding lamp signal glows. When both lamps glow, the operator knows that both stations have hung up their receivers and that the connection is at an end, whereupon she disconnects by removing the two plugs from their jacks. If during the connection one station wishes to attract the attention of the operator, he can do so by moving the receiver hook up and down, thus causing the supervisory lamp signal to flash.

Lamp signals as above described are much used in the larger exchanges, and are rapidly coming into more extended use. The magnetic signals are, however, largely employed in the smaller exchanges.

In furnishing many lines with currents from the same battery, precautions must be taken to eliminate cross-talk. This is accomplished by using storage-batteries of large capacity and very low internal resistance, and of copper bus-bars of large cross-section. The multiple board is largely used, usually of the divided type. A good description of the common-battery system is to be found in Miller's "American Telephone Practice."

PARTY LINES.

Until 1896 or 1897 no party-line system seems to have been invented that was at all satisfactory for regular use ; but the advent of the "B.W.C." system, put forward by the Bell Co.'s, has changed all that, so that in residence districts lines with six or more subscribers are becoming very common ; and, as the charge for such installations is materially less than for the direct line-system, and only the latest and best instruments with metallic circuit are used, the service is equal to the best.

A good description of the "B. W. C." (Barrett, Whittemore, Craft) system has been published in the *American Electrician* for January and February, 1899.

No special systems can be described here except in illustration of principles of working.

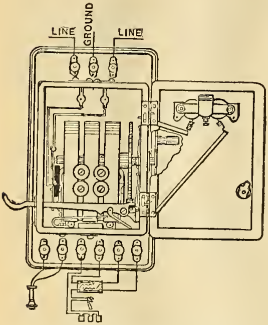
As the telephonic current is undulatory, it is retarded by coils of wire having self-induction ; and all such coils connected into the line hinder the good working of its instruments. For this reason but few telephones can be connected in series and work with any kind of satisfaction, as the self-induction of the bell-magnets soon cuts down the transmission below the working-point. In practice, telephones for party lines are connected in multiple ; and J. J. Carty, of the New York Telephone Co., invented the so-called bridging-bell, which enables us to couple up ten to thirty stations in parallel.

The magnet-coils of the bridging-bell are wound with a large number of turns of No. 33 B. and S. wire, and measure 1000 ohms resistance.

The magnets, therefore, have high self-induction, which stops off telephone currents, but does not prevent the bell ringing. The disadvantage is that all the bells ring when any one of them is started ; and it is necessary, therefore, to have some code of signals by which calls for different stations may be distinguished.

The generator armature of the bridging-bell is wound with low resistance, so as to give plenty of current for ringing the bells.

The following three diagrams show the bridging-bell and its connections.



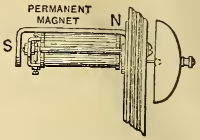


FIG. 24. Polarized Bell with long core for Ringer of Bridging-Bell.

FIG. 23. The Bridging-Bell

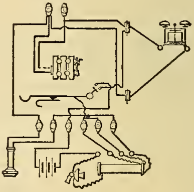
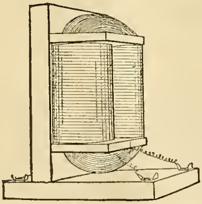


FIG. 25. Diagram of Connections of Bridging-Bell.

LONG-DISTANCE LINES.

In American telephone parlance the term "long distance" has come to mean lines of the very best construction, and instruments of the latest and best pattern.

The standard size of wire used on long distance lines is No. 12 N. B. S. G., 104 mils, hard-drawn copper, weighing 172 pounds to the mile. On the longer lines No. 8 wire, 165 mils, weighing 435 pounds to the mile, is used. 30-ft. poles are used, set 130 feet apart and 6 feet in the ground.



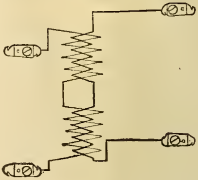


FIG. 26. Standard Repeating-Coil.

Fig. 27. Diagram of Connections of Repeating-Coil.

Cross-arms are 10 feet long, $3\frac{1}{4} \times 4\frac{1}{4}$ inches. They are placed 12 inches apart, secured to the poles by bolts, and supported by iron braces.

Double cross-arms and transposition insulators are provided on every tenth pole; and at each such pole some of the circuits are transposed in order to avoid inductive disturbance.

Great care is taken to keep each side of long-distance circuits balanced; and for this reason all central-office appliances are connected in "bridge."

For joining local or grounded lines to the long-distance so as not to disturb the balance, the circuits are connected through a *repeater*, which is an induction coil, well made, and proportioned for the purpose.

Figs. 26 and 27 show the standard repeating coils, as connected and as made up. There is a closed core of fine iron wire, with its ends interwoven and spliced after the two coils are wound on as shown. There are 10,000 turns of No. 30 B. and S. wire wound in four coils, one-half of one circuit being the inner half of each coil, the two being connected in series. The other circuit is wound outside of these coils, one-half over each side.

The following diagrams show the method of connecting grounded, local, and long-distance lines together through repeaters.

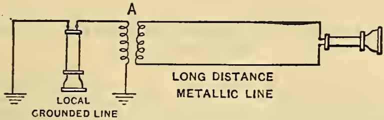


FIG. 28. Long-distance circuit connected to grounded circuit through repeater coil *A*.

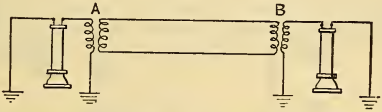


FIG. 29. Two distant grounded circuits connected through repeating coils *A* and *B* to a long-distance metallic circuit.

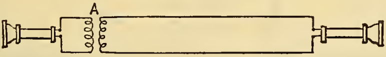


FIG. 30. Local metallic and long-distance metallic circuits connected through repeating coil *A*.

DUPLEX AND MULTIPLEX TELEPHONY.

The following diagrams show a method of duplexing and multiplexing telephone lines invented by Frank Jacobs. They are interesting, but have not yet proved to be of great practical use.

The duplex system is an arrangement by Wheatstone bridge, with resistances R_1, R_2, R_3, R_4, connected as shown. Those at either end must be equal to each other, but the two ends need not be the same.

These resistances must be greater than that of the line in order that the currents from T_3 and T_4 may pass along the line rather than around the coils. The condensers C may be placed in shunt to the coils in order not to retard the current, so that T_1 and T_2 may work better.

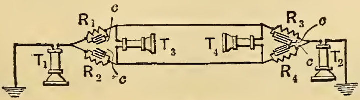


FIG. 31. Duplex Telephony.

The second diagram shows the method of multiplexing; but it is easily seen that T_1, T_2, T_3, T_4, will not work well owing to the resistances interposed.

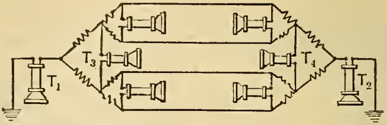


Fig. 32. Multiplex Telephony.

SIMULTANEOUS TELEGRAPHY AND TELEPHONY.

A system of simultaneous telephony and telegraphy is extensively employed in the United States, and is an improvement upon the system invented by Van Rysselberghe of Belgium, the system being often called by his name. The figure, taken from Maver's "American Telegraphy," gives a general idea of the working of the system.

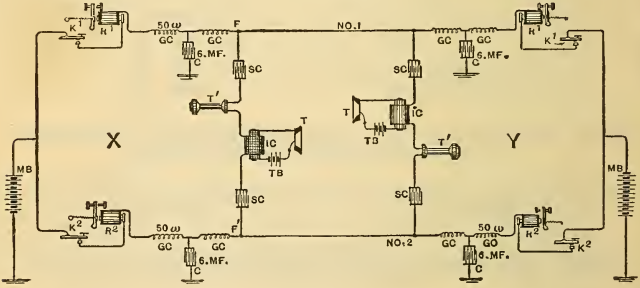


Fig 33.

It consists of a combination of telephone and telegraph apparatus with condensers and retardation or impedance coils so arranged that the Morse signals do not react upon the telephone apparatus and the telephone currents do not react upon the telegraph apparatus. The letters attached to the component parts of the figure are self-explanatory. The retardation coils in the line circuit keep back the telephone currents, and the condensers in the telephone legs keep back the Morse currents.

INTERIOR TELEPHONE SYSTEMS.

Condensed from articles by W. S. Henry in Am. Elec. — 1900.

The systems considered may be divided into *series party lines*, *bridging party lines*, *intercommunicating systems*, and *small central switchboard systems*. As the last system differs practically only in size from the regular central station system no description of it will be undertaken here. In these systems either magneto or microphone transmitters may be used, and the signaling apparatus may be either magneto bells and generators or the common vibrating bell and battery.

Where microphone transmitters or vibrating bells are employed, the batteries may be distributed at the various stations or, in some cases, all concentrated at one place. It is generally desirable, although not really necessary, so to arrange the circuits that the bell at the calling station, or the home bell as it is called, should ring when calling up another station. This assures the person signaling that his own circuit and probably the whole system is in working order, and that his call is being transmitted to the desired station.

One of the simplest telephone systems comprises magneto instruments connected in series in one line. Fig. 34 shows an arrangement of this kind requiring at each station two magneto instruments; T is the transmitter and R is the receiver. An ordinary vibrating battery bell, V, a battery, B, of two or more cells, and a hook switch, H, complete the equipment. When the receiver, R, is hanging on the hook, the line is connected to the lower contact; when the receiver is removed, a spring pulls the lever up against the contact, b. The smaller auxiliary switch, l, is arranged to normally rest on the contact, c. It may be pressed down upon d, but when released it should be returned to c by a stiff spring.

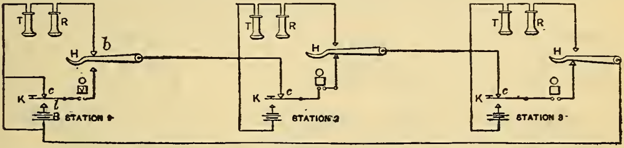


FIG. 34. Series System with Magneto Transmitters and Signaling Batteries.

In Fig. 35 a very similar arrangement is shown, the only difference being the use of magneto generators, G, in the place of the signaling batteries, B, of Fig. 34, and the substitution of magneto bells for the simple bells used in the first system. The signalling key, K, has only the upper contact, to normally short-circuit the generator, G, as indicated in the sketch. Some magneto generators are provided with an automatic arrangement on the spindle which short-circuits the armature of the magneto whenever the spindle is at rest. The act of turning the handle of the magneto removes the short-circuit and allows the induced current to pass out to the line. When this type of magneto is used, the push button, K, is, of course, unnecessary.

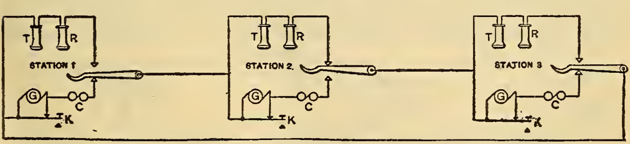


FIG. 35. Series System with Magneto Transmitters and Generators.

The arrangements described are known as *series party lines*, meaning that all of the stations connected up are in series with each other. As intimated above, when this arrangement is used even for a small number of stations, the bell magnets should have as low resistance and as few turns of wire on them as possible, in order to reduce the impedance of the circuit; and the generators should be wound with rather fine wire, because the current generated must pass through all of the bells in series.

In order to avoid forcing the talking current through the magnets of the signaling bells, the latter may be "bridged" directly across the circuit, as shown in Fig. 36, in which case the bells may be wound for high resistance and impedance so that the talking currents will be turned past them.

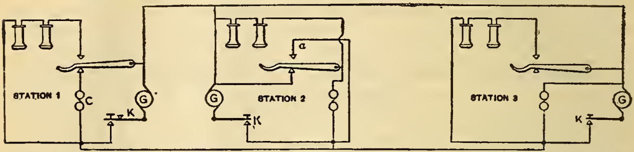


FIG. 36. Bridging System, with Magneto Transmitters and Generators.

In Fig. 36, three different methods of bridging are shown. At Station 1 the bell is removed entirely from the circuit when the receiver hook is up; at Station 2 the bell remains constantly across the circuit in series with the transmitter and receiver, but when the hook is up it is short-circuited by the hook and its upper contact through the wire, *a*; at Station 3 the bell remains permanently connected across the circuit, and when the receiver hook is up the transmitter and receiver are connected in parallel with it.

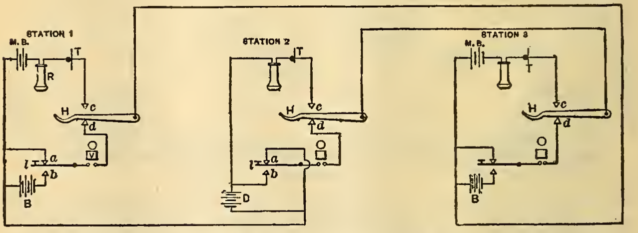


FIG. 37. Series Systems with Microphones and Batteries.

Fig. 37 shows the simplest method of using microphone transmitters. The instruments are a transmitter, *T;* an ordinary receiver, *R;* a vibrating bell, *V*, and one or two separate batteries at each station. The battery, *B*, is used only for ringing the bells; the battery *M. B.*, only for operating the microphone transmitters, and the battery *D*, for both purposes. In this

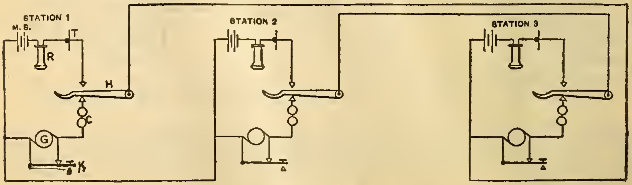


FIG. 38. Series System with Microphones and Magnetos.

arrangement, as well as in the one shown by Fig. 38, the microphones, receivers, and microphone batteries are directly in series with the line, no induction coils being used.

Instead of vibrating bells and batteries for ringing, we may use a polarized bell, *C*, and a generator, *G*, as shown in Fig. 38. In such an arrangement the talking current must pass through all the polarized bells except those at the stations where the receivers are removed from the hooks.

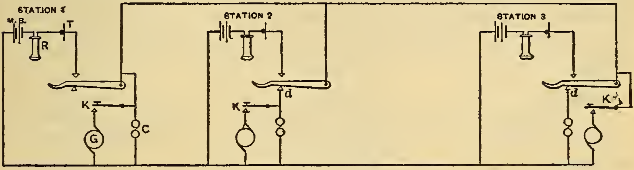


FIG. 39. Bridging System with Microphones and Magnetos.

A better arrangement is to use high-impedance bells bridged across the two-line wires, as shown in Fig. 39. The generator, as explained in connection with Fig. 36, is normally on open circuit.

Three bridging methods are shown. At Station 1 some of the current from the battery, *M.B.*, can flow through the bell when the receiver is off the hook, but this will do no harm; in fact, it may be beneficial, for it allows a larger direct steady current to flow through the microphone. The fluctuations in the current produced by the microphone cannot pass through the bell-magnet coils, but will pass through the line circuit on account of the lower impedance of the latter. At Station 3 the bell is cut out when the hook switch is raised, and at Station 2 both the generator and bell circuits are cut off by raising the hook. An extra contact, *d*, is required at these two stations, but on the other hand, there are two bells less across the circuit to form shunts or leaks for the current when two parties are conversing. On the whole, the arrangement at Station 3 is the best of the three.

Fig. 40 represents a series party system (corresponding with that which was shown at Station 1 in Fig. 37) in which a battery, *B*, and vibrating bell, *V*, are used for signaling, and an induction coil, *I*, is added to the speaking apparatus. The primary of the induction coil is in series with the microphone transmitter, *T*, and its battery, *M B.*, and the secondary is in series with the telephone receiver and the line.

The connections at Stations 1 and 2 are identical; when the receiver hook, *H*, is down the talking instruments are entirely cut out, and when it

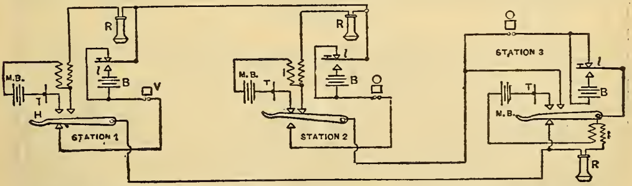


FIG. 40. Series Party System, with Induction Coils and Signaling Batteries.

is up the signaling key, battery and bell are thrown out of circuit and the main circuit passes through only the telephone receiver and the secondary of the induction coil. At Station 3 the connections are different; when the receiver hook is down the telephone receiver and secondary of the induction coil are merely short-circuited, while the transmitter, its battery, and the primary of the induction coil are open-circuited. When the hook is up, the talking instruments are connected up for service and the signaling part of the apparatus is short-circuited. Fig. 41 corresponds with Fig. 40, except that magneto-generators, *G*, and magneto bells, *C*, have been substituted in the place of the signaling battery and vibrating bells shown in Fig. 40. The station connections correspond also, the receiver hook, *H*, at Stations 1 and 2 being arranged to throw in and out of circuit the talking apparatus and the signaling apparatus, while the hook at Station 3 merely short-circuits the signaling apparatus or the receiver circuit, according to its position. This arrangement is the preferable one of the two, for the reason that faulty switch contacts at the receiver hook will not open the circuit, so that there will always be a continuous line through which one may signal.

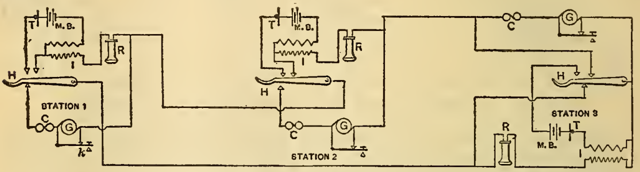


FIG. 41. Series Party System Using Induction Coils and Signaling Magnetos.

A simple system installed where there was considerable noise, dirt, and vibration, is represented diagrammatically by Fig. 42. Here, there are three line wires, *a*, *b*, and *c*, the line *c* forming a common return for both the signalling and the talking circuits, *a* and *b*, on which the apparatus is arranged in series. In this system the talking line is never open-circuited, the telephone hook, *H*, serving to merely short-circuit the receiver and the secondary of the induction coil when down, and to remove the short-circuit and close the local circuit of the transmitter and induction coil primary when up. It is obvious that the middle line wire, *c*, gives a free path to the talking current, instead of its being forced through the signaling bells. Such an arrangement facilitates the separation of the signaling and talking apparatus, so that the call bells can be located where they can be easily heard, while the transmitter and receiver may be put in a sound-proof closet. The disagreeable noises due to induction from lighting or power circuits may be overcome by using a twisted three-conductor cable between stations. Such an installation is greatly superior to the series system shown by Figs. 40 and 41.

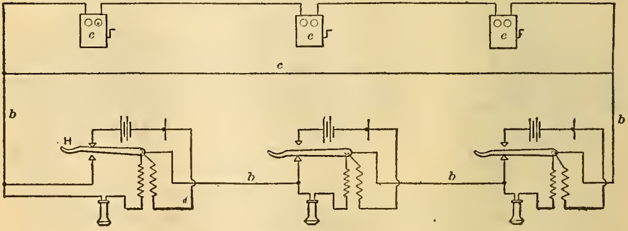


FIG. 42. Three-wire Series Party System.

Fig. 43 shows a series system in which one battery is used both for signalling and for talking. In this system the connections are alike at all stations; when the receiver hook, *H*, is down and the signaling key, *l*, is up, there are included in the line circuit only the vibrating bells. Depressing the signaling key *l*, puts the battery in the line and causes all the bells to ring. It is preferable to have the batteries so connected up that if two or more signaling keys should be depressed at once the batteries will agree in polarity. When the receiver hook is up the battery is connected in series with the transmitter and the primary of the induction coil, while the signaling key and bells are thrown out of circuit and the telephone receiver and secondary winding of the induction coil are included in the line, as shown at Station 3.

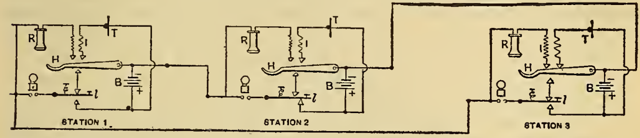


FIG. 43. Series Party System using only Battery at each Station for both Talking and Signaling.

In this, as in previous series systems, with the exception of Fig. 42, the talking current must flow through the signaling bells at idle stations. The advantage of the system is obviously that it eliminates half the batteries, only the one battery being used at each station for both signaling and talking. As in all series systems where vibrating bells are used, the vibrators, should be short-circuited on all bells except one.

The best method for connecting a large number of telephones on a single system where only two line wires may be used is to bridge them, as shown in Fig. 44. The dots *A* and *A′*, represent the binding-posts of each complete outfit. The bells are permanently bridged between the two line wires at Stations 1, 2, and 4, irrespective of the position of the receiver hooks. The magneto generator is also bridged across the two line wires in an independent circuit, which is normally kept open either by a push-button, *k*, or by an automatic device on the magneto spindle.

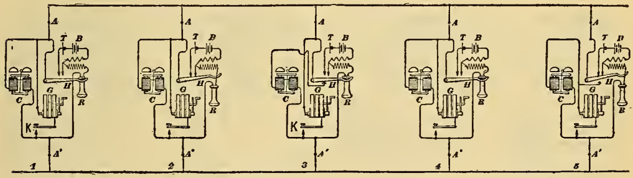


FIG. 44. Bridging Party-Line System; Three Arrangements of Station Instruments.

At Station 3 the magneto generator is bridged permanently across the line as in Stations 1, 2, and 3, but the bell is connected across only when the receiver hook is down, being thrown out when the hook is up. At Station 5 the bell and generator are bridged across the line wires when the receiver hook is down, and are cut out entirely when it is up. At all of the stations a third bridging circuit includes the receiver and the secondary winding of the induction coil in series, this circuit being open when the receiver hook is down, and closed when it is up. The hook also closes the local transmitter circuit in the usual way when it is up, and opens it when it is down. The connections shown at Stations 3 and 5 possess the advantage of cutting out their signaling bells entirely when the receiver hooks are up, instead of leaving the bells shunted across the line continuously, as is the case at Stations 1, 2, and 3.

INTERCOMMUNICATING SYSTEMS.

An intercommunicating system may be defined as a system having three or more telephones connected to the same system of wiring in such a manner that one may from any station call up and converse with any other station, without requiring any central-station switchboard whatever. Intercommunicating systems require one wire from each station to every other station and at least one more wire running through all the stations. Where vibrating bells and one common ringing battery are employed, at least two more wires than there are stations are necessary. At each station there must be a switch of some kind whereby the telephone at each station may be connected to any one of the wires belonging to the other stations. Intercommunicating systems are very practical and satisfactory up to fifteen or even twenty stations; beyond that, the large number of wires running through all stations makes the cost of the system increase rapidly, especially when the stations are some distance apart. For a large number of stations well scattered, a simple central-station switchboard system is preferable.

Fig. 45 shows a very common but not a good method of interconnecting a number of telephones, where each station is equipped with ordinary series bells and magneto generators. Theoretically any number of telephones may be connected on such a system, but practical consideration would place the limit at about twenty. In this figure there are four stations; at Nos. 1, 2, and 4 the telephone connections are drawn in full, while at No. 3 is shown the telephone outfit as it usually appears. There are four individual line wires, numbered 1, 2, 3, and 4, and a common return wire. Thus there is one more wire than there are stations, and all these wires run through all the stations, each wire being tapped at each station and not cut. At each station there is one ordinary telephone instrument consisting of the usual talking apparatus, magneto-generators and polarized bells. Below each telephone there is an intercommunicating switch, the buttons of which are connected to the respective line wires, and the common return wire. When not in use the switch at each station should remain on the home button.

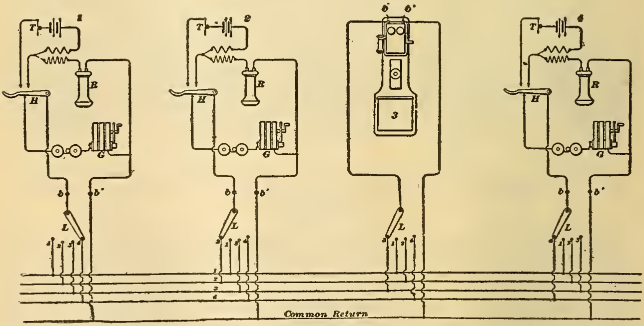


FIG. 45. Intercommunicating System, with Magneto Signaling Generators and Polarized Bells.

With all the levers in this position, a person at any station can call up any other station by moving the switch lever to the button connected with the individual line of the station desired, and turning the generator handle; only the bells at the home station and at the station called up will ring. The ringing and talking currents pass through only the instruments at the stations in communication. After finishing the conversation, the switch lever at the home station must be returned to its home position, otherwise the system will be crippled.

In Fig. 46 is shown a method of wiring the intercommunicating switch that avoids the principal objection mentioned in connection with Fig. 45, that is, the failure to return the switch to the home position does not leave the station so that it cannot be called up. Only four stations are shown, but the system can be extended to include as large a number as may be desirable. The usual telephone sets, consisting of a microphone transmitter, induction coil, receiver, hook switch, two cells of battery, a series magneto-generator and polarized bell, are included in the outfits indicated by T_1, T_2, etc. The inside connections of these telephones are the same as shown in the preceding figure.

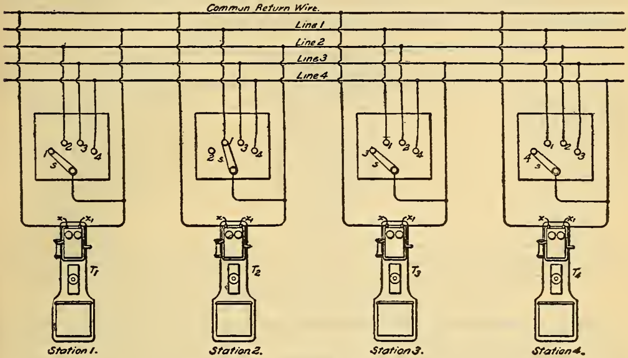


FIG. 46.

In Fig. 46 one binding-post of each telephone is connected to the common return wire, and the other binding-post is connected to both the lever arm, *s*, and the individual line wire belonging to that particular station.

The home button in this last system is the first on the left and is not connected to anything; it is really a dummy button, but it should be there by all means, for the lever, *s*, of the switch should always be returned to it when the original calling party leaves the telephone. If all switch arms, *s*, are on the home buttons it will be found that the circuits of all instruments are open and no bell will ring, no matter what generator is turned. If Station 2 desires to call Station 1 it will be necessary to first move the switch arm, *s*, at Station 2 to button 1.

Fig. 47 is a system similar to that shown in Fig. 46, but arranged for vibrating bells and one common calling battery, CB, in place of magneto-

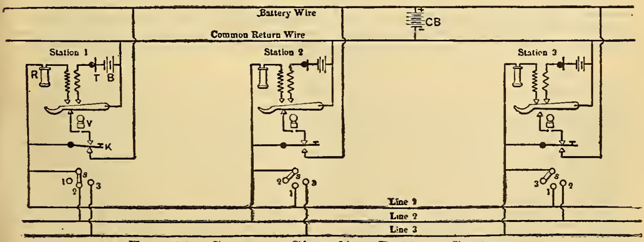


FIG. 47. Common Signaling-Battery System.

generators and polarized bells. A battery is used at each station for operating the transmitter. This is probably the best arrangement of batteries for such a system where vibrating bells are used. This system requires one more wire than that shown in Figs. 45 and 46 where magneto-calling apparatus is employed; thus there are two more wires throughout than there are stations. The calling battery, CB, must be connected to the two wires shown, but it may be located at any convenient place. In this arrangement only the bell at the station called will ring, the bell at the calling station remaining silent. If the bells are not arranged in this manner, the vibrators on the two bells that happens to be connected in series when making a call might interfere more or less with good ringing. Furthermore, it would not do to short-circuit any of the vibrators, because there is no telling which two stations may be connected together in making a call.

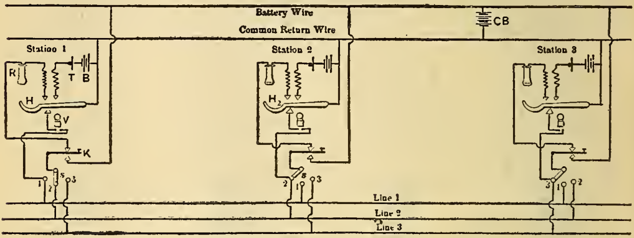


FIG. 48. Common Signaling-Battery System.

Trouble is experienced with intercommunicating systems similar to that of Fig. 47 by reason of the user carelessly leaving the selective switch S, off the home button after using the telephone. Fig. 48 shows a method of wiring such a system which obviates to a considerable extent this trouble. Here, the vibrating bell is permanently connected to the home button, and the pivot of the switch, S, is connected to the arm of the push-switch, K. Any station can still be called up, no matter on what button its switch, S, may be left.

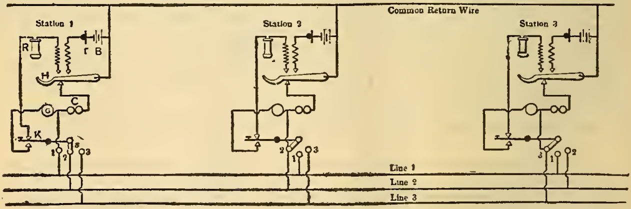


FIG. 49.

The same system of wiring employed in Fig. 48 is applied to the system shown in Fig. 49, in which magneto-generators, G, and polarized bells, C, are used in place of the battery and vibrating bells. There is no need of having a push button or automatic shunt on the generator, although it will do no harm. The generator is normally on open circuit because one of its terminals is connected to the under contact of the push switch, K. In order to call up a station, the switch, S, is placed on the button belonging to the station desired, the push switch, K, depressed, and the generator handle turned. Since no common battery is employed for ringing, this system requires one less wire through all the stations than the preceding arrangement.

In Fig. 50 is shown an arrangement in which one conveniently located common battery, C B, supplies current for ringing and also for all transmitters. No matter where the lever of the selective switch is left, the bell can still be rung, but conversation cannot be carried on until the switch at the station called is returned to the home button. This system includes a piece of apparatus at each station that has not been required in any of the systems previously described, to-wit: the impedance coil E. Where a common battery supplies all the local microphone circuits with current in systems of this kind, there is very apt to be cross talk between two pairs of telephones that may be in use at the same time, in which case the battery will be supplying current to four microphones.

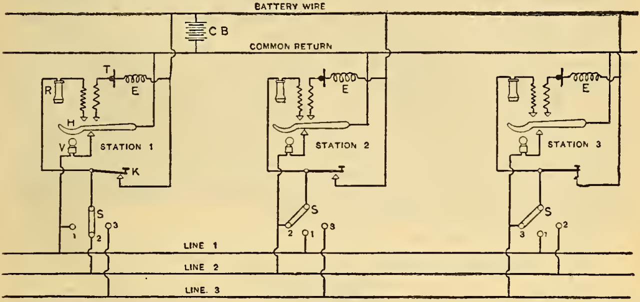


FIG. 50. Common Battery System with Impedance Coils.

The cross talk is due to the variation in the fall of potential along the battery and common return wires.

The cross talk may be greatly reduced by using batteries of very low internal resistance, such as storage cells, and making the common return and battery wires extra large, that is, small in resistance, so that the variable fall of potential through the battery and in these two wires may be small. However, it is impractical to make the resistance of these two wires low enough, especially where they are of considerable length, to eliminate all cross talk.

Another way to reduce the trouble from cross talk is to insert an impedance coil in each microphone circuit, as shown in Fig. 50. This makes the impedance of each microphone circuit large compared to that of the two lines and battery, and in order to get the same current as before in each microphone the e. m. f. of the battery must be increased. These impedance coils reduce the efficiency of the system, but the reduction in cross talk compensates for this loss to a great extent.

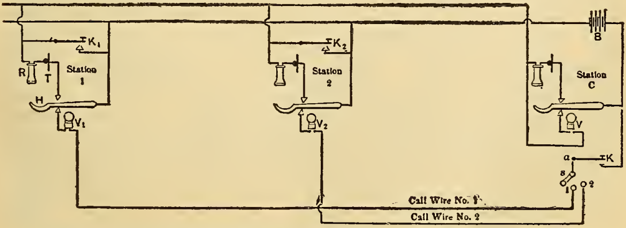


FIG. 51. Radial System; Selective at One Station Only.

It sometimes occurs that a system is required to be so arranged that one station can call up any one of the others, but the others can call up and converse with the first station only. Fig. 51 is a diagram of such a system; Station No. 1 or No. 2 can call up station C by merely depressing the push switch K1 or K2, but they cannot call up or converse with each other. Station C by means of the switch, S, and push, K, can call up either Station No. 1 or No. 2. There are only two wires that must run through all the stations. There is one wire, however, from Station C to each one of the other stations. These wires, Call Wire No 1 and Call Wire No. 2, are used only when Station C calls up one of the other stations. One wire could be made to answer if there was no objection to having all but the home bell ring when Station C makes a call. In this case a certain number of rings would be necessary for each station except C, and the one common call wire would be connected to the signaling key at *a*, Station C, and there would be no need of the switch, S.

As arranged in the diagram, the push switch, K, is normally open. When Station C desires to call Station No. 2, for instance, the switch, S, must be turned to button 2 and the push switch, K, depressed. The one common battery, B, furnishes current for all ringing and talking. At each station there is an ordinary receiver, microphone transmitter, and vibrating bell. There is only one bell in circuit when a call is made so that each bell must have a vibrator. It makes no difference upon what button the switch, S, is left.

In the systems so far described there is nothing to prevent the intercommunicating switch from being left off the home button when the conversation is finished and the receivers hung up.

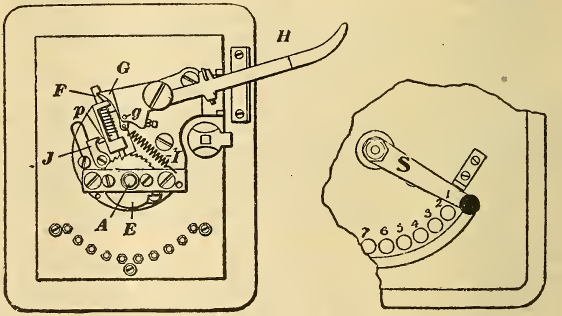


FIG. 52. Ness Automatic Switch.

An example of a device obviating this trouble is the Ness automatic switch, illustrated by Fig. 52, arranged so that the replacing of the receiver upon the hook causes the switch to fly back to its home position. In the engraving S is the lever of the selective switch, adapted to be rotated over the various contact buttons, 1, 2, 3, etc. It is mounted upon a shaft, A, passing through the front board of the box and carrying a ratchet-wheel, E, inside the box. This ratchet-wheel is held in any position to which it may be rotated by a pawl, F, and thus prevents the lever S, from turning backward. Upon the short arm of the hook lever, H, is pivoted a dog, G, adapted, when the receiver is removed from the hook, to engage a notch in the pawl, F; when the receiver is replaced, the dog, G, is pulled upwards and lifts the pawl out of the engagement with the ratchet-wheel, allowing a spiral spring around the shaft, A, to return the switch lever, S, to the home button. After raising the pawl out of the notch on the ratchet-wheel the dog slips out of the notch on the pawl, thus allowing the latter to return into contact with the ratchet-wheel in order to be ready for the next use of the telephone. In order, however, that the pawl may not engage the ratchet-wheel before the lever, S, has fully returned to its normal position, a second dog, J, is provided which is pressed by a spring so as to occupy a position under the pin, *p*, carried on the pawl, F, thus holding it out of engagement with the ratchet-wheel until the rotation of the lever is completed. At this point a pin on the farther side of the ratchet-wheel pushes the dog, J, out of engagement with the pin, *p*, and allows the pawl, F, to drop into contact with the ratchet-wheel.

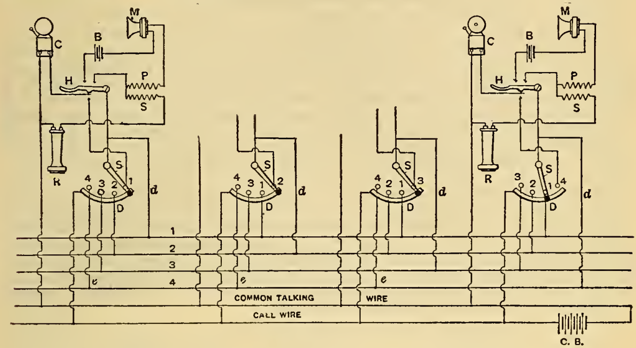


FIG. 53. Common Signaling Battery System; Individual Talking Batteries.

In Fig. 53 are shown the circuits of a four-station system using one common battery, CB, for ringing up the various stations, each station having an ordinary vibrating bell, C. The circuits of Stations 1 and 4 are shown in full, while those of the intermediate stations, being exactly the same, are partially omitted. It will be noticed that the switch lever, S, at each station is connected with the line wire bearing the same number as that station, by means of the wire, *d*. Each line wire is also connected at each of the stations not bearing its own number with a button on the switch of

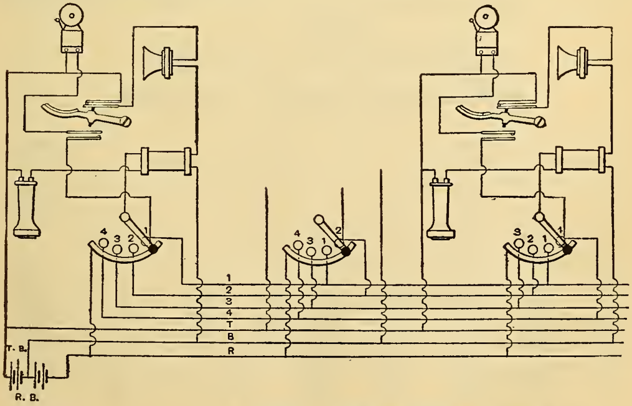


FIG. 54. System having Common Talking and Signaling Battery.

that station which does bear the same number in the manner previously described, by means of the wire, *e*. In this common-battery call system two additional wires are run, one being termed the "call wire" and the other the "common talking wire." The call wire and the talking wire are connected through the calling battery CB, as shown. It is evident that the number of wires passing through all the stations will be two more than the number of stations, irrespective of that number.

If Station 4 desires to call up Station 1, for example, No. 4 will turn his switch lever until it rests upon button 1, then a slight pressure upon the switch knob causes the switch lever, S, to touch the contact strip, D, completing a circuit from the battery, CB, to contact strip, D, lever, S, and button, 1, at Station 4; line wire, 1, wire, *d*, switch, H, and bell, C, at Station 1, and back to the battery through the common talking wire. When both subscribers remove their receivers from the hooks, the circuits are completed over line wire 1 with the common talking wire as a return. At the close of the conversation the receiver is simply hung upon the hook, and the automatic mechanical device returns the lever to the home position.

Fig. 54 shows the application of the Ness automatic switch to an intercommuicating system, using one common and centrally located battery for supplying both the ringing and talking current. The section, TB, of the battery supplies all the microphone transmitter circuits, and the whole battery, RB, supplies the current for ringing the ordinary vibrating bells that are used in this system. In this arrangement it is evident that the number of wires passing through all the stations will in any size of system be three in excess of the number of stations.

ELECTRO-CHEMISTRY.—ELECTRO-METALLURGY.

ELECTRO-CHEMISTRY.

Electrolysis.

THE separation of a chemical compound into its constituents by means of an electric current. Faraday gave the nomenclature relating to electrolysis. He called the compound to be decomposed the Electrolyte, and the process Electrolysis. The plates or poles of the battery he called Electrodes. The plate where the greatest potential exists he called the Anode, and the other pole the Cathode. The products of decomposition he called Ions.

Lord Rayleigh found that a current of one ampere will deposit 0.017253 grain, or 0.001118 gramme, of silver per second on one of the plates of a silver voltameter, the liquid employed being a solution of silver nitrate containing from 15 per cent to 20 per cent of the salt.

The weight of hydrogen similarly set free by a current of one ampere is .00001044 gramme per second.

Knowing the amount of hydrogen thus set free, and the chemical equivalents of the constituents of other substances, we can calculate what weight of their elements will be set free or deposited in a given time by a given current.

Thus the current that liberates 1 gramme of hydrogen will liberate 7.94 grammes of oxygen, or 107.11 grammes of silver, these numbers being the chemical equivalents for oxygen and silver respectively.

To find the weight of metal deposited by a given current in a given time, find the weight of hydrogen liberated by the given current in the given time, and multiply by the chemical equivalent of the metal.

Thus: Weight of silver deposited in 10 seconds by a current of 10 amperes = weight of hydrogen liberated per second × number seconds × current strength × 107.11 = .00001044 × 10 × 10 × 107.11 = .1118 gramme.

Weight of copper deposited in 1 hour by a current of 10 amperes =
$$.00001044 \times 3600 \times 10 \times 31.55 = 11.86 \text{ grammes.}$$

Since 1 ampere per second liberates .00001044 gramme of hydrogen, strength of current in amperes

$$= \frac{\text{weight in grammes of } H. \text{ liberated per second}}{.00001044}$$

$$= \frac{\text{weight of element liberated per second}}{.00001044 \times \text{chemical equivalent of element}}$$

Resistances of Dilute Sulphuric Acid.

(Jamin and Bouty.)

Density.	Ohms per c.c. at				Ohms per Cu. In. at			
	0° C. or 32° F.	8° C. or 46.4° F.	16° C. or 60.8° F.	24° C. or 73.2° F.	0° C. or 32° F.	8° C. or 46.4° F.	16° C. or 60.8° F.	24 °C. or 73.2° F.
1.1	1.37	1.04	.845	.737	.540	.409	.333	.290
1.2	1.33	.926	.666	.486	.524	.364	.262	.191
1.25	1.31	.896	.624	.434	.516	.353	.246	.171
1.3	1.36	.940	.662	.472	.535	.370	.260	.186
1.4	1.69	1.30	1.05	.896	.666	.512	.413	.353
1.5	2.74	2.13	1.72	1.52	1.16	.838	.677	.598
1.6	4.82	3.62	2.75	2.21	1.90	1.43	1.08	.870
1.7	9.41	6.25	4.23	3.07	3.71	2.46	1.67	1.21

Elements.	Symbols and Valencies.	Atomic Masses.*	Chemical Equivalents.	Electro-Chemical Equivalents. Grammes per Coulomb.	Grammes per Ampere-hour.	Ampere-hours per Gramme.	Pounds per Ampere-hour.	Ampere-hours per Pound.
Aluminium† . . .	Al III	26.9	8.965	.0000936	0.3370	2.9674	.000743	1346.0
Antimony	Sb III	119.5	39.83	.0004157	1.4965	0.6682	.003299	303.1
Bromine	Br I	79.34	79.34	.0008281	2.9812	0.3354	.006572	152.1
Calcium	Ca II	39.8	19.90	.0002077	0.7477	1.3374	.001648	606.6
Carbon	C IV	11.9	2.975	.0000310	0.1116	8.9606	.000246	4064.5
Chlorine	Cl I	35.18	35.18	.0003672	1.3219	0.7565	.002914	343.1
Copper (cupric) . .	Cu II	63.1	31.55	.0003293	1.1855	0.8435	.002614	382.6
Copper (cuprous) . .	Cu I	63.1	63.10	.0006586	2.3710	0.4218	.005228	191.3
Gold	Au III	195.7	65.23	.0006809	2.4512	0.4080	.005404	185.1
Hydrogen	H I	1.000	1.000	.00001044	0.0376	26.5957	.000083	12063.6
Iodine	I I	125.89	125.89	.0013140	4.7304	0.2114	.010429	95.9
Iron (ferric)† . . .	Fe III	55.6	18.53	.0001934	0.6962	1.4364	.001535	651.5
Iron (ferrous) . . .	Fe II	55.6	27.80	.0002902	1.0447	0.9576	.002302	434.4
Lead	Pb II	205.36	102.68	.0010718	3.8585	0.2592	.008506	117.6
Magnesium	Mg II	24.1	12.05	.0001258	0.4529	2.2080	.000998	1001.5
Manganese	Mn II	54.6	27.30	.0002850	1.0260	0.9747	.002262	442.1
Mercury (mercuric) .	Hg II	198.5	99.25	.0010360	3.7296	0.2681	.008222	121.6
Mercury (mercurous)	Hg I	198.5	198.50	.0020719	7.4588	0.1340	.016444	60.8
Nickel	Ni II	58.25	29.125	.0003040	1.0944	0.9137	.002413	414.4
Nitrogen	N III	13.93	4.64	.0000484	0.1742	5.7405	.000384	2603.8
Oxygen	O II	15.88	7.94	.0000829	0.2984	3.3512	.000658	1520.1
Platinum (platinic) .	Pt IV	193.4	48.35	.0005047	1.8169	0.5504	.004006	249.7
Platinum (platinous)	Pt II	193.4	96.70	.0010094	3.6338	0.2752	.008012	124.8
Potassium	K I	38.82	38.82	.0004052	1.4587	0.6855	.003216	310.9
Silver	Ag I	107.11	107.11	.0011180	4.0248	0.2485	.008873	112.7
Sodium	Na I	22.88	22.88	.0002388	0.8597	1.1632	.001895	527.6
Tin (stannic) . . .	Sn IV	118.1	29.525	.0003082	1.1095	0.9013	.002446	408.8
Tin (stannous) . . .	Sn II	118.1	59.05	.0006164	2.2190	0.4506	.004892	204.4
Zinc	Zn II	64.9	32.45	.0003387	1.2193	0.8201	.002688	372.0

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* From the report of the Committee on Atomic Weights to the American Chemical Society, published in the Journal of the American Chemical Society, February, Nineteen Hundred.

† Effective Valency, or number of Hydrogen atoms it will replace.

(Compiled and Calculated by R. S. Woodward, Jr., and G. A. Miller, Jr.)

Resistances of Sulphate of Copper at 10° C. or 50° F.

(Ewing and MacGregor.)

Density.	Ohms per		Density.	Ohms per	
	c.c.	Cu. In.		c.c.	Cu. In.
1.0167	164.4	64.8	1.1386	35.0	13.8
1.0216	134.8	53.1	1.1432	34.1	13.4
1.0318	98.7	38.8	1.1679	31.7	12.5
1.0622	59.0	23.2	1.1829	30.6	12.0
1.0858	47.3	18.6	1.2051	29.3	11.5
1.1174	38.1	15.0	Saturated		

Resistances of Sulphate of Zinc at 10° C. or 50° F.

Density.	Ohms per		Density.	Ohms per	
	c.c.	Cu. In.		c.c.	Cu. In.
1.0140	182.9	72.0	1.2709	28.5	11.2
1.0187	140.5	55.3	1.2891	28.3	11.1
1.0278	111.1	43.7	1.2895	28.5	11.2
1.0540	63.8	25.1	1.2987	28.7	11.3
1.0760	50.8	20.0	1.3288	29.2	11.5
1.1019	42.1	16.6	1.3530	31.0	12.2
1.1582	33.7	13.3	1.4053	32.1	12.6
1.1845	32.1	12.6	1.4174	33.4	13.2
1.2186	30.3	11.9	1.4220	33.7	13.3
1.2562	29.2	11.5	Saturated		

Specific resistance of fused sodium chloride (common salt) at various temperatures.

Temperature Cent.	720°	740°	750°	770°	780°
Ohms per cu. cm.	.348	.310	.294	.265	:247

Application of Electro-Chemistry.

The various forms of primary and secondary batteries may be regarded as applications of electro-chemistry, but they are treated as special subjects in other parts of this book. Other important practical applications are the processes for producing chemicals by electrolysis or by electrical heating. Among the materials thus produced in large quantities are caustic soda, carbonate of soda, chlorine, bleaching powder, chlorate of potash, calcium carbide, phosphorus, cyanide of potassium, etc.

The production of caustic soda may be effected by electrolysing a solution of common salt the reaction being $NaCl \times H_2O = NaOH \times H \times Cl$ the products being caustic soda ($NaOH$) which remains in solution, hydrogen and chlorine that pass off as gases the latter being collected and used for making bleaching powder.

There is a tendency to form a mixed product of caustic soda and salt and a certain amount of hypochlorite of soda. These difficulties are avoided by separating the caustic soda from the rest of the solution either by a porous diaphragm or by drawing it off as fast as produced. In the Castner process, mercury is used as the cathode and absorbs the metallic sodium deposited upon it. In another chamber the sodium decomposes water and forms caustic soda.

Calcium Carbide is produced by heating a mixture of burnt lime and pulverized coke or anthracite coal in an electric furnace, the reaction being:

$$CaO+3C=CaC_2+CO$$

The carbonic oxide (CO) passes off as a gas and the calcium carbide after cooling is a solid grayish mass which is broken up for use. A rotary form of furnace is used at the large works of the Carbide Company at Niagara Falls, the material being fed in at one side and the calcium carbide being taken out at the other.

ELECTRO-METALLURGY.

Electro-metallurgy may be defined as that branch of science which relates to the electrical reduction or treatment of metals.

The subject may be divided into three important and quite distinct branches, as follows:

1. **Electrolytic Metallurgy**, which consists in reducing or separating metals by the decomposing effect which occurs when an electric current is passed through their compounds while in the liquid state. These compounds may be rendered liquid either by dissolving or fusing them; hence there are:

(*a.*) Wet methods with *solutions.*

(*b.*) Dry methods with *fused materials.*

Electrolytic metallurgy is applied to the following purposes:

(*c.*) *Electrotyping*, which is the art of reproducing the exact form of type, engravings, medals or other articles by electrodepositing metal on the article itself or on a mould obtained from it.

(*d.*) *Electroplating*, which is the art of coating articles with an adherent layer of metal by electrodeposition.

(*e.*) *Electrolytic reduction of metals*, which is the art of obtaining metals from their ores or compounds by electrically decomposing such ore or compound in the state of solution or fusion.

(*f.*) *Electrolytic refining of metals*, which is the art of eliminating impurities by electrodepositing the metal itself, the foreign substances being left in the anode or liquid, or vice versa.

2. **Electrical smelting**, which consists in reducing metallic oxides by carbon at a high temperature produced by the passage of an electric current.

3. **Electrical working of metals**, which consists in treating metals mechanically with the aid of heat generated by electric currents. Various mechanical processes which are facilitated by softening or fusing the metal may be effected in this way, the principal ones being: *welding*, *forging*, *rolling*, *casting*.

Electrotyping.—To reproduce an engraving, typographical composition, or other object, a mould of gutta percha, wax, plaster or fusible alloy is made from the object. If it is not a conductor it is coated with graphite to start the action, connection being made to it by a wire or clamp put around it. It is used as the cathode in a bath consisting of a saturated solution of copper sulphate acidulated with sulphuric acid. The anode is a plate of copper. The ordinary thickness of deposit is .01 to .02 inch. The "shell" thus formed is separated from the mould and backed by a filling of type metal.

Electroplating an article with an adherent coating of metal requires the article to be thoroughly *cleaned* mechanically and chemically.

Cleaning.—Solutions for cleaning *Gold*, *Silver*, *Copper*, *Brass* and *Zinc* are prepared as follows:

	Water.	Nitric Acid.	Sulphuric.	Hydrochloric.
For copper and brass	100	50	100	2
Silver	100	10	—	—
Zinc	100	—	10	—
Iron, wrought	100	2	8	2
Iron, cast	100	3	12	3

Lead, Tin, Pewter, are cleaned in a solution of caustic soda.

Objects to be plated with gold or silver must be carefully and thoroughly freed from acids before transfer to the solutions. Objects cleaned in soda or those cleaned in acid for transfer to acid coppering solutions may be rinsed in clean water, after which they should be transferred immediately to the depositing solution.

Baths for plating.—The reader is referred to the various books on *electroplating* for particulars, as but few, and those the most used solutions can be referred to here.

Solutions should be adapted to the particular object to be plated, and must have little if any action upon it. Cyanide of gold and silver act chemically upon copper to a slight extent and the objects should be connected to the electrical circuit before being immersed.

Solutions are best made chemically, but can be made by passing a current through a plate of the required metal into the solvent.

Copper.—A good solution for plating objects with copper is made by dissolving in a gallon of water 10 ounces potassium cyanide, 5 ounces copper carbonate, and 2 ounces potassium carbonate.

The rate of deposit should be varied to suit the nature and form of the surface of the object, large smooth surfaces taking the greatest rate of deposit. Electrotype plates must be worked at a slow rate, owing to the rough and irregular surface.

Non-metallic Surfaces may be plated by first providing a conducting surface of the best black lead or finely ground gas coke. Care is required in starting objects of this sort, to obtain an even distribution of the metal, and hollow places may be temporarily connected by the use of fine copper wire.

Copper on iron or on any metal that is attacked by copper sulphate is effected by an alkaline solution. One which can be worked cold is made up of ¼ ounce of copper sulphate to a pint of water. Dissolve the copper sulphate in a half pint of water, add ammonia until all the first formed precipitate re-dissolves, forming a deep blue solution, then add cyanide of potassium until the blue color disappears. A heavy current is required with this solution, enough to give off gas from the surface. This solution will deposit at a high rate but ordinarily leaves a rough and crystalline surface, and will not do good work on steel.

A cyanide solution is the most used, takes well on steel or brass, as well as on iron, and permits of many variations.

For each gallon of water use:

Copper carbonate	5 ozs.
Carbonate of potash	2 ozs.
Potassium cyanide, chem. pure.	10 ozs.

Dissolve about nine-tenths of the potassium cyanide in a portion of the water then add nearly all the copper carbonate, which has also been dissolved in a part of the water: dissolve the carbonate of potash in water and add slowly to the above solution stirring slowly until thoroughly mixed. Test the solution with a small object, adding copper or cyanide until the deposit is uniform and strong. For coppering before nickel plating, the coating of copper must be made thick enough to stand hard buffing, and for this reason the coppering solution must be rich in cyanide and have just enough copper to give a free deposit. Use electrolytically deposited copper for anodes, as it gives off copper more freely. Regulate the current for the work in the tanks, and it should be rather weak for working this solution.

Brass Solutions of any color may be made by adding carbonate of zinc in various quantities to the copper solution. The zinc should be dissolved in water with two parts, by weight, of potassium cyanide, and the mixture should then be added to the copper bath. A piece of work in the tank at the time will indicate the change in color of the deposit. Two parts copper to one zinc gives a yellow brass color. For the color of light brass add a little carbonate of ammonia to the brass solution. To darken the color add copper carbonate. Varying the amount of current will also change the color, a strong current depositing a greater amount of zinc, thus producing a lighter color.

Silver.—The standard solution for silver plating is chloride of silver dissolved in potassium cyanide. This solution consists of 3 ounces silver chloride with 9 to 12 ounces of 98 per cent potassium cyanide per gallon of water. Rub the silver chloride to a thin paste with water. dissolve 9 ounces potassium cyanide in a gallon of water and add the paste, stirring until dissolved. Add more cyanide until the solution works freely. The bath should be cleaned by filtering. Great care should be taken to keep the proper proportions between current, silver and cyanide. A weak current requires more free cyanide than a strong one, and too much cyanide prevents the work plating readily, and gives it a yellowish or brownish color. If there is not enough cyanide in the solution the resistance to the current is increased and the plating becomes irregular.

The most suitable current for silver plating seems to be about one ampere for each sixty (60) inches of surface coated.

Gold. — Cyanide of gold and potassium cyanide make the best solution for plating with gold. The solution is prepared in the same manner as the silver solution just described, using chloride of gold in place of chloride of silver. The electrical resistance of the bath is controlled by the quantity of cyanide, the more cyanide the less the resistance, but an excess of cyanide produces a pale color. Hot baths for hot gilding require from 11 to 20 grains of gold per quart of solution and a considerable excess of cyanide. Baths for cold gilding and for plating should have not less than 60 grains per quart and may have as much as 320 grains, this quantity being used with a dynamo current for quick dipping.

Nickel. — The solution now almost universally used for nickel plating is made up from the double sulphate of nickel and ammonia, with the addition of a little boracic acid under certain conditions.

The double salt is dissolved by boiling, using 12 to 14 ounces of the salts to a gallon of water, the bath is then diluted with water until a hydrometer shows a density of 6.5° to 7° Baumé.

Cast anodes are to be preferred as they give up the metal to the solution more freely. Anodes should be long enough to reach to the bottom of the work and should have a surface greater than that of the objects being plated.

Current strength should be moderate, for if excessive the work is apt to be rough, soft or crystalline, voltage may vary from 3.5 to 6 volts and the most suitable current is from .4 to .8 ampere per 15 square inches surface of the object. Zinc is the only metal requiring more current than this, and takes about double the amount named.

A nickel bath should be slightly acid in order that the work may have a suitable color. An excess of alkali darkens the work and an excess of acid causes " peeling."

Iron. — A hard white film of iron can be deposited from the double chloride of iron and ammonia, which can be prepared by the current process. It is somewhat used for coating copper plates to make them wear a long time, the covering being renewed occasionally.

The Electro-motive Forces suited to the different metals are : —

Copper in sulphate, ...	Volt, 1·5 – 2·5
" cyanide, ...	4· – 6·
Silver in "	1· – 2·
Gold in "	·5 – 3·
Nickel in sulphate, ...	2·5 – 5·5

The Resistance will depend on the nature of the surface. Work is best effected with about equal surface of anode and objects, and the coating will be more even, the greater the distance between them, especially where there are projecting points or rough surfaces.

Copper and *silver* should never show any sign of hydrogen being given off at the objects; gold may show a few bubbles if deep color is wanted. Nickel is always accompanied with evolution of hydrogen, but the bath should not be allowed to froth.

The Rate of Deposit is proportional to current, as described under the head of " Electrolysis," in the proportions given in the table of electro-chemical equivalents except in the case of gold, the equivalent of which in combination with cyanogen is 195.7, but subject to modifications dependent upon the hydrogen action just described; there is also a partial solution of the metal, so that there is always a deduction to be made from the theoretical value. Thus : —

Gold gives about		80 to 90	per cent.
Nickel	"	80 to 95	"
Silver	"	90 to 95	"
Copper	"	98	"

An ampere of current maintained for one hour, which serves as a unit of quantity called the "ampere hour," represents

Gramme	.0376	Grain	.58
Ounce Troy	.00121	Ounce Avoir.	.00132

which multiplied by the chemical equivalent will furnish the weight of any substance deposited.

Separation of Metals.

Aluminum.—There are several successful processes in use. *Hall's process* is operated on a large scale at Niagara Falls. The cell is an iron vessel lined with carbon, which forms the cathode, and contains molten cryolite (sodium and aluminum double fluoride), into which is fed the alumina, Al_2O_3, ; this is electrolysed, the oxygen passes off as CO_2 at the anode, which is a carbon cylinder. The aluminum having a higher specific gravity than the fluoride, settles at the bottom of the bath, from which it is tapped or ladled off. The temperature of the bath is 1,600° to 1,800° Fahr., while from 7 to 8 volts are required, and a current of 5,000 amperes is used, producing 1 pound of metal per 10 $K.W.$ - hours. About 1 pound of carbon electrode is consumed per 1 pound of aluminum produced.

The *Cowles process* is chiefly for producing alloys of aluminum and silicon with copper and iron. Corundum (aluminum oxide) or bauxite is mixed with iron filings or granulated copper, and is smelted in a furnace as follows:—The furnace pit is built of fire brick with holes in the ends for admitting the carbon electrodes; the furnace is lined internally with limed charcoal, the lime keeping apart the carbon particles, which would otherwise connect and make a short circuit. The carbon electrodes are brought together and the charge of corundum, &c., is put in, the furnace is then covered, and the current is gradually started. The electrodes are then gradually separated, and the current is increased and maintained for about an hour, when the reduced metal is drawn from the bottom of the furnace. With the cupro-aluminum process the current is easily maintained steady, but with the ferro-aluminum process the conductivity of the charge varies greatly during the process, and regulation of current is very difficult.

Electrolytic Refining of Copper.

The most important application of electrolytic metallurgy is the refining of copper which is carried on at many places in this country and abroad on a very large scale. The crude copper obtained from the smelting furnaces is cast or rolled in the form of plates which are used as anodes in electrolytic cells. Theelectrolyte is a solution of copper sulphate acidulated with sulphuric acid to increase its conductivity. The cathodes are usually thin sheets of pure copper upon which the refined copper is electrodeposited, the impurities are left behind in the anodes or solution, or as a scum or sediment. In some cases the plates are arranged in series and in others in parallel. The former has the advantage of requiring electrical contracts to be made to the first and last plates only, whereas the parallel plan requires connection to each plate; but in the series arrangement there is a considerable leakage of current amounting to about 15 or 20 per cent. The pressure required is from .2 to .4 volt per cell with a current density of 10 to 15 amperes per square foot. It requires in practice 400 to 475 ampere-hours per pound of copper, the theoretical amount being 382.6 ampere-hours. About 8 or 9 pounds of copper are produced per kilowatt-hour at about .3 volt which is the ordinary value. The cost of the process is about .7 cent per pound of copper. A great advantage of the electrolytic method of refining copper is the fact that the silver and gold contained in the copper is left behind in the sediment, from which it is extracted afterward usually by electrolysis. The silver and gold thus recovered constitute an important item in the output of an electrolytic refinery.

The *Elmore process* consists in depositing the copper on a revolving iron mandrel which forms the cathode; an agate burnisher travels along the mandrel and presses the crystals of metal into a fibrous form which is said to account for the superior strength of the metal deposited by this process. The copper is removed from the mandrel by expansion, for which purpose steam is used. Specimens tested by Prof. Kennedy have broken at 27 to 41 tons per square inch with an extension of 5 to 7½ per cent. The tubes may be cut into sheets or strips for drawing into wire. The conductivity is very high, being sometimes 2 or 3 per cent above Matthiessen's standard.

Silver is refined from copper bullion by taking anodes of the bullion ½ inch thick and 14 inches square, and cathodes of sheet silver slightly oiled. The electrolyte consists of water with 1 per cent of nitric acid. When the current is started the copper and silver form nitrates of copper and silver and free nitric acid from which the silver is deposited, leaving the copper in solution. Trays are placed under the cathode for catching the deposited silver, and if there is any copper deposited owing to the solution containing too little silver or a superabundance of copper, the copper falls into the trays and is re-dissolved.

In the Moebius process the deposit is continually removed from the cathode by means of a mechanical arrangement of brushes, and falls into the trays above mentioned.

ELECTRIC HEATING, COOKING AND WELDING.

HEAT UNITS AND EQUIVALENTS.

The unit of heat in mechanics is the "calorie" or "lesser calorie," which is the heat necessary to raise one cubic centimeter of water from 4° to 5° Centigrade in one second.

The British Heat Unit, known as the "British Thermal Unit," or "B.T.U.," is the quantity of heat necessary to raise one pound of water from 60° to 61° Fahrenheit, and is equal to 778 foot pounds, or 1055 Joules. The Joule is the heat generated by a watt in a second.

Joule's Law shows that the heat generated in a conductor is directly proportional to:

Its resistance, the square of the current strength, and the time during which the current flows, or,

$$H = I^2Rt.$$

According to Ohm's law, $I = E \div R$, hence,

$$I^2Rt = \frac{E}{R}\, IRt = EIt = \frac{E^2t}{R}.$$

And calling Q the quantity of electricity flowing, then

$$It = \frac{E}{R}\, t,$$

and $H = EQ$ or the heat = E.M.F. × Quantity,

in which E.M.F. is the difference of potential between the ends of the conductor.

The table on the following page clearly shows the equivalent values of the electrical and mechanical units.

VARIOUS METHODS OF UTILIZING THE HEAT GENERATED BY THE ELECTRIC CURRENT.

I. **Metallic Conductors** (Uninterrupted Circuit).

1. Exposed coils of wire or strips.
   - (*a*) Entirely surrounded by air.
   - (*b*) Wound around insulating material.
2. Wire or strips of metal imbedded in enamel.
   - (*a*) In the form of coils. } Leonard, Carpenter, Crompton, and
   - (*b*) In flat layers. } others.
3. Wire or strips of metal imbedded in asbestos.
   - (*a*) In the form of coils.
   - (*b*) In flat layers.
4. Wire imbedded in various insulating compounds.
   - (*a*) Crystallized acetate of sodium, etc. Tommasi.
5. A Film of metal.
   - (*a*) Rare metal fired on enamel. } Prometheus.
   - (*b*) Rare metal fired on mica. }
   - (*c*) Silver deposited on glass. Reed.
6. Sticks of metal.
   - (*a*) Crystallized silicon in tubes of glass. Le Roy.
   - (*b*) Metallic powder mixed with clay and compressed. Parvillé.

Equivalent Values of Electrical and Mechanical Units.

(H. W. Leonard in "The Electrical Engineer," Feb. 25, 1895, Modified.)

Unit.	Equivalent Value in other Units.	Unit.	Equivalent Value in other Units.	Unit.	Equivalent Value in other Units.
1 K. W. Hour =	1,000 watt hours. 1.34 H.-P. hours. 2,654,200 ft.-lbs. 3,600,000 joules. 3,412 heat-units. 367,000 kilogram meters. .235 lb. carbon oxidized with perfect efficiency. 3.53 lbs. water evap. from and at 212° F. 22.75 lbs. of water raised from 62° to 212° F.	1 H.-P. =	746 watts. .746 K. W. 33,000 ft.-lbs. per minute. 550 ft.-lbs. per second. 2,545 heat-units per hour. 42.4 heat units per minute. .707 heat units per second. .175 lb. carbon oxidized per hour. 2.64 lbs. of water evap. per hour from and at 212° F.	1 Heat. unit =	1055 watt seconds. 778 ft. lbs. 107.6 kilogram meters. .000293 K.W. hour. .000393 H.-P. hour. .0000688 lb. carbon oxidized. .001036 lb. water evap. from and at 212° F.
1 H.-P. Hour =	.746 K.W. hours. 1,980,000 ft.-lbs. 2,545 heat-units. 273,740 kg. m. .175 lb. carbon oxidized with perfect efficiency. 2.64 lbs. water evap. from and at 212° F. 17.0 lbs. water raised from 62° F. to 212° F.	1 Joule =	1 watt second. .000000278 K.W. hour. .102 kg. m. .0009477 heat-units. .7373 ft.-lb.	1 Heat-unit per Sq. Ft. per min. =	.122 watts per sq. in. .0176 K.W. per sq. ft. .0236 H.-P. per sq. ft.
1 Kilo-watt =	1,000 watts. 1.34 horse-power. 2,654,200 ft.-lbs. per hour. 44,240 ft.-lbs. per minute. 737.3 ft.-lbs. per second. 3,412 heat-units per hour. 56.9 heat-units per minute. .948 heat-unit per second. .2275 lb. carbon oxidized per hr. 3.53 lbs. water evap. per hour from and at 212° F.	1 Ft.-lb. =	1.356 joules. .1383 kg. m. .000000377 K.W. hours. .001285 heat-units. .0000005 H.-P. hour.	1 Kilo-gram meter =	7.233 ft.-lbs. .00000365 H.-P. hour. .00000272 K.W. hour. .0093 heat-unit.
		1 Watt =	1 joule per second. .00134 H.-P. 3.412 heat units per hour. .7373 ft.-lb. per second. .0035 lb. water evap. per hour. 44.24 ft.-lbs. per minute.	1 lb. carbon oxidized with perfect efficiency =	14,544 heat units. 1.11 lb. anthracite coal oxidized. 2.5 lbs. dry wood oxidized. 21 cu. ft. illuminating gas. 4.26 K.W. hours. 5.71 H.-P. hours. 11,315,000 ft.-lbs. 15 lbs. of water evap. from and at 212° F.
		1 Watt per sq. in. =	8.19 heat-units per sq. ft. per minute. 6371 ft.-lbs. per sq. ft. per minute. .193 H.-P. per sq. ft.	1 lb. water evap. from and at 212° F. =	.283 K.W. hour. .379 H.-P. hour. 965.7 heat units. 103,900 kg. m. 1,019,000 joules. 751,300 ft.-lbs. .0664 lb. of carbon oxidized.

II. **Heat of the Electric Arc** (Interrupted Circuit).

1. The Electric Furnace. Siemens, Cowles, Parker, and others.
2. Heat of Arc acting upon material, producing local fusion. Meritens, Werdemann, Bernardos, Howells, and others.
3. Welding by bringing metals in contact. Thomson.
4. Deflecting Arc by Magnet. Zerener.

III. **Hydro-electrothermic System, or Water-Pail Forge.** Burton, Hoho and Lagrange.

Referring to the above classification, Section I., the methods referred to under subhead 1 and 3 require no further explanation. The method under subhead 2 consists in imbedding the resistance wire in some fireproof insulation such as enamel or glass. This insulation is of comparatively poor quality as a conductor of heat, and so thin that it affords the least possible resistance to the flux of heat from the heated resistance.

Tommasi (subhead 4) imbeds the coil of wire in a material having great latent heat of fusion, such as crystallized acetate of sodium, hyposulphide of sodium, etc., the principle being that the material acts as a reservoir of heat. The heaters, it is claimed, are first heated by immersion in hot water, then the current is turned on, and after they have been brought to the desired temperature, the current is cut off, and the heaters remain active for about four hours more.

The **Prometheus System** (subhead 5) is extensively used in Germany, and consists of firing a broad strip of rare metal on to an enamel, which forms the outside of the vessel. The efficiency of this apparatus has been found by Prof. Dr. Kittler to be between 84 and 87 per cent.

The **Reed** method of depositing a layer of silver on glass was described in the *Electrical World*, June 5, 1895.

The method employed by **Le Roy** (subhead 6) consists of inclosing sticks of crystallized carbon, having a specific resistance 1333 as high as that of ordinary arc light carbon, in glass tubes. For 110 volts rods are 100 mm. long, 10 mm. wide, and 3 mm. thick. This takes about 150 watts; and having a surface of 26 sq. cm., the dissipation of heat is at the rate of about 5 kg. calories per sq. cm. of surface, or an absorption of electrical energy of 6 watts per sq. cm. of surface.

Parvillé (*L'Eclairage Elec.*, Jan. 28, 1899) uses rods of metallic powder, mixed with fusible clay (quartz, kaolin), compressed under a pressure of 2000 kg. per sq. cm., and baked at a temperature of 1350° C. A rod 5 cm. long, 1 cm. wide, 0.3 cm. thick, has a resistance of 100 ohms, and absorbs 16500 watts per kg. One quart of water boils in 5 minutes with 15 amp. and 110 volts.

The above methods are utilized in the construction of electric cooking and heating apparatus, while those enumerated under sections II. and III. are employed for purposes of welding, smelting, and forging.

ELECTRIC COOKING.

Cost of Operating Electric Cooking Utensils.

On account of the number of variables which enter into the determination of the cost of electric heating and cooking, it is impossible to present any general data. These variables may be classified as follows:

1. Cost of current. 2. The skill of the operator from the cooking standpoint. 3. The skill of the operator from the standpoint of using the electrical apparatus economically. 4. The type of apparatus employed.

It is possible, however, by assuming an arbitrary cost for current, to calculate the cost of heating a given quantity of water. Let it be required to heat one gallon of water at a temperature of 50° F. (10° C.), without actually boiling it, to the boiling-point, or 100° C.; it would then be elevated 90° C. Hence 3786 cubic centimeters would be raised 90° C. or $3786 \times 90 = 340,740$ water-gramme-degrees-centigrade of heat are produced. The unit corresponding to a water-gramme-degree-centigrade is the calorie, which requires an expenditure of 4.18 joules, so that the work required to be done in raising a gallon of water to the temperature of 100° C. is equal to 340,740 × 4.18 = 1,424,293 joules. Assuming the cost of electric current, in large quantities, to be 5 cts. per kilowatt-hour (which is equal to 3,600,000 joules, as 1 joule = 1 watt per second), the cost of raising one gallon of water to the boiling-point is approximately 2 cents. If we assume the current to cost 15 cts. per kilowatt-hour, then the cost would be 6 cents.

This calculation, however, is strictly theoretical, as the assumption is made that all the heat generated is utilized in raising the temperature of the water. This, of course, is not the case, as a certain amount of the heat is transmitted to the metal vessel and the air during the time of the operation (about 15 minutes). Assuming the efficiency of the vessel to be 70 per cent, which represents the ratio between the useful and the total developed heat, then the actual cost of heating a gallon of water from 10° to 100° C. at a cost for current of 5 cts. per kilowatt-hour would be $2 \times \frac{100}{70} = 2.86$ cents, or at 15 cents per kilowatt-hour would be $3 \times 2.86 = 8.58$ cents.

Before proceeding to cite actual results achieved with electric cooking apparatus, the following table, furnished by the American Electric Heating Corporation, may be of value:

Time Required.

Stoves and griddles are ready for use, *i.e.*, have reached a temperature for cooking, in from 5 to 8 minutes from time current is turned on. Broiler, 12 to 14 minutes; Oven, 20 minutes; Farina Boilers, 6 to 8 minutes; Chafing-dishes, 10 minutes; Stew-pan, 5 minutes; Laundry-irons, 8 to 10 minutes very hot; Tailor's Irons, 6 to 12 minutes; Foot-warmers, 5 to 15 minutes; Curling-iron Heater, 6 to 8 minutes; Plate-warmer, 10 minutes; Soldering-Iron, 5 to 8 minutes; Glue-pots, 15 to 30 minutes.

To boil water, starting with water and heater cold, Stew-pan, 1 pint 16 minutes; small Teakettle, 1 pint 15 minutes; Five O'clock, 1 quart 18 minutes; 6 inch stoves (using suitable flat-bottom vessel), 1 quart 18 minutes; Teakettle, 1 quart 15 minutes, 2 quarts 28 minutes; Hot-water Urns, 1 gallon, one-half full in 35 minutes, full in one hour; 2 gallons, one-half full in 50 minutes, full in 1 hour 20 minutes; three gallons, one-half full in 37 minutes, full in 60 minutes; 5 gallons, one-half full in 30 minutes, full in 55 minutes. Very hot water, about 175 degrees F., can be had in about two-thirds the time stated for boiling. Water-heaters can be made to boil the quantities mentioned in about half the time, but the current required would be nearly double that mentioned for any standard articles. Coil-heaters when immersed in a covered vessel give the following results, using maximum current, and after water boils will maintain it at the boiling-point with one-fourth of the maximum.

(400 Watts) 1 pt., 10 minutes; 1 qt., 19 minutes; 2 qts., 35 minutes.
(660 ") 1 pt., 7 minutes; 1 qt., 12 minutes; 2 qts., 21 minutes; 3 qts., 28 minutes.
(880 ") 1 pt., 5 minutes; 1 qt., 8 minutes; 2 qts., 15 minutes; 1 gal., 28 minutes.
(1100 ") 1 qt., 6 minutes; 1 gal., 18 minutes; 2 gals., 35 minutes; 3 gals., 45 minutes.
(1650 ") 2 qts., 8 minutes; 1 gal., 14 minutes; 2 gals., 26 minutes; 3 gals., 35 minutes.

Practically the same results are obtained with immersion disk-heaters of the same watt capacity.

Mr. Colin (*Bul. Soc. Int. des Elec.*, Feb., 1897) found that the surface temperature of a broiler should be from 270° to 280° C. The total heat emitted will then be 11922 calories per hour. The surface of such a broiler 20 cm. by 14 cm., will require 140 watts per sq. decimeter for ordinary heating; 120 watts will give the best results.

C. O. Grimshaw (*Lond. Elec.*, Dec. 23, 1898) estimates the cost of electric cooking, based on 8 cts. per kilowatt-hour, as follows:—

Apparatus.	Capacity.	Cost per Hour in Cents.	Cost for One Operation from Cold in Cents.
Kettle	1½ pints	2.56	0.96
Griller	2 chops	4.48	1.06
Saucepan	2 quarts	3.2	1.6
Fish kettle . . .	16 quarts	9.12	. . .

At the Carmelite Hospice, Victoria Free Park, Niagara, an electric range has a heating surface of 6 sq. ft., each square foot consuming 15 amp. at 110 volts. The two small ovens consume 23 amp. each, the large one 50 amp. The oven equipment is designed for four 25 lb. roasts at one time. In the small ovens bread is baked in 18 minutes. The current for water heating, cooking, and lights costs $25 per H. P., while the 75 H. P. used in heating the corridor and bedrooms is secured at about one-fifth this price per H. P.

Mr. Dowsing, in the London *Electrical Review*, refers to a trial with a gas oven in which it was found that out of a total of over 13,000 heat units required in roasting a joint of 8.5 lbs. 2,203 units were actually used in the food itself, or about 16 per cent.

In a lecture before the A. I. E. E. in 1897, Prof. J. P. Jackson made the following statement:

To determine the relative cost of cooking with electricity and coal, the same foods were cooked on the No. 8 Othello coal stove ordinarily used by the family. The coal was carefully weighed. The results gave an average of 12.6 pounds per meal, which at $5.00 per ton gives a cost of 3.15 cents per meal. The results show the cost of cooking by coal to be about 19 per cent of the cost of cooking by electricity.

Prof. Dr. Kittler made a series of tests of the "Prometheus" cooking apparatus, and from a table prepared by him the following data are taken:

Quantity of Water Heated.	Time required, Seconds.	Energy consumed, Watt Seconds.	Temp. Incr. Fahr.	Efficiency of Apparatus.
300 grams . . .	255	131,835	191.3	83.9%
400 grams . . .	327	169,400	191.3	87.1%

Mr. R. E. Crompton accurately measured the temperature of a number of electric heating utensils, and utilized the facts obtained in the compilation of the following table:

	Time in Minutes.	Energy in K.W. hrs.	Cost at 8 cts. per K.W. hr.	Temp. Fahr. Scale.
TABLE I. — Showing energy required to raise a heater plate from 50° F. to 400° F. in half an hour.	. . .	. . .	. . .	50
	10	0.116	.92	257
	14	0.164	1.34	332
	21	0.248	2.00	337
	30	0.404	3.22	400

	Time in Minutes.	Energy in K.W. hrs.	Cost at 8 cts. per K.W. hrs.	Temp. Fahr. Scale.
TABLE II. — Shows the energy required for a radiator plate such as is used for heating the air of a room.	. . .	. . .	. . .	50
	10	0.091	0.728	171
	30	0.277	2.2	240
	40	0.350	2.8	257
	50	0.430	3.44	261
	60	0.500	4.00	264
TABLE III. — Shows the energy required to boil 1 lb. of water in a kettle.	. . .	. . .	. . .	50
	18	0.075	0.64	212
TABLE IV. — Shows energy required by a smaller kettle containing ¾ lb. of water, *i.e.*, sufficient for two cups of tea.	. . .	. . .	. . .	50
	12	0.051	0.4	212

This shows that the efficiency of the operation in Table III. is 63 per cent, and that in Table IV. is 71.5 per cent.

The following curves show the rise of temperature in the case of a heater plate and a radiator and also the energy consumed:

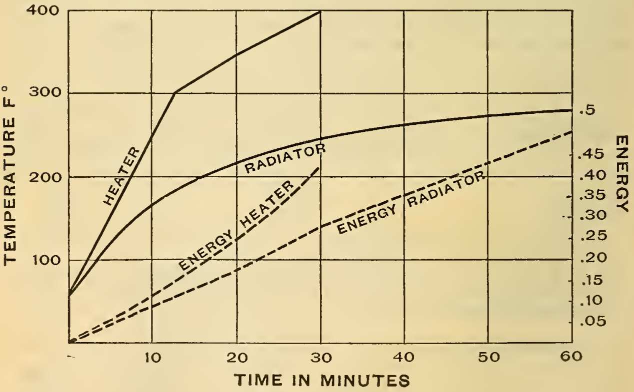


FIG. 1.

Efficiency of Heating Apparatus.

In the foregoing references it will be seen that the efficiency of electric cooking apparatus varies from about 63 per cent to 90 per cent (for ovens), depending upon a number of variable conditions, such as time, size, quantity to be heated, temperature rise, etc.

According to Mr. Crompton, the efficiency of an ordinary cooking-stove using solid fuel is only about 2 per cent, 12 per cent being wasted in obtaining a glowing fire, 70 per cent going up the chimney, and 16 per cent being radiated into the room.

In a gas-stove, considering that the number of heat units obtainable from the gas at a certain price is but small compared with solid fuel, the ventilating current required for the operation alone consumes at least 80 per cent of the heat units obtained by burning the gas.

In the case of an electrical oven, more than 90 per cent of the heat energy can be utilized; and thus, although possibly 5 to 6 per cent only of the heat energy of the fuel is present in the electrical energy, 90 per cent of this, or 4½ per cent of the whole energy, actually goes into the food, and thus the electrical oven is practically twice as economical as any other oven, whether heated by solid fuel or by gas.

ELECTRIC RADIATORS.

Unless electricity is produced at a very low cost it is not commercially practicable to heat residences or large buildings. While this is true, the electric heater still has a field of application, in heating small offices, bathrooms, snuggeries, cold corners of rooms, street railway waiting rooms, the summer villa on cool evenings, and in mild climates a still wider range. It has the peculiar advantage of being instantly available, and the amount of heat is regulated at will. The heaters are perfectly clean, do not vitiate the atmosphere, and are portable.

According to Houston and Kennelly, one joule of work expended in producing heat will raise the temperature of a cubic foot of air about $\frac{1}{18}$ ° F.

The amount of power required for electrically heating a room depends greatly upon the amount of glass surface in the room, as well as upon the draughts and admission of cold air.

In order to make a comparison between heating an ordinary city house by means of coal burnt in a furnace and by electricity furnished by a central station, let it be assumed that 100 lbs. of coal are consumed per day in the furnace. Assuming the furnace to have an efficiency of 50 per cent, 50 lbs. of coal are utilized throughout the building in the form of heat. Reducing this to actual horse-power we have

$$\frac{50 \times 14{,}000}{700{,}000} \text{ heat units.}$$

$$700{,}000 \times 778 = 544{,}600{,}000 \text{ ft.-lbs.}$$

$$\frac{544{,}600{,}000}{33{,}000} = 16{,}503 \text{ H.-P. minutes.}$$

$$\frac{16{,}503}{60} = 275 \text{ H.-P. hours.}$$

Assuming that a H.-P. hour is furnished at 5 cents the cost would be

$$275 \times .05 = \$13.75.$$

ELECTRIC CAR HEATING.

At the Montreal meeting of the American Street Railway Association in 1895, Mr. J. F. McElroy read an exhaustive paper on the subject of car-heating, from which the following abstracts are taken:

In practice it is found that 20,000 B. T. U. are necessary to heat an 18 to 20 foot car in zero weather. When the outside temperature is 12½ ° F. only 16,000 B. T. U. are required, etc., which shows the necessity of having electric heaters adjustable.

The amount of heat necessary in a car to maintain a given inside temperature, depends on: 1. The amount of artificial heat which is given to it. 2. The number of passengers carried. The average person is capable of giving out an amount of heat in 24 hours which is equal to 191 B. T. U.

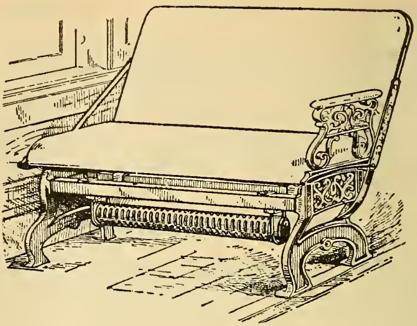


FIG. 2.

Cost of Car Heating.

The following table was compiled by Mr. McElroy from the reply received from the Albany Railway Company:

Average fuel cost on Albany Railway, per amp. hour = .241 cent.

Average total cost for fuel, labor, oils, waste, and packings per amp. hour = .423 cent.

	Cost of fuel per hour for heating a car with electric heaters with coal at $2.00 per 2000 lbs.				
	Position of Switch.				
	1st	2d.	3d.	4th.	5th.
	Amperes equal.				
	2.14	2.88	6.88	8.09	12.0
	cts.	cts.	cts.	cts.	cts.
Simple high speed condensing	.43	.58	1.40	1.62	2.41
Simple low speed condensing	.40	.54	1.30	1.51	2.24
Compound high speed condensing	.39	.52	1.27	1.47	2.20
Compound low speed condensing	.36	.48	1.17	1.36	2.03

Average Cost Per Day for Stoves.

33 lbs. of coal at $4.55 per ton	$.075
Repairs	.005
Dumping and removing coal and ashes, coaling up and kindling fire, including cost of kindling, and part of cleaning car	.100
Removing stoves for summer, installing for winter, repairing head linings, repainting, etc., average per day	.0125
Total	$.1925

ELECTRIC IRONS FOR DOMESTIC AND INDUSTRIAL PURPOSES.

Comparing the hand-irons heated by gas with those heated electrically, it is claimed that if gas can be purchased at $1.25 per 1000 cu. ft., and the cost of electricity is about 1 cent per H P., the two systems are about on a par, as far as cost only is concerned.

According to the American Electric Heating Corporation, the power consumption for the various types of irons is as follows : —

	Watts
4 lbs. Troy Polishing, diamond face	330
3½ lbs. Small Seaming (can be connected to lamp socket)	200
4 lbs. Gentleman's Small Hat Iron	200
5½ lbs. Light Domestic	500
5½ lbs. Light Domestic, round nose	500
7 lbs. Domestic	600
9 lbs. Heavy Laundry	680
9 lbs. Hatters'	550
9 lbs. Corset	500
15 lbs. Hatters' Factory	550
5½ lbs. Morocco Bottom	500
Morocco Bottom, round nose	500

ELECTRIC WELDING AND FORGING.

The current employed in electric welding may be either continuous or alternating. By the use of alternating currents, a slightly more uniform heating of the contact surfaces is obtained, because alternating currents tend to develop a greater heat at the surface of a large mass than at the central portions.

Thomson Electric Welding Process.

The principle involved in the system of electric welding, invented by Prof. Elihu Thomson, is that of causing currents of electricity to pass through the abutting ends of the pieces of metal which are to be welded, thereby generating heat at the point of contact, which also becomes the point of greatest resistance, while at the same time mechanical pressure is applied to force the parts together. As the current heats the metal at the junction to the welding temperature, the pressure follows up the softening surface until a complete union or weld is effected; and, as the heat is first developed in the interior of the parts to be welded, the interior of the joint is as efficiently united as the visible exterior.

Horse-Power Used in Electric Welding.

The power required for the different sizes varies nearly as the cross sectional area of the material at the joint where the weld is to be made.

Within certain limits, the greater the power, the shorter the time; and vice versa.

The following tables are based upon actual experience in various works, and from very careful electrical and mechanical tests made by reliable experts. The time given is that required for the application of the current only.

Round Iron or Steel.

Diameter.	Area.	H.-P. Applied to Dynamo.	Time in Seconds.
¼ in.	.05	2.0	10
⅓ in.	.10	4.2	15
½ in.	.22	6.5	20
⅝ in.	.30	9.0	25
¾ in.	.45	13.3	30

Extra Heavy Iron Pipe.

Inside Diameter.	Area.	H.-P. applied to Dynamo.	Time in Seconds.
½ in.	.30	8.9	33
¾ in.	.40	10.5	40
1 in.	.60	16.4	47
1¼ in.	.79	22.0	53
1½ in.	1.10	32.3	70
2 in.	1.65	42.0	84
2½ in.	2.25	63.7	93
3 in.	3.00	96.2	106

General Table.

Iron and Steel.			Copper.		
Area in sq. in.	Time in Seconds.	H.-P. applied to Dynamos.	Area in sq. in.	Time in Seconds.	H.-P. applied Dynamos.
0.5	33	14.4	.125	8	10.0
1.0	45	28.0	.25	11	23.4
1.5	55	39.4	.375	13	31.8
2.0	65	48.6	.5	16	42.0
2.5	70	57.0	.625	18	51.9
3.0	78	65.4	.75	21	61.2
3.5	85	73.7	.875	22	72.9
4.0	90	83.8	1.0	23	82.1

Axle Welding.

1″ round axle requires 25 Horse-power for 45 seconds.
1″ square " " 30 " " " 48 "
1¼″ round " " 35 " " " 60 "
1¼″ square " " 40 " " " 70 "
2″ round " " 75 " " " 95 "
2″ square " " 90 " " " 100 "

The slightly increased time and power required for welding the square axle is not only due to the extra metal in it, but in part to the care which it is best to use to secure a perfect alignment.

Tire Welding.

1″ x 3/16 tire requires 11 Horse-power for 15 seconds.
1¼″ x ⅜″ " " 23 " " " 25 "
1½″ x ⅜″ " " 23 " " " 30 "
1½″ x ½″ " " 23 " " " 40 "
2″ x ½″ " " 29 " " " 55 "
2″ x ¾″ " " 42 " " " 62 "

The time above given for welding is of course that required for the actual application of the current only, and does not include that consumed by placing the axles or tires in the machine, the removal of the upset, and other finishing processes.

From the data thus submitted, the cost of welding can be readily figured for any locality where the price of fuel and cost of labor are known.

HYDRO-ELECTROTHERMIC SYSTEMS.

Hoho and Lagrange System.

In this system an electrolytic bath is employed, into which an electric current of considerable E.M.F. is led, passing from the positive pole which forms the boundaries of the bath and presents a large surface to the electrolyte and thence to the negative pole, consisting of the metal or other material to be treated, and which is of relatively small dimensions.

Through the electrolytic action hydrogen is rapidly evolved at the negative pole and forms a gaseous envelope around the pole; as the gas is a very poor conductor of electricity, a large resistance is thus introduced in the circuit, entirely surrounding the object to be treated. The current in passing through this resistance develops thermal energy, and this is communicated to the metal or other object which forms the negative pole.

This system has been extensively used in England, and is described in *The Electrical World*, Dec. 7, 1895.

Burton Electric Forge.

In a patent granted to George D. Burton on an electrolytic forge, the portion to be heated is placed in a bath consisting of a solution of sal soda, or water, carbonate of soda, and borax. The tank is preferably made of porcelain or fire-clay. The anode plate has a contact surface with the liquid much greater than the area of contact of the article to be heated. This plate is composed of lead, copper, carbon, or other suitable conducting material.

Zerener System.

In this system an arc is used in combination with a magnet which deflects the arc, making a flame similar to that of a blow-pipe, but having the temperature of the arc. The apparatus contains a self-regulating device which is driven by a small electric motor; for welding iron a current of 40 to 50 amperes at 40 volts will suffice for strips of metal three mm. thick.

Bernardos System.

In this system the article to be operated upon is made to constitute one pole of the electric circuit, while a carbon pencil attached to a portable insulated holder, and held by the workman, constitutes the other pole, the electric arc — which is the heating agent of the process — being struck between the two poles thus formed. This system has been used extensively in England for the repair of machinery. The Barrbeat-Strange Patent Barrel Syndicate use this system for the welding of the seams of sheet-steel barrels.

Voltex Process for Welding and Brazing

Consists in the use of an electric arc formed between two special carbon rods inclined to each other at an angle of about 90°. The whole apparatus can generally be held in one hand. With gas and coke, gas costing only 70 cents per 1000 cubic feet, it is claimed the complete cost of brazing and filling up a bicycle frame is $1.43, while with the Voltex process, at 6 cents per kilowatt hour, it is only 46 cents.

Stassano Process of Electric Smelting

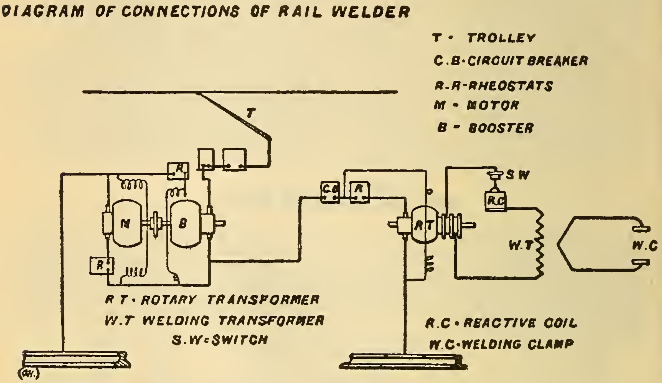
Consists of heating, in an arc furnace, briquettes composed of iron ore, carbon, and lime made into a paste with tar. The smelting process occurs in a blast furnace, the iron being reduced, and the siliceous matter of the ore slagged off.

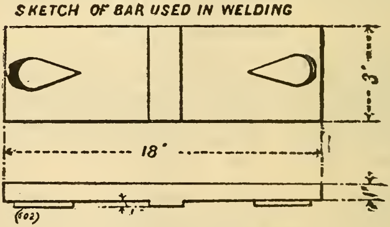
Annealing of Armor Plate.

The spot to be treated is brought to a temperature of about 1000 ° F. The current used is equivalent to 40,000 amperes per square inch, a density which is only possible by the use of cooling by water circulation. The operation generally takes seven minutes.

Electric Rail Welding.

The "Electric" joint, applied by the Lorain Steel Co., is made by welding plates on both sides of the web of the rail. The plates shown in Fig. 4 are 1 inch by 3 inches, by 18 inches, and have three bosses, three welds being made at each joint. Great pressure up to 35 tons is maintained on the joint whilst making and cooling. The welding current runs as high as 25,000 amperes. The connections are shown in Fig. 3.





Web Plates

FIGS. 3 AND 4. — The Lorain Steel Company Method of Electric Welding.

FUSE DATA.

In a lecture on "The Rating and Behavior of Fuse Wires," before the A. I. E. E., in October, 1895, Messrs. Stine, Gaytes, and Freeman arrived at the following conclusions:

1. Covered fuses are more sensitive than open ones.
2. Fuse wire should be rated for its carrying capacity for the ordinary lengths employed.

2 (a). When fusing a circuit, the distance between the terminals should be considered.

3. On important circuits, fuses should be frequently renewed.
4. The inertia of a fuse for high currents must be considered when protecting special devices.
5. Fuses should be operated under normal conditions to ensure certainty of results.
6. Fuses up to five amperes should be at least 1½ inch long, one-half inch to be added for each increment of five amperes capacity.
7. Round fuse wire should not be employed in excess of 30 amperes capacity. For higher currents flat ribbons exceeding four inches in length should be employed.

(For additional data on Fuses see p. 204.)

SOME NOTES ON THE OPERATION OF ELECTRIC MINING PLANTS.

From Pamphlet by General Electric Company.

Mr. F. J. Platt of the Scranton Electric Construction Company, Scranton, Pa., gives some figures on electric haulage. They are from plants which have been in operation for one year or longer. The expenses given are the actual figures for labor, oil, repairs, etc.

In figuring the cost of mule-power, the cost per mule has been taken at 50 cents per working-day, which includes feed, attendance, medicine, shoeing, harness, and the item of mortality. Depreciation on the electric plant is figured at 5%, and is given per working-day.

The first plant on which Mr. Platt presents figures is the Green Ridge Colliery, installed in March, 1895, for Mr. O. S. Johnson, in the city of Scranton.

The Green Ridge Colliery.

The Green Ridge Colliery plant consists of one 100 H.P. automatic, high-speed engine, and one 75 H.P. dynamo, with switchboard and station equipment, all of which are installed in a frame building 30 feet by 45 feet.

From the dynamo a feeder wire is run down the slope 1,000 feet to the main gangway, where a 6½ ton electric locomotive is in operation over about 1¼ miles of trolley road. This locomotive gathers trips from three different points in the mines, and delivers them to the foot of the outside slope. The main gangway, which is very crooked, is about 3,100 feet long, and branching from it are two other roads, one of which is 1,000 feet and the other 2,100 feet in length. For the past year this locomotive has made a daily average of twenty trips, each trip consisting of eight cars, which is very much below its capacity.

The grades on the main roads are about 1% in favor of the loaded and against the empty cars. On the 1,000 foot branch the locomotive has about 500 feet of 3% and 500 feet of 1% grade against the empty cars. On the 2,100 foot branch the grades are very uneven, and most of them are against the loaded cars. The grades of this road, against the loaded cars, consist approximately of 150 feet of 7% grade, 500 feet of 2% grade, 350 feet of 5⅓% grade, and 450 feet of 3½% grade.

This 6½ ton locomotive has been hauling trips of four cars up these grades ever since it was installed, and on some days has hauled trips of five cars.

The roof of the mine is very low, being about five feet in the highest places; and as this height was obtained by blowing the roof over the center of the road, the height on the main road will not average much over four feet. This is one difficulty which would have been met had a steam locomotive been introduced instead of an electric locomotive.

Cost of Haulage at the Green Ridge Colliery.

After very carefully going over all the expenses connected with this plant, the following results were obtained:

The plant cost $7,625.18. Depreciation at 5% per year would amount to $381.25, or taking 200 working-days per year the depreciation per working-day would be $1.90.

Cost of operation per day is as follows:

Station Engineer	$1.75
Motorman	1.75
Helper	1.60
Repairs	76
Depreciation	1.90
Oil and waste	20
Total	$7.96

The coal hauled per day by the electric locomotive is 288 tons, at a cost per ton, as shown above, of 2.76 cents.

To haul this coal by mule-power would require

Seventeen mules at 50 cents each	$8.50
Three drivers at $1.45 each	4.35
Three drivers at $1.25 each	3.75
Four boys at $1.00 each	4.00
Total	$20.60

This shows a cost for haulage by mule-power of 7.15 cents per ton, and a saving by electric haulage of 4.39 cents per ton. On the 288 tons hauled per day the saving is $12.64, and for a year of 200 working-days it amounts to $2,528.00.

This locomotive has averaged 30 miles per day, making a total of about 12,700 miles since it was installed.

The expense of repairs taken on the basis of mileage is a trifle over two cents per mile.

This statement shows the actual results at this particular plant, and what is being saved per day. The number of mules saved in the above case, is the number that it would require to haul an amount equal to the output of the locomotive on any one day; but it is doubtful if seventeen mules would be able to do this work continually, as they would interfere with each other on the main roads, and would not deliver the coal as regularly as does the locomotive.

Among others referred to are the two electric haulage plants at the mines of the New York and Scranton Coal Company, at Peckville, Pa. The figures given are based on the expenses of the year 1896.

The New York and Scranton Coal Company.

One of the mines operated by the New York and Scranton Coal Company is known as The Sturges Shaft. The plant consists of a 160 H.P. engine and generator and a 6½ ton locomotive, operating over 4,500 feet of trolley road. The cost of the plant was $6,103.00. The depreciation per year at 5% would amount to $305.15, or for 200 working-days, $1.52 per day.

Cost of operation per day is as follows:

Motorman	$1.75
Helper	1.25
Electrician	.78
Repairs	1.03
Depreciation	1.52
Oil	24
Total	$6.57

The coal hauled per day is 250 tons, at a cost per ton, as shown above, of 2.62 cents.

To haul this coal by mule-power would require

Fourteen mules at 50 cents each	$7.00
Seven boys at $1.35 each	9.45
Total	$16.45

This shows a cost for haulage by mule-power of 6.58 cents per ton, and a saving by electric haulage of 3.96 cents per ton. On the 250 tons hauled per day the saving is $9.90, and for a year of 200 working-days it amounts to $1,980.00.

The locomotive runs about 32 miles per day, and up to this time has covered about 7,800 miles, with a cost for repairs of 2.7 cents per mile.

The other haulage plant operated by the New York and Scranton Coal Company is located at the tunnel opening.

The cost of the plant was $7,039.00. The depreciation per year at 5% would amount to $351.95, or for 200 working-days $1.75 per day.

Cost of operation per day is as follows :

Motorman	$1.75
Helper	1.25
Electrician	.78
Repairs	.65
Depreciation	1.75
Oil	.24
Total	$6.42

The coal hauled per day is 600 tons, at a cost per ton as shown above, of 1.07 cents.

To haul this coal by mule-power would require

Twelve mules at 50 cents each	$6.00
Six boys at $1.35 each	8.10
Total	$14.10

This shows a cost for haulage by mule-power of 2.35 cents, and a saving by electric haulage of 1.28 cents per ton. On the 600 tons hauled per day the saving is $7.68, and for a year of 200 working-days it amounts to $1,536.00.

The Hillside Coal and Iron Company.

The Hillside Coal and Iron Company was one of the first companies to install electric haulage. At Forest City, Pa., they have two openings operated by electric haulage from one power-house. The power-house contains about 150 Kw. direct connected generators and one 62 Kw. belt driven machine. At what is known as the "No. 2 Shaft" they have one twenty-ton, eight-wheel locomotive, one twelve-ton single motor locomotive, and one six-ton locomotive. At the Forest City Slope there is a twelve-ton single motor locomotive. In addition to this, they have two electric pumps.

The plant here has been in operation since 1891, although the power-house has been increased and rebuilt since the original plant was installed.

Mr. W. A. May, Superintendent, very kindly furnished the following figures, which are on exactly the same basis as the figures in Mr. Platt's paper.

Cost of operation per day is as follows :

	No. 2 Shaft.	Forest City Slope.
Engineer of power-house	$1.20	$0.60
Motormen	4.23	2.11
Helpers (Brakemen)	3.20	1.60
Electrician	1.67	.83
Repairs to motors	5.95	4.09
Depreciation, 5%	5.20	2.60
Oil and waste	.22	.14
Total	$21.67	$11.97
Coal hauled per day — tons	989	541
Cost per ton	$.0219	$.0221

This plant has never been operated with mules, but the mine foreman has gone over the matter very carefully, and has made up the following estimate of the number of mules it would require to do the work. He finds that it would take fifty-three mules in the shaft and twenty-four in the slope. Again using Mr. Platt's figures, we get the following cost per day for haulage by mule-power in No. 2 Shaft.

Fifty-three mules at 50 cents each	$26.50
Twenty-four drivers at $1.48 each	35.52
Twenty-four team leaders at $1.04 each	24.96
Total	$86.98

This shows a cost for haulage by mule-power of 8.79 cents per ton and a saving by electric haulage of 6.60 cents per ton. On the 989 tons hauled per day the saving is $65.27, and for a year of 200 working-days it amounts to $13,054.00.

In the Forest City Slope the cost per day for haulage by mule-power is as follows:

Twenty-four mules at 50 cents each	$12.00
Ten drivers at $1.48 each	14.80
Ten team leaders at $1.04 each	10.40
Two runners at $1.59 each	3.18
Total	$40.38

This shows a cost for haulage by mule-power of 7.47 cents per ton, and a saving by electric haulage of 5.26 cents per ton. On the 541 tons hauled per day the saving is $28.46, and for a year of 200 working-days it amounts to $5,692.00.

Mr. May remarks that in their particular case this estimate is not entirely correct, as the expenses of the engineer, motormen, helpers, etc., are steady expenses, their time on idle days being occupied with more or less running around and making repairs about the mines. They have therefore made an additional set of figures, using the actual number of days that the mines were running, with the actual cost. The No. 2 Shaft ran 141¼ days, and the Forest City Slope 138¾ days. Under these circumstances the cost of operation per day is as follows:

	No. 2 Shaft.	Forest City Slope.
Engineer of power-house	$2.84	$1.45
Motormen	9.31	4.76
Helpers (Brakemen)	3.61	2.63
Electrician	3.68	1.87
Repairs to motors	8.42	5.89
Repairs to line	.46	.03
Repairs to generators	.61	.30
Fireman	2.50	1.26
Depreciation, 5%	8.17	4.16
Oil and waste for motors	.35	.21
Oil and waste for generators	.74	.37
Interest on plant at 3%	4.41	2.25
Total	$45.10	$25.18
Coal hauled per day — tons	989	541
Cost per ton	$.0456	$.0465

Then, again, taking their own figures on the cost of keeping what mules they have, they obtained the following cost per working-day for haulage in No. 2 Shaft:

The depreciation on 53 mules, at $1.67 each per month, is $88.51, and for 12 working-days per month the depreciation per day is $7.38.

Depreciation on 53 mules	$7.38
Feed for 53 mules (at 25 cents each per day per month)	33.12
Shoeing and harness	1.59
Care of mules	3.97
Forty-eight drivers and team-leaders	60.48
Total	$106.54

This shows a cost for haulage by mule-power of 10.77 cents per ton, and a saving by electric haulage of 6.21 cents per ton. On the 989 tons hauled per day the saving is $61.42, and for a year of 141¼ days it amounts to $8,675.75.

In the Forest City Slope the depreciation figured as above on 24 mules is $3.34, and the detailed cost of haulage by mule-power is as follows:

Depreciation on 24 mules	$3.34
Feed for 24 mules (at 25 cents each per day per month)	15.00
Shoeing and harness	.72
Care of mules	1.80
Twenty-two drivers, leaders, and runners	28.38
Total	$49.24

This shows a cost for haulage of mule-power of 9.10 cents per ton, and a saving by electric haulage of 4.45 cents per ton. On the 541 tons hauled per day the saving is $24.07, and for a year of 138¾ days it amounts to $3,339.71.

To the cost of the mule-power might yet be added interest at 3% on the value of the mules and harness, but as it has not heretofore been included, it has been left out here.

From the foregoing it will be seen that in either case there is a considerable saving in favor of electric haulage, and that this saving will increase as the number of idle days increases and with the increase in tonnage in the colliery.

LIGHTNING CONDUCTORS.

Views concerning the proper function and value of lightning rods, conductors, arresters and all protective devices have undergone considerable modification during the past ten years. There may be said to be four periods in the history of the development of the lightning protector. The first embraces the discovery of the identity of lightning with the disruptive discharge of electrical machines and Franklin's clear conception of the dual function of the rod as a conductor and the point as a discharger. The second begins with the experimental researches of Faraday and the miniature house some twelve feet high, which he built and lived in while testing the effects of external discharges. Maxwell's suggestion to the British Association, in 1876, embodies a plan based upon Faraday's experiments, for protecting a building from the effects of lightning by surrounding it with a cage of rods or stout wires. The third period begins with the experiments of Hertz upon the propagation of electro-magnetic waves, and finds its most brilliant expositor in Dr. Oliver J. Lodge, of University College, Liverpool, whose experiments made plain the important part which the momentum of an electric current plays, especially in discharges like those of the lightning flash, and all discharges that are of very high potential and oscillatory in character. The fourth period is that of the present time, when individual flashes are studied; and protection entirely adequate for the particular exposure is devised, based upon some knowledge of the electrical energy of the flash, and the impedance offered by appropriate choke coils or other devices. For example, under actual working conditions, with ordinary commercial voltages, effective protection to electrical machinery connected to external conductors may be had with a few choke coils in series with intervening arresters.

A good idea of the growth of our knowledge of the nature and behavior of the lightning flash may be obtained from the following publications:

Franklin's letters.

Experimental Researches. . . . Faraday.

Report of the Lightning Rod Conference, 1882.

Lodge's "Lightning Conductors and Lightning Guards," 1892.

"Lightning and the Electricity of the Air." . . . McAdie and Henry, 1899.

FIG. 1 EFFECT OF THE ACTION OF LIGHTNING UPON A ROD.

That a lightning rod is called upon to carry safely to earth the discharge from a cloud was made plain by Franklin, and the effect of the passage of the current very prettily shown in the melting of the rod and the point (aigrette).

Here indeed was a clew to the measurement of the energy of the lightning flash. W. Kohlrausch in 1890 estimated that a normal lightning discharge would melt a copper conductor 5 mm square, with a mean resistance of 0.01 ohm in from .03 to .001 second. Koppe in 1895 from measurements of two nails 4 mm in diameter fused by lightning, determined the current to be about 200 amperes and the voltage about 20,000 volts. The energy of the flash, if the time be considered as 0.1 second, would be about 70,000 horse power, or about 52,240 kilowatts.

Statistics show plainly that buildings with conductors when struck by lightning suffer comparatively little damage compared with those not provided with conductors. The same rod, however, cannot be expected to serve equally well for every flash of lightning. There is great need of a classification of discharges based less upon the appearance of the flash than upon its electrical energy. Dr. Oliver J. Lodge has made a beginning with his study of *steady strain* and *impulsive rush* discharges. "The energy of an ordinary flash," says Lodge, "can be accounted for by the discharge of a very small portion of a charged cloud, for an area of ten yards square at the height of a mile would give a discharge of over 2,000 foot-tons energy."

We must get clearly in our minds then the idea that the cloud, the air, and the earth constitute together a large air condenser, and that when the strain in the dielectric exceeds a tension of ½ gramme weight per square centimeter, there will be a discharge probably of an oscillatory character. And as the electric strain varies, the character of the discharge will vary. Remember too that the air is constantly varying in density, humidity and purity. We should therefore expect to find, and in fact do, every type of discharge from the feeble brush to the sudden and terrific break. Recent experiments indicate that after the breaking-down of the air and the passage of the first spark or flash, subsequent discharges are more easily accomplished; and this is why a very brilliant flash of lightning is often followed almost immediately by a number of similar flashes of diminishing brightness. The heated or incandescent air we call lightning, and these lines of fracture of the dielectric can be photographed; but the electrical waves or oscillations in the ether are extremely rapid, and are beyond the limits of the most rapid shutter and most rapid plate. Dr. Lodge has calculated the rapidity of these oscillations to be several hundred thousand per second. Lodge has also demonstrated experimentally that the secondary or induced electrical surgings in any metallic train cannot be disregarded; and, as in the case of the Hotel de Ville at Brussels which was most elaborately protected by a network, these surgings may spark at nodal points, and ignite inflammable material close by.

While therefore it cannot be said that any known system of rods, wires, or points affords complete and absolute protection, it can be said with confidence that we now understand why "spitting-off" and "side" discharges occur; and furthermore, to quote the words of Lord Kelvin, that "there is a very comfortable degree of security . . . when lightning conductors are made according to the present and orthodox rules."

Selection and Installation of Rods.—The old belief that a copper rod an inch in diameter could carry safely any flash of lightning is perhaps true, but we now know that the core of such a rod would have little to do in carrying such a current as a lightning flash, or, for that matter, any high frequency currents. Therefore, since it is a matter of surface area rather than of cubic contents, and a problem of inductance rather than of simple conductivity, tape or cable made of twisted small wires can be used to advantage and at a diminished expense.

All barns and exposed buildings should have lightning rods with the necessary points and earth connections. Ordinary dwelling-houses in city blocks well built up have less need for lightning conductors. Scattered or isolated houses in the country, and especially if on hillsides, should have rods. All protective trains, including terminals, rods, and earth connections, should be tested occasionally by an experienced electrician, and the total resistance of every hundred feet of conductor should not greatly exceed one ohm. Use a good iron or copper conductor. If copper, the conductor should weigh about six ounces per linear foot; if iron, the weight should be about two pounds per foot. A sheet of copper, a sheet of iron, a tin roof, if without breaks, and fully connected by well soldered joints, can be utilized to advantage.

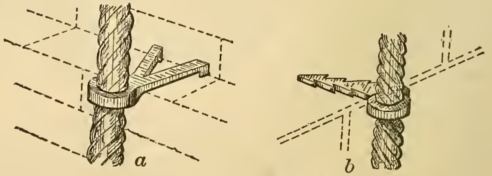


FIG. 2 AND 3 APPROVED CONDUCTORS AND FASTENINGS.

In a recently published* set of Rules for the Protection of Buildings from Lightning, issued by the Electro-Technical Society of Berlin, Dr. Slaby gives the results of the work of various committees for the past sixteen years studying this question. The lightning conductor is divided into three parts, — the terminal points or collectors, the rod or conductor proper attached to the building, and the earth plates or ground. All projecting metallic surfaces should be connected with the conductors, which, if made of iron, should have a cross section of not less than 50 mm square (1.9 sq. inches); copper, about half of these dimensions, zinc about one and a half, and lead about three times these dimensions. All fastenings must be secure and lasting. The best ground which can be had is none too good for the lightning conductor. For many flashes an ordinary ground will suffice, but there will come occasional flashes when even the small resistance of $\frac{1}{10}$ ohm may count. Bury the earth plates in damp earth or running water. The plates should be of metal at least three feet square.

"If the conductor at any part of the course goes near water or gas mains, it is best to connect it to them. Wherever one metal ramification approaches another, connect them metallically. The neighborhood of small bore fusible gas pipes, and indoor gas pipes in general, should be avoided." — DR. LODGE.

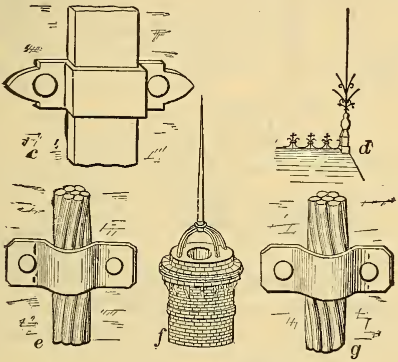


FIG. 4 CONDUCTORS AND FASTENINGS.
(FROM ANDERSON, AND LIGHTNING ROD CONFERENCE.)

The top of the rod and all projecting terminal points should be plated, or otherwise protected from corrosion and rust.

Independent grounds are preferable to water and gas mains. Clusters of points or groups of two or three along the ridge rod are good. Chain or linked conductors should not be used.

It is not true that the area protected by any one rod has a radius equal to twice the height of the conductor. Buildings are sometimes, for reasons which we understand, damaged within this area. All connections should be of clean well-scraped surfaces properly soldered. A few wrappings of wire around a dirty water or gas pipe does not make a good ground. It is not necessary to insulate the conductor from the building.

DIRECTIONS FOR PERSONAL SAFETY DURING THUNDER STORMS

Do not stand under trees or near wire fences; neither in the doorways of barns, close to cattle, near chimneys or fireplaces. Lightning does not, as a rule, kill. If you are near a person who has been struck do not give him up

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Electrotechnische Ztschrift, 1901, May 29, *ei* as beyond recovery, even if seemingly dead. Stimulate respiration and circulation as best you can. Keep the body warm ; rub the limbs energetically, give water, wine, or warm coffee. Send for a physician.

TESTS OF LIGHTNING RODS.

To make the test, first determine the resistance of the lead wire l_1 and call it l_1. Then connect E_1 and E_2 as shown in the diagram, call the result R_1; then connect E_1 and E_3, call the result R_2; connect E_2 and E_3 and call the result R_3.

TESTS OF LIGHTNING RODS.

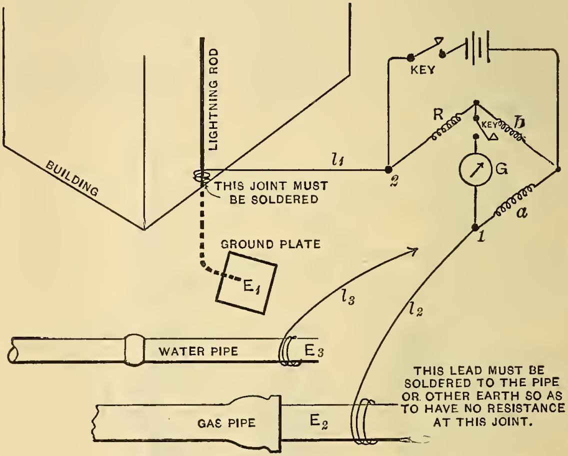


FIG. 5 DIAGRAM OF CONNECTIONS FOR TEST OF LIGHTNING RODS.

Now, $R_1 = l_1 + E_1 + E_2$ and $E_2 = R_1 - l_1 - E_1$
$R_2 = l_1 + E_1 + E_3$ and $E_3 = R_2 - l_1 - E_1$
$R_3 = E_2 + E_3$

solving, we have

$$E_1 = \frac{R_1 + R_2 - R_3}{2} - l_1$$

All lightning rods should be tested for continuity and for resistance of ground plate each year, and the total resistance of the whole conductor and ground plate should never exceed an ohm.

DETERMINATION OF WAVE FORM OF CURRENT AND ELECTRO MOTIVE FORCE.

THERE are numerous methods of determining wave form, those used in laboratory experiments commonly making use of the ballistic galvanometer. Of the simple methods used in shop practice, R. D. Mershon, of the Westinghouse Electric and Manufacturing Co., has applied the telephone to an old ballistic method in such a manner as to make it quite accurate and readily applied.

Mershon's Method.—The following cut shows the connections. A telephone receiver, shunted with a condenser, is connected in the line from the source of current, the wave form of which it is wished to determine. A contact-maker is placed in the other leg, and an external source of steady current, as from a storage battery, is opposed to the alternating current, as shown. The pressure of the external current is then varied until there is no sound in the telephone, when the pressures are equal and can be read from the voltmeter. The contact-maker being revolved by successive steps, points may be determined for an entire cycle.

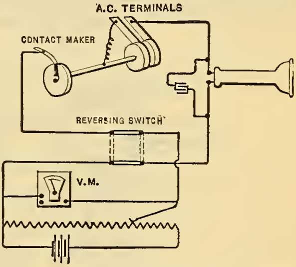


FIG. 1. Mershon's method of determining Wave Form.

Duncan's Method.—Where it is desirable to make simultaneous determinations it will ordinarily require several contact-makers, as well as full sets of instruments. Dr. Louis Duncan has devised a method by which one contact-maker in connection with a dynamometer for each curve will enable all readings to be taken at once. The following cut shows the connections. The fixed coils of all the dynamometers are connected to their respective circuits, and the fine wire movable coils of about 1,000 ohms each, are connected in series with a contact-maker and small storage battery. The contact-maker is made to revolve in synchronism with the alternating current source. Now, if alternating currents from the different sources are passed through the fixed coils, and at intervals of the same frequency current from the battery is passed through the movable coils, the deflection or impulse will be in proportion to the instantaneous value of the currents flowing in the fixed coils, and the deflections of the movable coils will take permanent position indicating that value, if the contact-maker and sources of alternating current are revolved in unison.

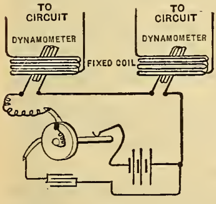


FIG. 2. Duncan's method of determining curves of several circuits at the same time.

The dynamometers are calibrated first by passing continuous currents of known value through the fixed coils, while the regular interrupted current from the battery is being passed through the movable coils.

Ryan's Method.—Prof. Harris J. Ryan, of Cornell University, designed a special electrometer for use in connection with a very fine series of transformer tests. This instrument will be found described and illustrated in the chapter on description of instruments.

The method of using it is shown in the cut below, in which the contact-maker shown is made to revolve in synchronism with the source of alternating current. The terminals, $d\ d_1$, of the indicating instruments can be connected to any one of the three sets of terminals, $a\ a_1\ b\ b_1\ c\ c_1$.

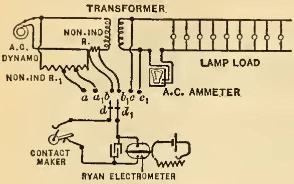


FIG. 3. Prof. Ryan's method of obtaining curves of wave form for studying transformers.

The terminals, $a\ a_1$, are for reading the instantaneous value of the primary impressed E.M.F.; $b\ b_1$, the same value of the current flowing through the small non-inductive resistance, R; and $c\ c_1$ the same value of the secondary impressed E.M.F.; the secondary current being read from the ammeter shown. Of course if the contact-maker be cut out, then all the above values will be $\sqrt{\text{mean}^2}$.

WAVE METER.

The instrument illustrated and described in the following pages has been in use in the laboratory of the General Electric Company at Schenectady, since early in 1896, and is, I think, the simplest form of apparatus yet suggested for determining wave forms in alternating currents.

The General Electric Company very kindly furnished the following description, and the diagrams and illustrations accompanying it.

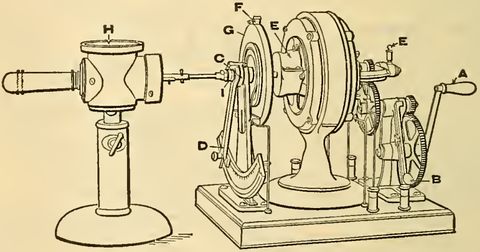


FIG. 4.

This device consists of a synchronous motor intended to run in synchronism with the machine under test. On the shaft of the motor is placed a contact device similar to the contact device usually placed directly on the shaft of the generator. By the use of a synchronous motor, the device becomes much more flexible, and enables the wave to be taken on any part of any alternating current circuit by merely attaching a pair of lead wires, thus doing away with all mechanical attachments to the generator. Since the advent of alternators with a considerable number of poles, the old method of mechanical connection has been found to be unsuitable on account of the great degree of accuracy required in dividing a cycle into the requisite number of degrees, owing to the fact that a complete cycle of 360° forms such a small part of the arc of the armature.

The operation of the machine in detail is as follows: —

The field requires about 1.35 amperes D. C., and the armature about 4 amperes for starting. The machine should then be started by means of the crank (marked A in Fig. 4) until it has been brought up to the frequency of the A. C. circuit, which will be indicated by tachometer (marked H). At 60 cycles the speed is 900 R. P. M. As soon as it is in synchronism (which can be easily told by the running of the machine) the lever (marked B) on the crank standard should be pressed, which releases the gear mechanism and allows the motor to run free. After the machine is running, current in the armature should be reduced to 3 amperes.

The following precautions are necessary in order to procure satisfactory working of the apparatus :—

1. The resistance in all the circuits must be unvarying; the contact, therefore, must be perfect.

2. The E.M.F. of the A. C. and D. C. circuits must be steady and unchanging. Complying with No. 1 and No. 2 secures steady currents in all the circuits.

3 Above all, the speed of the source must be kept constant; and if this is not possible, readings must be taken only at a certain speed, that speed being preferred to which the generator most frequently returns.

4. Avoid any leads other than shown on the diagram coming in contact with the terminals of the D. C. voltmeter. It will be noticed that a connection between the large and small segments will cause alternating current to flow through the direct current voltmeter.

5. The tension on the contact spring "F" must be stiff enough to insure a good contact. If the brush does not make an even contact on the contact-disk, it can be remedied by placing a piece of emery cloth on the contact-disk and revolving the brush over the rough side of the emery cloth by hand.

6. The carbon brushes must make as perfect contact on collector rings as possible.

7. In taking a wave, it is recommended that the voltmeter reading should vary from a minimum of zero to a maximum of nearly a full scale deflection.

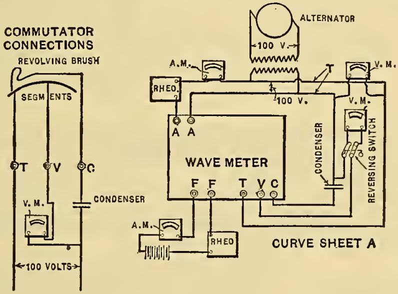


FIG. 5.

This absolute zero can be obtained by loosening the set screw (marked C) on the end of index lever "D." The contact disk, "G," can then be rotated on the shaft until the voltmeter reading is at zero, with index pointer set on zero degrees. In case the maximum deflection is too low, it can be increased by either inserting more capacity in the circuit or by using a higher voltage on the condenser circuit; this would be accomplished by using a small step-up transformer or compensator at the point marked T in Curve Sheet No. 8. The transformer voltage should not exceed 150 volts at this point.

8. In case the voltage is too low to give a readable deflection on the voltmeter, a D'Arsonval galvanometer can be used in place of the voltmeter.

9. The oil-cups (marked E) should be kept full of oil, as a thorough lubrication is found necessary to procure perfect results.

10. If the machine sparks at contact disk, that is, if spark causes arcing from one segment to the following one, it will be necessary to rub the surface of the disk with fine sandpaper.

The external wiring connections of the machine are shown on Curve Sheet A attached. The connections of the contact device are also shown. This consists of a contact-disk with 4 large and 4 small segments. The 4 large segments are connected to the inner copper ring on the side of the contact-disk. By means of a spring contact and leads the latter is connected to the terminal V. Similarly the smaller segments are connected through the outer ring and spring contact and leads to the terminal T.

The revolving brush is in contact by means of brush and contact ring as seen on the end of the shaft (marked I) to the frame, and from the latter by means of wire under the base to the terminal C.

The principle on which the method is based is the following: When the revolving brush, F, leaves the small segment of the contact disk, G, and breaks the contact between the condenser and the E.M.F. to be measured, it leaves the condenser charged with the potential difference which occurred at that instant. As soon as the revolving brush touches the large segment, the condenser discharges into the voltmeter until the brush leaves it. As the speed is constant, the time of discharge is constant, and as the discharging circuit is unaltered during the test, the instantaneous E.M.F's cause proportional deflections; the latter follow so quickly as to give steady deflections.

Reading, Plotting, and Calculating. — The movable index pointer is turned till the spring-actuated pin drops into the small hole above zero on the fixed scale, and the deflection of the voltmeter noted on a sheet of paper having two parallel columns counting the degrees from zero to 360, as indicated below: —

DEGREE.	DEFLECTION.	DEGREE.	DEFLECTION.
0		180	
5		185	
10		190	
15		195	
20		etc.	
etc.		"	
"		"	
175		355	
180		360	

After taking the reading at zero, the pointer is moved to 5, then to 10, and so on. If after finishing this series of readings a marked difference is noted between corresponding deflections in the left and right hand columns, such points must be taken over again.

The average of the two corresponding deflections is taken, and the results are then multiplied by such a constant as to make the maximum = 10. These values are plotted as ordinates, and the corresponding degrees are abscissae. See sample test and Curve Sheet B.

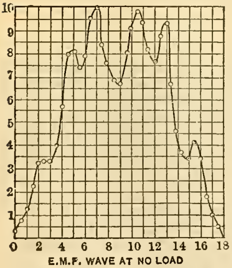


Fig. 6. Curve Sheet B.

To find the average E.M.F., divide the area in terms of squares of the paper used, by 10 times the actual length of one cycle in terms of one side of the same squares, as the maximum is plotted to a scale of 10 instead of one. On Curve Sheet B the length of the half-cycle = 9 units, and therefore the area must be divided by 90.

The effective E.M.F., or $\sqrt{\text{mean square}^2}$, is the square root of the mean squares of the same instantaneous values used before. The simplest method of obtaining this is the following: Plot the same deflections on polar coordinate paper similar to that used in Curve Sheet C, and find the area of the resulting curve.

The *effective E.M.F.* is then equal to the radius of a semi-circle whose area expressed in terms of squares of the rectilinear co-ordinate paper, is equal to the area enclosed by the wave plotted on the polar co-ordinate paper after being reduced to the same dimensions by multiplying by the ratio of $\frac{(a)^2}{b} \left(\frac{a}{b}\right)^2$.

To find the area a planimeter is used, or the curve is traced or copied by means of carbon paper on paper of uniform thickness, which is then weighed on a chemical balance, or in case neither of the above methods is available, the area can be found by actually counting the number of squares it contains.

The *form factor* is the ratio of the *effective* to the *mean* E.M.F. The form factor of a sine wave is 1.11.

The *amplitude factor* is the ratio of the maximum to the effective E.M.F., which, as the maximum is one, is equal to the reciprocal of the effective E.M.F. The amplitude factor of a sine wave is 1.414.

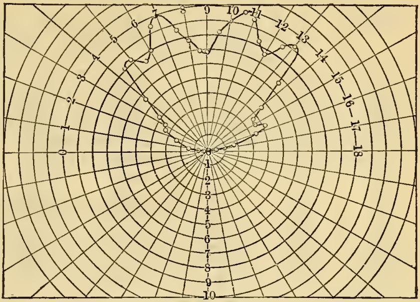


FIG. 7. Curve Sheet C.

These values are to be used in making calculations for alternating currents whose wave shapes have been determined by means of the wave meter instead of employing the usual values based on the sine curve. The accompanying record sheets give the results obtained with an actual E.M.F. wave taken with the machine. In the sample test, columns 2 and 4 give the readings obtained for the different angular deflections. Column 5 is the average of the readings obtained. These values are then multiplied by a constant, which in this case is .1127, to give a maximum of 10. The resultant values plotted in rectilinear and polar co-ordinates are shown on curve sheets B and C.

SAMPLE TEST.

(Nov. 21, 1897.)

E.M.F. Wave of Experimental Alternator.

No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	Degrees.
0	—4.5	180	—4.5	—4.5	— .507	175
5	+2.5	185	+2.5	+2.5	+ .28	0
10	7.	190	7.	+7.	.79	5
15	11.	195	11.	+11.	1.24	10
20	21.	200	19.5	+19.75	2.23	15
25	29.5	205	29.5	29.5	3.32	20
30	30.	210	29.5	29.75	3.35	25
35	29.5	215	29.5	29.5	3.32	30
40	36.	220	36.	36.	4.06	35
45	51.	225	50.	50.5	5.695	40
50	71.	230	72.	71.5	8.05	45
55	72.5	235	71.5	72.	8.12	50
60	66.	240	66.	66.	7.44	55
65	70.	245	71.	70.5	7.95	60
70	85.	250	85.	85.	9.58	65
75	89.	255	88.5	88.75	10.	70
80	75.5	260	73.5	74.5	8.4	75
85	68.5	265	67.5	68.	7.66	80
90	61.5	270	60.5	61.	6.87	85
95	59.5	275	60.	59.75	6.73	90
100	72.	280	72.5	72.25	8.15	95
105	81.	285	81.	81.	9.13	100
110	87.	290	87.5	87.25	9.82	105

SAMPLE TEST — (*Continued*).

No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	Degrees.
115	84.	295	83.	83.5	9.40	110
120	72.5	300	73.	72.75	8.2	115
125	67.5	305	68.	67.75	7.63	120
130	77.	310	77.5	78.25	8.81	125
135	82.5	315	82.5	82.5	9.3	130
140	60.	320	59.5	59.25	6.68	135
145	41.	325	41.5	41.25	4.65	140
150	32.	330	32.5	32.25	3.64	145
155	30.5	335	30.5	30.5	3.44	150
160	37.5	340	37.	37.25	4.2	155
165	30.	345	30.5	30.25	3.41	160
170	16.	350	15.5	15.25	1.775	165
175	8.5	355	9.0	8.75	.98	170

The different constants of this wave are given below in "Method of Determining Constants of E.M.F. Curve." This also gives the constants for a sine wave for comparison.

SPECIAL DATA ON THE MOTOR ILLUSTRATED.

Resistance of field = 10.87 ohm.
Resistance armature and brushes = 2.055 ohm.
Armature alone = .560 ohm.

Armature winding — 14 turns of No. 28 D. C. C. copper wire doubled in each slot.

Field frame consists of $\frac{1}{10}$ H.P. U. I. Fan Motor — 125 cycles, 104 volts.

METHOD OF DETERMINING CONSTANTS OF E.M.F. CURVE.

Area Rect. Co-ord. Curve "B" = 51.32.

$$\text{Mean E.M.F.} = \frac{51.32}{9 \times 10} = .571.$$

Polar Area = 4,062, which must be multiplied by $\left(\frac{11.33}{8.95}\right)^2$ to be comparable to the area in rectilinear co-ordinates. 11.33 is the maximum ordinate of the rectilinear co-ordinate in centimeters, and 8.95 is the maximum ordinate of the polar co-ordinate curve; therefore the corrected polar area $= 40.62 \times 1.6 = 64.992$.

Now $\frac{1}{2}\pi r^2 = 64.992$, therefore $r = .643$, which is the effective E.M.F.

$$\text{The form factor being therefore } \frac{\text{effective}}{\text{mean}} = \frac{.643}{.571} = 1.127.$$

$$\text{The amplitude factor} = \frac{\text{maximum}}{\text{effective}} = \frac{1}{.643} = 1.554.$$

For comparison the constants of a sine wave are also given in the recapitulation below.

	MEAN E.M.F.	EFFECT. E.M.F.	FORM FACTOR.	AMP. FACTOR.
Rect. Co-ord. Curve B 51.32 }	.571	.643	1.127	1.554
Polar " " C 40.62 }				
Sine Wave	.637	.707	1.110	1.414

CERTAIN USES OF ELECTRICITY IN THE UNITED STATES ARMY.

Electricity enters into nearly every branch of the military art, being used for the operation of searchlights, turret-turning, manipulation of coast-defense guns, ammunition hoists, range and position finders; for firing submarine mines; field and fortress telephones and telegraphs; firing devices for guns, ground mines; in tide gauges; submarine boats and dirigible torpedoes; while electrically operated chronographs are employed in the solution of ballistic problems.

SEARCHLIGHTS.

Searchlights are used both as offensive and defensive auxiliaries; defensive when used by shore fortifications to light channels or by a vessel to discover the approach of torpedo boats; offensive when used as "blinding-lights" to smother the light of an approaching vessel and confuse her pilot.

The accompanying illustrations show the searchlight manufactured by Schuckert & Co. of Nurnberg, Germany.

The lamp is placed on top of the two lowest longitudinal rods of the casing, and is held in place by four lugs, two on each side. The carbon holders reach upward through a slit in the casing, and there is a small wheel in rear for moving the light parallel to the axis of the reflector, for the purpose of focusing it. The trunnions of the casing are fastened to two longitudinal rods on each side, parallel to the axis of the cylinder, and can be moved forward or back so that the casing and what is carried with it will have no preponderance. The trunnions are supported in trunnion beds in the ends of supports which project upwards from the racer.

The elevating arc is attached to another longitudinal rod beneath the cylindrical casing and is capable of adjustment on this rod. Engaging in this arc is a small gear attached to a horizontal shaft passing through the right trunnion support and carrying a small hand wheel. This small hand wheel is for the purpose of elevating or depressing the light rapidly.

The light may be elevated or depressed slowly by means of a small hand wheel attached to another horizontal shaft in front of the one just described. This shaft near its center carries a worm, engaging in a worm wheel on a vertical shaft, to which is also attached a bevel gear. This gear engages in another, which is attached to the quick-motion shaft, but is free to turn about it until it is connected with the elevating gear wheel by means of a friction clamp. The relation between the worm and worm wheel is such that a slow motion is obtained.

The racer rests upon live rollers and is joined by a pintle to the base ring. Attached to the base ring is a toothed circular rack, into which on the outside a gear wheel attached to a vertical shaft engages. This vertical shaft projects upward through the racer and carries a worm wheel, which engages in a worm carried on a horizontal shaft having a hand wheel. The worm wheel is entirely independent of its vertical shaft, except when connected with it by means of a friction clamp. When so connected, by turning the hand wheel the light is traversed by a slow motion. To traverse the light rapidly, the friction clamp is released and the light turned by hand, taking hold of the trunnion supports. One of the ends of the slow motion elevating and traversing shafts is connected with a small electric-motor, which is encased in a box on top of the racer. By means of these motors the motion of the searchlight can be controlled from a distant point. A switch is provided with contacts so arranged that the current can be passed into the armatures of the motors in either direction, so as to obtain any movement the operator may desire. The current needed for the movement is obtained from the lines supplying the current used in the light itself. The current is brought to the motors by means of contact points, bearing on circular contact pieces attached to the racer.

The reflector is a parabolic mirror embedded in asbestos in a cast-iron frame, and is held in place by a number of brass springs. The frame of the reflector is fastened to the overhanging rear ring of the casing with studs and nuts, the overhanging part of the ring protecting the reflector from

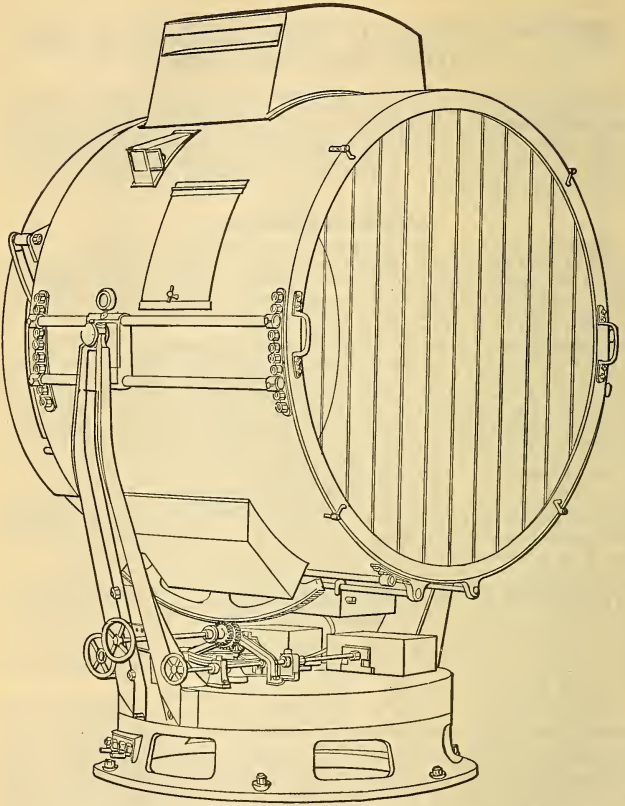


FIG. 1. Schuckert Searchlight as used in U. S. army.

moisture. In order to enable the operator to observe the position of the carbons and the form of the crater while the apparatus is in use small optical projectors are arranged at the side and on top of the casing, which enables images of the arc as seen from above and from the side to be observed. When the light is properly focused the positive carbon reaches a line on the glass on top of the casing.

There are two screws on the positive carbon holder which enable the end of this carbon to be moved vertically or horizontally to bring it to a proper adjustment.

In consequence of the ascending heat the carbons have a tendency to be consumed on top; and to avoid this there is placed just back of the arc and concentric with the positive carbon a centering segment of iron, attached to the casing, which, becoming magnetic, so attracts the current as to equalize the upward burning of the carbons. In taking the light out of the casing this centering segment must be unfastened, and swung to the side on its hinge.

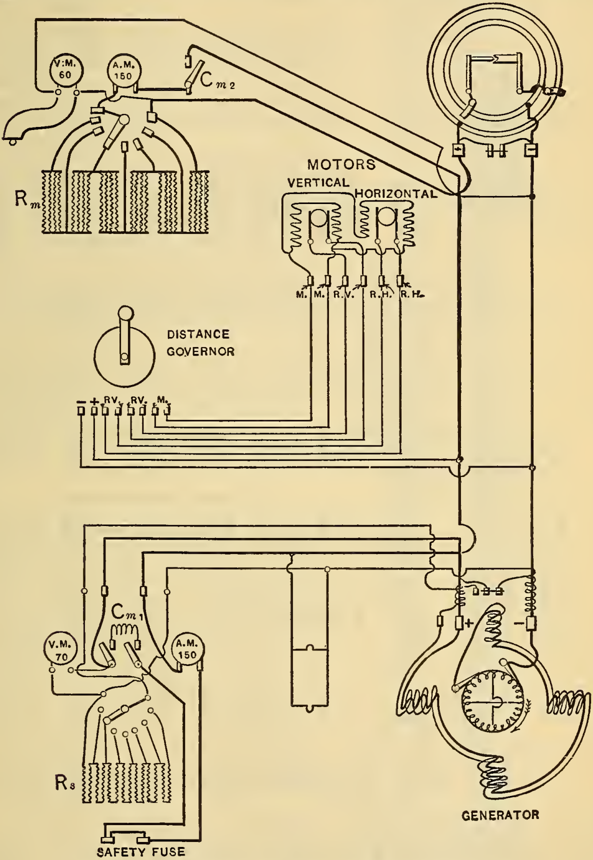


FIG. 2. Diagram showing Searchlight Connections.

An example of the method of calculating the intensity of the light sent out by the mirror follows:—

Diameter of parabolic mirror, 59.05 inches.
Diameter of positive carbon, 1.5 inches.
Diameter of negative carbon, 1 inch.
Power consumed, 150 amperes × 59 volts.
Maximum intensity of rays impinging upon the mirror, 57,000 candle-power.

DATA RELATIVE TO SEARCHLIGHTS.

Diameter of Mirror D in mm.	Strength of Current in Amperes.	Potential in Volts.	Watts.	Standard Candle-power in one Watt.	Intensity of Rays Impinging on Mirror in Candle-power. Maximum.	Intensity of Rays Impinging on Mirror in Candle-power. Average.	Average Intensity of Rays Reflected by Mirror in Standard Candle-power.	Diameter of Crater d in mm.	Intensifying Power of Mirror $\frac{D^2}{d^2}$.	Intensity of Ray of Light Sent out by Mirror in Candle-power.	Focal Distance of Mirror in mm.	Dispersion.	Field of Illumination at 1000 m. in m.
400	20	43.5	870	4	3480	2780	2500	9.3	1845	4,635,000	180	2° 58′	51
	25	44	1100	4.6	5000	4000	3600	9.4	1811	6,490,000	180	2° 59′	52
	30	44	1320	4.8	6300	5000	4500	9.5	1773	8,000,000	200	2° 43′	47
450	20	43.5	870	4	3480	2780	2500	9.3	2341	5,850,000	200	2° 40′	46
	30	44	1320	4.8	6300	5000	4500	9.5	2244	10,600,000	200	2° 43′	48
	40	45	1800	5.14	9250	7400	6660	10.	2025	13,500,000	200	2° 52′	50
600	40	45	1800	5.14	9250	7400	6660	10.	3600	24,900,000	250	2° 18′	40
	50	46	2300	5.35	12,300	9800	8820	10.9	3030	26,700,000	250	2° 30′	44
	60	47	2820	5.55	15,500	12,400	11,160	12.1	2459	27,200,000	250	2° 47′	48
750	60	47	2820	5.55	15,500	12,400	11,150	12.1	3840	42,300,000	310	2° 16′	39
	75	49	3675	5.8	21,200	17,000	15,300	14.3	2744	42,300,000	310	2° 38′	46
	90	51.5	4680	6.	28,100	22,500	20,300	16.7	2020	42,300,000	310	3° 6′	54
900	100	53	5300	6.05	32,000	25,700	23,130	17.5	2640	61,000,000	380	2° 43′	47
	125	55.5	6660	6.23	41,500	33,200	29,880	20	2030	61,000,000	420	2° 44′	48
	150	59	8900	6.45	57,000	45,600	41,040	23	1530	61,000,000	420	3° 8′	55
1100	150	60	9000	6.5	58,000	46,400	41,750	23	2287	96,000,000	520	2° 32′	44
1500	150	60	9000	6.5	58,000	46,400	41,750	23	4300	180,000,000	650	2° 2′	36

Average intensity of rays impinging upon mirror, 45,600 candle-power.
Diameter of crater, 0.905 inch.

Intensifying power of the mirror, $\frac{D^2}{d^2} = \frac{(59.05)^2}{(0.905)^2} = 4,253.$

Total intensity of light sent out by mirror, 45,600 × 4,253 = 194,000,000 candle-power.

The focal distance of the mirror is 25.5 inches.

The dispersion angle of the concentrated beam is 2° 2′.

The diameter of the illuminated area at a distance of 1,111 yards is 84 yards.

The resistance R_m on the switchboard at the light is in series with the main current for the purpose of regulating the amperage at the lamp. The voltmeter at the lamp should indicate about 60 volts. The connection of the distance governor with the two motors for elevating and traversing is also shown.

The largest searchlight so far built is the one that was on exhibition at the Paris Exposition of 1900 in the section "Navigation de Commerce et Armées de Terre et de Mer," which is 6 feet 6 inches in diameter, and gives a beam of 316.000,000 candles.

The table on preceding page gives data in regard to searchlights of various sizes.

CHRONOGRAPHS.

In the experimental work of testing guns, etc., it becomes necessary to ascertain the velocity of projectiles both while passing through the bore of the gun and during flight. Chronographs of various sorts are used for this purpose.

In order to ascertain the velocity of a projectile during flight, two screens or targets are set up in the course of the projectile, generally 100 feet apart. These screens ordinarily consist of a frame of wood carrying a number of small parallel copper wires. The breaking of the wires in the successive frames by the projectile causes the interruption of the current through the instrument, and thus registers the time of flight between the screens.

Probably the best-known instrument of this class is the one invented by Captain Le Boulengé of the Belgian artillery, which was afterwards modified by Captain Breger.

Boulengé Chronograph.

This instrument depends for its accuracy upon the law of falling bodies or the acceleration due to gravity, namely 32 feet per second.

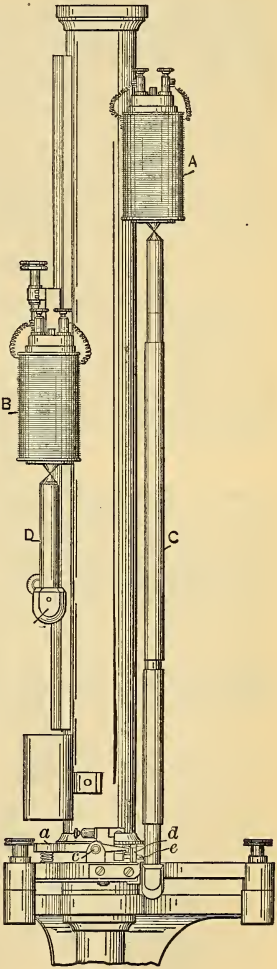


FIG. 3.

It consists of a vertical column (Fig. 3) to which are affixed two electromagnets; the right-hand one, *A*, is actuated by the current of the first frame and supports an armature called the chronometer; the left-hand magnet, B, is actuated by the current of the second frame, and supports an armature, D, called the registrar.

The chronometer, C, is a long, cylindrical brass tube terminating at its upper extremity in a piece of soft iron, and bearing at its lower extremity a steel bob. It is surrounded by a zinc or copper cylinder called the recorder. The rupture of the first target causes the demagnetization of the magnet A, releasing the rod C. The registrar is of the same weight as the chronometer, and is a tube with soft iron and bob. The cores of the electro-magnets and the soft iron of the armatures terminate in cones slightly rounded at their vertices in order that the armatures when suspended can take a vertical position.

When the registrar is set free by the rupture of the second target it strikes a horizontal plate (a), which turns upon its axis (c) and releases the spring (d). The spring is furnished with a square knife (e), which strikes the recorder and leaves an indentation upon it.

If the two currents be ruptured simultaneously the indentation is found upon the recorder at a height h, indicating that since the chronometer commenced to fall the time t has elapsed. $t=\sqrt{\frac{2h}{g}}$.

It is evident that t is the time required for the apparatus to operate; it is a systematic retardation inherent in the instrument.

A special device, called the disjunctor, permits the simultaneous rupture of the circuits to be produced, so that the time t is always known.

A very simple device is resorted to in order to render it constant. If the current of the registrar is not ruptured until after that of the chronometer, and if an interval T has elapsed between these ruptures, the time during which the chronometer will fall before receiving the indentation of the knife will simply be augmented by t, and calling H the height of the indentation, we will have

$$t+T=\sqrt{\frac{2H}{g}}.$$

Thus the determination of an interval T always comprises two operations: the measurement of the time (t) required for the instrument to operate, and that of the time $t+T$. The difference of these two measurements gives the time sought. This indirect method of ascertaining the result is the characteristic of the instrument and explains its accuracy. When the rupture of the currents is produced by the projectile the portion (D) of the trajectory between the targets is regarded as rectilinear and the mean velocity V is

$$V=\frac{D}{\sqrt{\frac{2}{g}(H-h)}}.$$

The arrangement of the circuit must vary according to circumstances, and no particular system can be prescribed. The general arrangement, however, is shown in the sketch

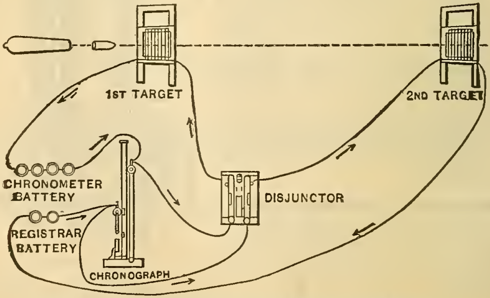


FIG. 4. Connections of Boulengé Chronograph.

Schultz Chronoscope.

The Boulengé chronograph measures velocity at one point only, but it is frequently necessary to measure the velocity of the same projectile at different points as in determining the laws of the resistance of the air to its motion, or in ascertaining the velocity of a projectile at different points in the bore.

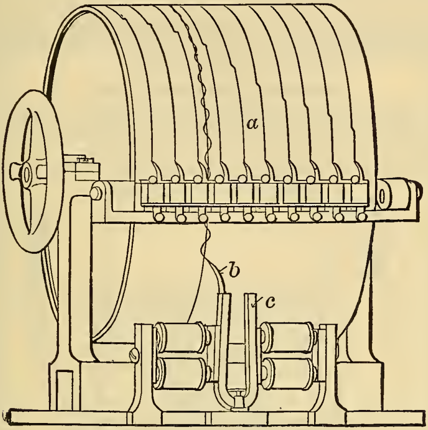


FIG. 5. Schultz Chronoscope.

For such purposes an instrument must be used which will give a scale of time of such length that all the phenomena may be registered upon it.

There are several instruments of this class, of which the best known is the Schultz chronoscope. In this instrument a drum (*a*), one meter in circumference, and covered with a coating of lamp-black, is driven by the means of a clock movement and weight, so as to revolve once per second and at the same time slowly advance longitudinally. In front of the drum, mounted on a support and actuated by two magnets, is a standard tuning-fork (*c*), vibrating 250 times a second; on one link of this fork is a quill (*b*) which traces a line on the blackened surface of the drum, and therefore will record 250 complete vibrations for every revolution of the drum.

A telescope with micrometer (not shown in drawing) is also attached to the support fork; and each vibration of the fork, traced on the drum in form of a curve, can be subdivided in 1000 parts, thus allowing readings to be made to $\frac{1}{250000}$ of one second. On the support with the tuning-fork is a small pointer which traces a straight line on the drum. This pointer has an electrical connection with an accurate chronometer which at every half-second closes the circuit and causes the pointer to make a succession of records on the revolving drum. These marks serve as starting-points to count the number of vibrations of the tuning-fork, and to check them up every half-second.

In order to measure the velocity of projectiles, the gun must be fitted along its bore with special electrical circuit breakers, usually placed one foot apart. Each circuit breaker is so constructed that the current is interrupted as the projectile passes, but is made again before the projectile reaches the next breaker one foot farther on.

These breakers, with appropriate battery, are all in one circuit with the primary of an induction coil. One terminal of the secondary of the coil is grounded to the frame of the chronoscope, while the other terminal consists of a fine point near the blackened surface of the drum. Therefore, when the primary circuit is opened by the first circuit breaker along the bore of the gun, the spark induced in the secondary of the induction coil jumps from the points to the revolving drum, leaving a distinct mark on the blackened surface As the next circuit breaker in the gun is passed, the spark again passes to the drum, and this operation is repeated for every breaker along the gun bore. Thus on the drum, alongside of the indications made by the tuning-fork, will be recorded a succession of spots at certain distances from each other. The time elapsing between any two of these spots can be calculated directly from the record which the tuning-fork made, and thus the time (measured to the $\frac{1}{250000}$ part of a second) taken by the projectile in passing a known distance along the gun barrel calculated. — *Electrical World and Engineer*, June 23, 1900.

Schmidt Chronograph.

This is a portable instrument, and while probably not so accurate as the Boulengé instrument is sufficiently so for the every-day work of the proving-ground.

The chronograph is composed of the following principal parts (see Figs. 6 and 7):

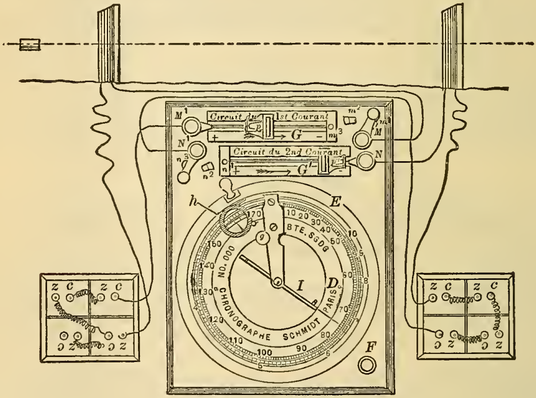


FIG. 6. Connections of Schmidt Chronograph.

The balance-wheel *A* with its spring and needle.

The electro-magnet *B*, which holds the balance-wheel at the starting-position and releases it the instant the first current is broken.

The electro-magnet *C*, with its mechanism, which stops the balance-wheel the instant the second current is broken.

The dial *D*, graduated for velocity readings.

A circular frame *E*, for setting the instrument at zero.

The button *F*, reëstablishing the current in the magnet *C*.

The rheostats *G* and *G′*, with their resistance coils for regulating the currents.

The balance-wheel, made of nonmagnetic metal, is about 2½ inches in diameter and mounted on the axis *o*, which is held by two strongly made bridges fastened to the face plate of the instrument. The pivots of the axis are set in jeweled bearings. The spiral spring *H* is fastened to the bridge and axis as in ordinary chronometers.

The needle, *I*, is composed of two parts, as shown in Fig. 8. One part, *a*, of bronze, is fastened rigidly to the axis; the other, *b*, a steel spring, is fastened at one end to *a*, the free end being limited in its motion by two small pins set into *a*.

The electro-magnet *B*, which holds the balance-wheel at the starting-point, is operated by the current passing through the first screen, and is mounted on the face plate so that the core is radial with reference to the balance-wheel. The core of the magnet projects beyond the coil and acts upon the small armature *c*, mounted on the rim of the balance-wheel.

The electro-magnet *C*, with its mechanism operated by the current passing through the second screen, stops the balance-wheel the instant the current is broken. This magnet is somewhat larger than the other, and is placed tangentially with reference to the balance-wheel. It acts upon the two armatures *d*, *d′*, placed opposite the extremities of the core. These armatures are fastened to the ends of the two levers *K*, *K′*, which are mounted on the axis *e*, *e′*, parallel to the axis of the balance-wheel and similarly supported. The other ends of the levers are joined by the coiled spring *L* with its adjusting-screw. Set in the levers near this end are four pins, *f*, *f*, *f′*, *f′*, that ordinarily, due to the tension of the spring, bear against

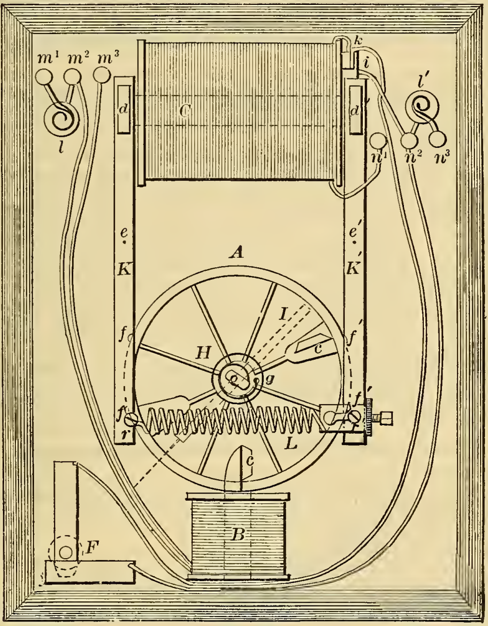


FIG. 7. Interior Schimdt Chronograph.

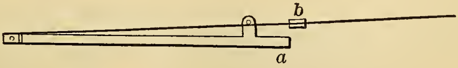


FIG. 8. Construction of Needle.

the rim of the balance-wheel, holding it fast. When the current passes through this magnet, the armatures on the levers are attracted by the core, the spring is elongated, and the pressure of the pins upon the balance-wheel is released. When the current is broken the armatures are released, and the tension of the spring closes the pins upon the wheel. To insure effective action the pins are accurately set and the rim of the wheel is milled.

The face of the chronograph is a graduated dial concentric with the balance-wheel axis. When the wheel is held at its starting-point the needle points at the zero of the graduation. The scale in black indicates the time in thousandths and two-ten-thousandths of a second. Another scale, in red, gives the velocity directly in meters per second when the screens are placed 50 meters apart.

The dial is covered with glass inclosed in the circular metal frame *E*. A pin, *g*, fixed in the glass, is used to set the needle at zero by turning the frame, to which is also fastened the lens *h*, to facilitate reading. This lens is provided with two pointers so placed that the reading is always taken in the vertical plane.

The button *F* is for the purpose of reëstablishing the current through the magnet *C* after it has once been broken. Pressing the button closes the circuit; the magnet then attracts the armatures *d*, *d′*, fixed to the ends of the levers *K*, *K′*. This motion of the levers brings the small spring *l*, mounted on *K′*, in contact with the projection *k*, thus forming a circuit through which the current continues to flow after the pressure on *F* has been released. This contact is broken by the motion of the lever when the current is interrupted by the shot. This arrangement prevents the current from passing through the magnet and releasing the balance-wheel before the circuit is closed by pressing the button *F*, even though the broken screen is repaired, and gives the operator time to take the reading and prepare for the next shot. This is especially important when targets that close the circuit automatically are used.

The rheostats for regulating the currents are placed above the dial, their resistance coils being inside the case. One binding-post of each rheostat is provided with a circuit closer for passing the currents through the resistance coils or directly into the rheostats.

The Squire-Crehore Photo-Chronograph.

This instrument was designed to overcome the minute errors inherent in other forms of chronographs, such as the inertia of the amature, the time required to magnetize iron, or in instruments employing a sparking device, the fact that successive sparks do not proceed from the same point by identically the same path.

The agents employed in this instrument are light and electricity. Briefly stated, a ray of light from an electric arc is reflected upon a revolving photographic plate. The interposition of a tuning-fork gives on the plate a curve which is used as a scale of time.

In the path of the beam of white light is placed a Nicol prism in order to obtain a beam of plane polarized light. This prism is made of two crystals of Iceland spar, which are cemented together by Canada balsam in such a way as to obtain only a single beam of polarized light. The crystal is a doubly refracting medium; that is, a light beam entering it is in general divided into two separate beams which are polarized and have different directions. One of these beams in the Nicol prism is disposed of by total reflection from the surface where the Canada balsam is located, and the other emerges a completely polarized beam ready for use.

A second Nicol prism exactly like the first is now placed in the path of the polarized beam. This second prism is called the "analyzer," and is set so that its plane is just perpendicular to that of the first prism, called the "polarizer," so that all the light vibrations not sorted out by the one prism will be by the second. In this position, the planes being just perpendicular to each other, the prisms are said to be "crossed," and an observer looking through the analyzer finds the light totally extinguished as though a shutter interrupted the beam.

By turning the analyzer ever so little from the crossed position, light passes through it, and its intensity increases until the planes of the prisms are parallel, when it again diminishes; and if one of the prisms is rotated there will be darkness twice every revolution. In order to accomplish this same end without actually rotating the analyzer a transparent medium which can rotate the plane of polarization of the light subject to the control of an electric current is placed between the two prisms. The medium used is carbon bisulphide contained in a glass tube. To produce a magnetic field in the carbon bisulphide a coil of wire through which passes an electric current, is wound around the glass tube. When the current ceases the carbon bisulphide instantly loses its rotatory power, and the ray of light is free to pass through the prisms.

Breaks in the current are made in the same way as in other ballistic chronographs. For a complete description of this instrument, with an account of experiments, see *The Polarizing Photo-Chronograph, John Wiley & Sons, New York.*

MANIPULATION OF COAST-DEFENSE GUNS.

Until recently all gun carriages installed in the coast fortifications of the United States were designed for the use of hand power in their manipulation. Tests, however, having demonstrated the adaptability of electrical power for this purpose, such guns are now being equipped with electric motors.

The following data is taken from recent tests of the equipment of a 10-inch disappearing carriage.

The equipment installed consists of:

One 3 h.p. motor connected directly by spur gearing to the crank shaft of the traversing mechanism.

One 5 h.p. motor for operating both the elevating mechanism and the retraction gear.

A hand brake applied to a drum on main crank shaft of traversing gear.

Control switches, wiring, etc.

The iron-clad motors and switch boxes are water and dust tight. The mechanical hand brake is used to overcome the tendency of the carriage to settle back when stopped quickly at a particular point, due to the great weight and inertia.

The weight of the gun is 67,000 pounds, and moving parts of carriage, approximately 170,000 pounds, a total of 237,000 pounds.

Results.

TRAVERSING MOTOR.—

At full speed,	130 volts. 20 amperes to start. 13 " running. 1.8 effective H.P.
At half speed.	119 volts. 23 amperes to start. 22 " running. 2.9 effective H.P.
Slowest speed.	120 volts. 23 amperes to start. 20 amperes running. 2.4 effective H.P.

Time required to traverse through entire field of fire, 106° 30′ twenty-five seconds [of time].

ELEVATING AND RETRACTING MOTOR.—

In depressing through extreme range, + 15° to — 5°.	128 volts full speed. 13 amperes full speed. 1.8 effective H.P. Time, 22 seconds.
In elevating gun through extreme range.	122 volts full speed. 20 amperes, full speed. 1.8 effective H.P. Time, 22 seconds.

RETRACTION.—

To bring gun from firing to loading position.	120 volts full speed. 20 amperes full speed. Time, 2 min. 2 sec.

A more complete description of this apparatus may be found in the *Electrical World and Engineer*, January 19, 1901.

ELECTRIC FUSES.

It is often necessary to fire at a distance from the gun, as in experiments, and for this purpose electric fuses are used.

The fuse consists of a $\frac{1}{4}$-inch length of fine wire of platinum-iridium alloy, called the bridge, surrounded by a little gun-cotton or powder; next to this is placed, when required for detonating, a few grains of fulminate of mercury. The whole is usually fixed inside a copper case. The bridge being inserted in an electrical circuit is heated by the current which ignites the gun-cotton and fires the fuse.

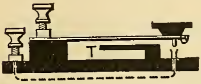
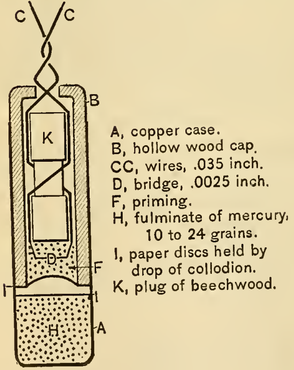
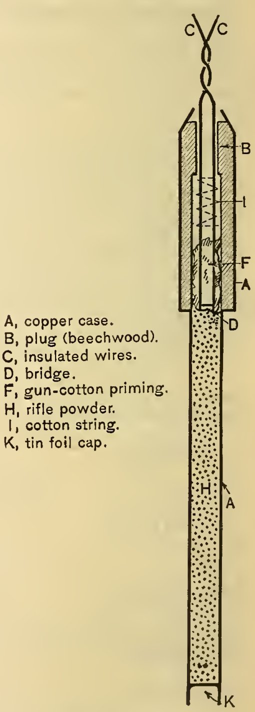


FIG. 11. Firing Key.





FIGS. 9 and 10. Electric Fuses.

Fig. 9 shows a gun-fuse. Fig. 10 is a mine-fuse, which is similar in construction, and is used in firing high explosives, or where it is desired to ignite several charges simultaneously, as in a group of submarine mines. Fig. 11 shows the firing-key, in which T is a turnbuckle of ebonite which prevents accidental closing of the circuit.

DEFENSIVE MINES.

A mine is a charge of explosive contained in a case which is moored beneath the surface of the land or water. The mines laid and operated in and around seacoast fortifications are for the most part defensive in their character, fixed in position, and hidden.

A defensive mine is either self-acting, — a mine which, once placed, ceases to be under control, and is fired by means within itself, mechanical or electrical, — or controlled, a mine fitted with electrical apparatus, which enables a distant operator to ascertain its condition, and to fire it at any time; it may also be fired automatically.

A controlled mine may be fired in four different ways: (*a*) by contact with the mine only; (*b*) at will of the operator only; (*c*) by contact and will, both of which are necessary; (*d*) by observation from two stations.

A controlled sea mine may be either a buoyant mine whose case floats 3 or 4 feet beneath the surface, and contains both the charge and electrical apparatus, or a ground mine. The latter is in two parts: one a case containing the charge and fuse, rests on the bottom; the other, containing the electrical apparatus, floats 3 or 4 feet beneath the surface.

Copper wires lead to two or three Sampson-Leclanché cells, which are put in circuit with the torpedo casemates of the fortification.

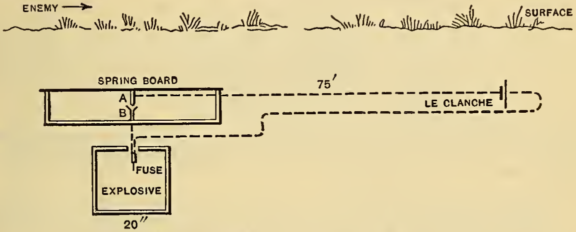


FIG. 12. Electrical Land Mine.

The sketch shows a self-acting electrical land mine, and is self-explanatory. By using three lead wires the mine may be fired by the enemy's contact with it, or by the operator at the station.

CIRCUIT CLOSER IN TORPEDO.

(See Fig. 13.)

NS, circular permanent magnet with attached electro-magnets N and S.

A, armature whose adjusting spring near K holds it away from the magnet, while a weak current flows in through the electro-magnet coils in a direction to assist the permanent magnet. But if a stronger current flows, the armature is attracted, and sticks to the magnet, until a reverse current is sent in. The spring then draws the armature away, and breaks the contact of the circuit closer K on W.

B, a brass ball $\frac{3}{4}$ inch diameter, held by spiral S.

T, a silk thread running through the vertical axis of the ball from adjusting screw to the armature. When the vessel strikes the mine the brass ball being knocked sidewise pulls, by means of the string, the armature against the poles where it sticks.

R, 1000-ohm resistance coil, which is cut out of the mine circuit by the contact of K on W.

PC, priming-charge.

F, fuse.

OPERATING-BOX ON SHORE.

WB′, watching-battery of gravity cells and brass bar.
FB′, firing-battery of Sampson cells and brass bar.
P′, firing-plug.
M′M′, ordinary electro-magnet, 100 ohms. (See Relay No. 7.)
A′, armature pivoted at the center. (See Relay No. 7.)
S′, spring holding armature back against a weak current. (Relay No. 7.)
L′, shutter arm pivoted above its center of gravity. When set as in relay No. 1, shutter-arm L′ makes electrical connection with the armature at N′; when armature is attracted it releases L′, whose lower end strikes a bell, and makes electrical contact with the firing-bar at B′.
b, terminal of mine circuit which may be plugged to WB′.
a, terminal for testing-set.
o, *o*, two reversing-keys.
X and Y are two stations, 1 to 3 miles apart, each having a key and an observer of the mine field.

OPERATION.

The torpedo having been planted and connected with its relay, whose shutter-arm L′ is set as in relay No 1, a small steady watching-current flows through G′, WB′, *b*, M′M′, H, N′, J′, O′, V, coil S, coil, N, W, R (1,000 ohms), G to G′ again. The direction of the current is such as to preserve the magnetism of the magnet. If the circuit closer is accidentally closed (indicated by a change of the resistance in the circuit) it can be opened by using the reversing-key from shore.

The fuse F may be fired in four ways: —

(*a*) *By contact with the mine only.* Insert firing-plug P′. When a vessel strikes a mine the brass ball B in the circuit-closer is thrown aside, closing K on W and thus short circuiting R. The watching-current, thus made stronger, flows from coil N through K, A, Z, fuse, $G_{,,}$ to G′. Coming from gravity cells it cannot fire the fuse, but is strong enough to operate the relay and drop L′, which throws in the firing-battery. A strong current now flows through G″, FB′, P′, B′, J′, O′, V, coil S, coil N, W, K, A, Z, F, $G_{,,}$ to G″ again, and fires the fuse.

(*b*) *At will of operator only*, who may at any time drop the shutter arm L′ by hand and insert the firing-plug. The firing-current is strong enough, even through R in the torpedo, to close K, short-circuiting R, and to fire the fuse.

(*c*) *By contact with the mine and at operator's will.* Remove firing-plug P′. The watching-current flows as above in (*a*). When the vessel strikes the mine L′ drops, striking the bell, when the operator inserts P′, throwing in the firing-current which fires the mine.

(*d*) *By observation from two stations;* shutter arm L′ set, and firing-plug P′ in. When a hostile vessel appears over the mine from the position of X the observer closes his key. Y has like instructions. When both keys are closed the main part of the current from WB′ flows through G′, WB′, *b*, M′M′, H, Q′, X, Y, G, to G′ again, drops the shutter-arm and fires the mine.

For obvious reasons the foregoing is not a description of the service circuit closer, but the principle of construction and operation of the mines of all countries are much alike.

MISCELLANEOUS.

Fortress Telephones and Telegraphs.

Covering as it does a considerable area, the modern fortification must have its several units within instant communication, in order to insure that concert of action so necessary to a successful command. The fort commander must communicate his orders to the battery commanders, and they in turn transmit the necessary commands to the gun commanders; and while much time and ingenuity has been spent in devising means of communication through the medium of printing and dial telegraphs, the telephone is to-day practically the universal method of communication from one part of a fire command to another. As ordinary commercial telephones are employed, no special description of them need be given in this section. The telephone is, however, at best, but an unsatisfactory method of communication, and will be rendered more so by the noise and confusion of battle.

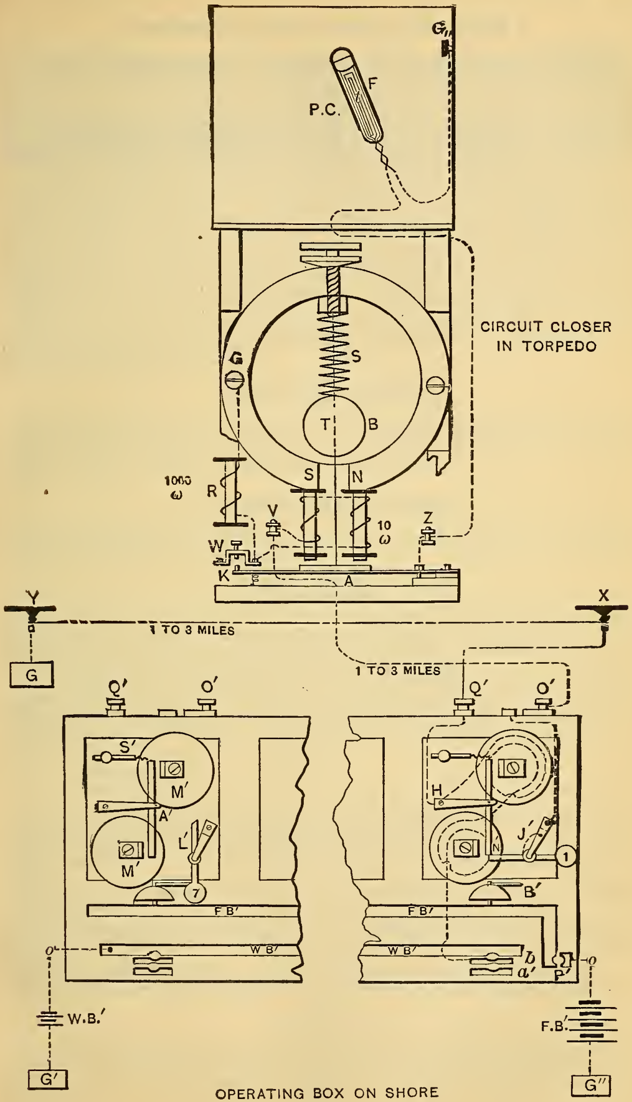


FIG. 13. Diagram of torpedo circuit closer and connections.

Field Telephones and Telegraphs.

But little is to be said of field telephones and telegraphs, as they do not differ from commercial instruments except in their portability. The wire is carried on reels mounted on wheeled trucks, and may or may not be strung on poles as the occasion demands. Light reels are also provided which may be strapped to a man's back to run wires to places otherwise inaccessible. The work to be done by field telegraphers is, however, an important one in keeping a commander constantly in touch with his outposts.

ELECTRICITY IN THE UNITED STATES NAVY.

THE application of electricity in ships in the United States Navy at the present time (July, 1901) is as follows : —

All ship's lights, searchlights, and signal lights are entirely electric.

Of power appliances the turret turning, elevating and loading of big guns, and hoisting ammunition, are always done electrically ; ship's ventilation is partly steam and partly electric, with the practice rapidly going to complete electric ; deck winches and boat cranes are usually steam, but very successful electric ones are in use ; steering-gear is entirely steam, hydraulically or mechanically controlled, and electric appliances are in the experimental stage ; an electric system of opening and closing water-tight doors is now in progress of development ; anchor-handling gear is entirely steam.

Interior communication appliances are almost entirely electric, but are in some cases paralleled with mechanical equivalents, as for example voice tubes paralleling telephones.

DYNAMO ROOM.

The generating plant is located in a compartment called the "Dynamo Room," which is under the protective deck and adjacent to the boiler rooms, so as to secure a direct lead of steam pipes.

GENERATING-SETS.

The following are the principal requirements contained in the standard specifications for generating-sets : —

Generators.

Generators to be of the direct current compound-wound multipolar type, giving 80 volts at the terminals. The compounding to be such that at the designed normal speed the voltage shall at no point of the external characteristic curve vary more than 1.5 volts from 80 volts.

There shall be no sparking whatever at the brushes when the generator is in operation with a constant load, nor shall there be any detrimental sparking with a change of one-half load, the brushes not being moved.

The allowable temperature rises above the air after a four-hour run at full load are : —

Field and armature windings	60° F.
Commutator	72° F.

The temperature of windings to be calculated from their resistance rise, and of the commutator to be measured by thermometer.

Generator to stand an over-load of 33 per cent for two hours without injury, and the engine to be able to produce normal voltage with this overload.

Insulation resistance to be one megohm, tested with a pressure not greater than 1000 volts.

The change of voltage at the terminals of the generator as measured on a dead-beat voltmeter not to exceed 10 volts, when full load is suddenly thrown on or off.

External magnetic field to be inappreciable at a distance of 15 feet.

Insulating substance used not to be injured by a temperature of 200° F.

Engines.

Engines to work most economically at 100 pounds steam pressure if compound, and 80 pounds if simple, vacuum being 25 inches ; but they must be able to work with pressure 20 pounds above and below these normal pressures.

Cylinders to be of hard cast iron cross-heads connecting rods, shafts, pistons and valve rods all nuts bolts, etc., to be of best forged steel.

The design must be such that all parts subject to wear shall be accessible for adjustment and repair, especially those parts which by reason of wear would affect the alignment of the engine.

Cylinders must be fitted with relief valves, arranged to work automatically, in addition to the usual drain cocks.

All parts must be able to bear without injury the throwing on or off of the entire load by quickly making or breaking the external circuit of the generator.

The governor must control the speed automatically, the throttle being wide open, within the following limits :

Variation of Load.	Variation of Steam Pressure.	Allowed Speed Variation.
Full load to 20% load .	Constant normal	2½%
Constant load	20 lbs. above to 20 lbs. below normal	3½%
Full load to no load .	20 lbs. above to 20 lbs. below normal	5%

If engines have more than one cylinder, the work done in each cyclinder must be practically equal at full load and normal pressure.

Cylinders and valve chests must be covered with suitable non-conducting material. Cylinders must be fitted with indicator motions.

It is very desirable that engines shall be capable of continuous running, without the use of lubricants in steam spaces.

The gross weight of complete sets not to exceed one-third of a pound per watt of rated capacity. Generator and engine to be mounted on a common bed-plate and direct connected.

The style of sets installed on the latest ships is a tandem compound engine with a six-pole generator, manufactured by the General Electric Company. The sizes used are 32 k.w. and 50 k.w.

The two cylinders are cast together, the L.P. on top, and separated by a hollow cast-iron head, which forms the stuffing-box for the L.P. piston rod.

The engine is entirely inclosed, and is provided with forced oil lubrication for the main bearings, crank pin, wrist pin, and cross-head guides. Rocker arms, governor and valve stems are provided with automatic grease cups. A cylinder lubricator is provided, but is only used a few minutes before shutting down, so that the cylinders will be coated with a film of oil while standing idle. United States Metallic packing is used.

32 k.w. size runs at 400 r.p.m. and the 50 k.w. size at 310 r.p.m.

Tests.

The 50 k.w. sets of the U.S.S. "Kearsarge" and "Kentucky" gave the following average results on tests :

STEAM CONSUMPTION AT FULL LOAD.

Steam pressure	100 pounds
Vacuum	24 inches
Steam per I.H.P. per hour	21 pounds
Steam per K.W.	35.2 pounds
Combined efficiency of set	80 %

REGULATION.

Normal speed	310 r.p.m.
Steam constant 100 pounds, full load to 20% load, gives variation of	1.56 %

Constant full load steam 120 pounds to 80 pounds gives variation of	1.5 %
No load with 120 pounds to full load with 80 pounds gives variation of	3.85 %
Normal voltage	80 volts
Throw off full load suddenly gives total fluctuation of	9.6 volts
Throw on full load suddenly gives total fluctuation of	6.9 volts

HEATING AFTER FOUR HOURS FULL LOAD.

Armature core surface	21°	C rise
Commutator bars	28	“
Shunt-field spool surface	11.4	“
Outboard bearing	7.	“
Armature conductors, by resistance	23.4	“
Field conductors, by resistance	17.7	“

Engine has L.P. cylinder 18 inches diameter, H.P. 10½ inches diameter, with stroke of 8 inches. Clearance in H.P. cylinders is 7½%, in L.P. cylinder is 7¼%. Weight of complete set is 15,000 pounds.

STEAM-PIPING.

The dynamo room is supplied by a special steam pipe which usually is so connected that it can take steam direct from any boiler or from the auxiliary steam pipe, it passes into a steam separator from which branches lead to each of the generating-sets in the dynamo room. This separator is drained by a steam trap which sends the water back to the hot well in the main engine room.

The exhaust pipe from each set joins a common exhaust which connects with the auxiliary exhaust service of the ship. If the sets are located below the level of the ship's auxiliary exhaust pipe, a separator is placed in the common exhaust pipe before it goes up and joins the ship's auxiliary exhaust. This separator is drained by a small steam pump, which is automatically started and stopped by means of a float in the body of the separator, which float starts the pump when the separator is full and stops it when empty.

SWITCHBOARDS.

The general problem of the design of a generator switchboard for a naval vessel is to be able to connect any number of generators to any set of busbars. There are usually four separate sets of busbars, one for the lighting system, one for the power system, and one for the turning-gear of each turret. The Ward-Leonard system of motor control being used for turning the turrets, it is necessary to use a separate generator for each turret. Separate equalizer buses are provided for both the lighting and power systems.

Current is supplied to the different appliances by means of distribution switchboards, which have two sets of busbars, one for lighting and one for power, and are connected directly to the corresponding busbars on the main generator board. Feeders run direct from these distribution boards, each feeder being provided with a fused switch. Distribution boards are sometimes located at various parts of the ship and sometimes made continuous with the main board.

The diagram of generator switchboard and turret turning system on page 738 shows connections as made on the U. S. S. "Illinois," except there are four more generators connected on exactly like the four shown. Each generator has a headboard carrying a double-pole circuit breaker, and clips for a series field short circuiting shunt used for turret turning. The diagram shows generators Nos. 1 and 2 operating in parallel on the power system, No. 3 alone on the light system, and No. 4 operating the after turret turning motors. It is to be noted that the three generators on the power and lighting systems have the right-hand blades of their triple pole field switches closed, giving self-excitation through the field rheostat, while the machine for turret turning has the middle blades closed, giving separate field excitation from the power bus-bars and through the field resistance attached to the controller in the turret.

WIRING.

Specifications.

The principal requirements of the Navy standard specifications for light and power conductors are :—

All layers of pure Para rubber must contain at least ninety-eight (98) per cent of pure Para rubber ; must be of uniform thickness, elastic, tough, and free from flaws and holes.

All layers of vulcanized rubber must contain not less than forty (40) per cent nor more than fifty (50) per cent of pure Para rubber ; must be concentric, continuous, and free from flaws or holes ; must have a smooth surface and circular section ; and must be made to a diameter in the finished conductor that will be in exact conformity with the diameter as tabulated.

All layers of cotton tape must be filled with a rubber insulating compound, the tape to be of the width best adapted to the diameter of that part of the conductor which is intended to bind. The tape must lay one-half ($\frac{1}{2}$) its width, and be so worked as to insure a smooth surface and circular section of that part of the finished conductor which is beneath it.

All exterior braid must be closely woven ; and all, except silk braid, must be thoroughly saturated with an insulating waterproof compound which will neither be injuriously affected, nor have any injurious effect on the braid, at a temperature of 200° F. (dry heat), or at any stage of test, the conductor being sharply bent. Wherever a diameter over vulcanized rubber or outsize braid is tabulated or specified, it is intended to secure a neat working-fit in a standard rubber gasket of that diameter for the purpose of insuring water-tightness of the joint, and no departure from such tabulated or specified diameter will be permitted.

All conductors to be of soft annealed pure copper wire.

No single wire larger than No. 14 B. & S. G. to be used.

When greater conducting area than that of No. 14 B. & S. G. is required, the conductor shall be stranded in a series of 7, 19, 37, 61, 91 or 127 wires, as may be required ; the strand consisting of one central wire, the remainder laid around it concentrically, each layer to be twisted in the opposite direction from the preceding, and all single wires forming the strand must be of the diameter given in the American wire gauge table as adopted by the American Institute of Electric Engineers, October, 1893.

The material and manufacture of the strand must be such that the measured conductivity of each single wire forming the strand shall not be less than ninety-eight (98) per cent of that of pure copper of the same number of circular mills, the measured conductivity of the conductor as a whole to be not less than ninety-five (95) per cent of that of pure copper of the same number of circular mills.

Each wire to be thoroughly and evenly tinned.

All conductors shall be insulated as follows :—

First.—A layer of pure Para rubber, not less than one sixty-fourth ($\frac{1}{64}$) of an inch in thickness taped or rolled on; if lapped, the tape to lap one-half of its width.

Second.—A layer of vulcanized rubber, of exact diameter as tabulated.

Third.—A layer of commercial cotton tape, lapped to about one thirty-second ($\frac{1}{32}$) of an inch in thickness.

Fourth.—A close braid to be made of No. 20 2-ply cotton thread, braided with three (3) ends for all conductors under 60,000 circular mills, and of No. 16 3-ply cotton thread braided with four (4) ends for all conductors of and above 60,000 circular mills. The outside diameter over the braid to be in exact conformity with that tabulated.

Tests. Two samples, each 500 feet long, will be selected by the Bureau from the coils of wire to be supplied, and must be sent by the Contractors to the New York Navy Yard for test.

(*a*) Both samples, after 24 hours imersion in sea water, must have an insulation resistance of not less than 1,000 megohms per nautical mile.

(*b*) Test to be at 72° F.

(*c*) To be tested by the direct deflection method at a potential of not less than 200 volts.

(*d*) Both samples will be tested for a conductivity of not less than 96 per cent of that of pure copper, having a cross-section of the specified number of circular mills.

(*e*) Chemical tests will be made to determine the constituents of the different layers of the insulation.

(*f*) Braid will be tested for water-proof qualities.

(*g*) Physical tests will be first made for qualities of strength, toughness, dimensions, etc.

(*h*) The physical and electrical characteristics of the insulation under change of temperature will be tested by exposing the finished conductor for several hours at a time, alternately, to a temperature of 200° F. (dry heat) and the temperature of the atmospere, during a period of three days.

(*i*) The tests for characteristics of the insulation will then be repeated and must show no practical deterioration on the results of the former tests.

Methods of Insulating Conductors.

Three methods of insulating conductors are used.

1. Conduit ; 2. Molding ; and 3. Porcelain supports

1. Conduit is the principal method, being used in almost all spaces below the protective deck, and wherever wiring is exposed to mechanical injury or the weather. Iron-armored insulated conduit is used, except in magazines, and within 12-feet of the standard compass, where brass is used.

Conduit passing through water-tight bulkheads is made water-tight by means of stuffing-boxes and hemp-packing. Water-tightness is provided at the ends of conduit by a stuffing-box and a soft-rubber gasket, through which the conductor passes. Long lines of conduit passing through several water-tight compartments are provided with gland couplings at proper intervals, which divide the run into water-tight sections, thus preventing an injury in a flooded compartment from allowing the water to run through the conduit into another compartment. These gland couplings are also used where conduit passes vertically through decks, and all vertical leads are run in conduit.

2. Wood molding is generally used in living spaces. It consists of a backing piece fastened to the iron work of the ship, to which the molding proper is secured by screws and covered with a wooden capping-piece. Where leads installed in molding pass through water-tight bulkheads, a bulkhead stuffing-box is provided for water-tightness.

3. Porcelain supports are used in dynamo rooms and for the long feeders which are run in the wing passages where there is no danger of interference. Stuffing-tubes are used where the wires pass through bulkheads, the same as with molding.

Connection Boxes.

All conductors are branched by being run into standard connection boxes, which are usually provided with fuses. Where conduit is used these boxes are tapped, to have the conduit screwed into them ; where molding or porcelain is used the boxes are provided with stuffing-tubes. The box covers are made water-tight with rubber gaskets ; inside the fuses and connection strips are mounted on porcelain bases.

LIGHTING-SYSTEM.

Wiring.

The maximum drop allowed on any main is 3 per cent at the farthest lamp. Mains are required to be of the same size throughout, and to be of 1000 circular mills per ampere of normal load.

Fixtures.

Most incandescent lamps are installed in air-tight glass globes of different shapes, depending upon position or location. Magazines are lighted by "Magazine Light Boxes," which are water-tight metal boxes set into the magazines through one of its walls, and provided with a water-tight door opening into the adjacent compartment, so that the interior of the box is accessible without entering the magazine. The sides of the boxes have glass windows, and each box is fitted with two incandescent lamps, each lamp having its own separate fused branch to the main, so that one lamp can be used as a spare.

"Switch Receptacles" containing a snap switch and a plug socket are provided for attaching portable lamps.

Lamps.

The principal requirements of the standard Navy specifications are:—

They must be of the best quality and finish, and uniform size; the bases must fit and be interchangeable in the standard socket.

All leading-in wires and anchors must be fused in the glass; all anchors must be made of metal.

The filaments must be centered in the bulb, and must not drop when the lamps are run in a horizontal position.

Each lamp must be marked on the inside of the bulb with the date of manufacture, and must have its rated candle-power, the voltage necessary to give this candle-power, and the name of the manufacturer conspicuously labeled on the outside of the bulb.

The material used for cementing the bases to the bulb must be so treated as to insure against danger of short circuiting the lamp when exposed to moisture. When porcelain is used all holes must be filled.

They must be designed for 80 volts, the rated candle-power to be given at not less than 78 nor more than 82 volts. No fraction of a volt beyond these limits will be permitted.

The efficiency of all 16 c. p. and 32 c. p. lamps must be not less than $3\frac{6}{10}$, nor more than 4 watts per candle-power, and that of 150 c.p. lamps not less than $3\frac{2}{10}$ nor more than $3\frac{6}{10}$ watts per candle-power, the efficiency to be measured when the lamps are new. The contractors shall guarantee that all lamps supplied will have an average life of at least 600 hours, and that the rated candle-power shall not have decreased more than 20 per cent after burning for this length of time at the initial potential.

Before acceptance a test lot will be selected at random from the lot of each type of lamp delivered as follows:—

From lots not exceeding 50 lamps, all lamps.

From lots exceeding 50 but not exceeding 500, 50 lamps.

From lots exceeding 500 lamps, 10 per cent of the lot.

The test lot will be subject to the following tests:—

(*a*) For design, dimensions, and construction.

(*b*) For vacuum, by trembling of filament and spark.

(*c*) For voltage and efficiency when rotating at a speed of 180 revolutions per minute.

(*d*) For rated candle-power by standard photometer.

A secondary standard lamp, standardized from the Bureau's standards, will be used in the tests.

A failure of 30 per cent of the test lot to comply with foregoing specifications will cause rejection of the lot represented by that test lot.

Diving-Lanterns.

Diving-lanterns consist of a glass cylinder closed at each end with a metal cap, having the joint between the glass and metal packed with a soft-rubber gasket. On the inside of one of the caps is provided a standard marine lamp-socket for 100 candle-power incandescent lamp, to which is connected 100 feet of twin conductor cable, at the other end of which is connected a double pole plug for a standard marine receptacle.

When first submerged a considerable amount of moisture is deposited in the inside, which is drawn out through a small hole made water-tight by a screw with a rubber gasket.

Searchlights.

The requirements of the standard Navy specifications are:—

It shall, in general, consist of a fixed pedestal or base, surmounted by a turntable carrying a drum. The base shall contain the turning mechanism and the electric connections, and be so arranged that it can be bolted securely to a deck or platform.

The turntable to be so designed that it can be revolved in a horizontal plane freely and indefinitely in either direction, both regularly and gradually by means of a suitable gearing, and rapidly by hand, the gearing being thrown out of action.

The drum to be trunnioned on two arms bolted to the turntable, so as to have a free movement in a vertical plane, and to contain the lamp and reflecting mirror. The drum to be rotated on its trunnions, both regularly and gradually by means of suitable gearing, and rapidly by hand; the gearing being thrown out of action. The axis of the drum to be capable of a movement of not less than 70° above and 30° below the horizontal.

The drum to be thoroughly ventilated and well-balanced; to be fitted with peep sights for observing the arc in two planes, and with hand holes to give access to the lamp. It must be so designed that either a Mangin or a parabolic mirror can be used, and means for balancing it with either mirror must be provided.

The mirror to be made of glass of the best quality, free from flaws and holes, and having its surface ground to exact dimensions, perfectly smooth and highly polished. Its back to be silvered in the most durable manner; the silvering to be unaffected by heat. To be mounted in a separate metal frame lined with a non-conducting material, in such a manner as to allow for expansion due to heat and to prevent injury to it from concussion.

The lamp to be of the horizontal carbon type, and designed for both hand and automatic feed. The feeding of the carbons must be effected by a positive mechanical action, and not by spring or gravitation. It must burn quietly and steadily on an 80-volt circuit in series with a regulating rheostat, and shall be capable of burning for about six hours without removing the carbons.

The front of the drum to be provided with two glass doors, one composed of strips of clear plate glass, and the other of strips of plano-concave glass lenses, so designed as to give the beam of light projected from the mirror a horizontal divergence of at least 20°. The doors to be interchangeable, and to be so arranged that either can be put in place on the drum easily and quickly.

Electrically Controlled Projector.

To be in all respects similar to the hand controlled, with the addition of two shunt motors, each with a train of gears; one motor for giving the vertical and the other the horizontal movement of the projector. The motors and gears to be contained in the fixed base, and to be well protected from moisture and mechanical injury. A means to be provided for quickly throwing out or in the motor gears, so that the projector can be operated either by hand or by motor, as desired.

The motors to be operated by means of a compact, light, and water-tight controller, which can be located in any desired position away from the projector. The design of the controller to be such that the movement of a single handle or lever, in the direction it is wished to cause the beam of light to move, will cause the current to flow through the proper motor in the proper direction to produce such movement. The rapidity of movement of the projector to be governed by the extent of the throw of the handle or lever. A suitable device to be included whereby the movement of the projector can be instantly arrested when so desired.

All projectors to be finished in a dead-black color throughout, excepting the working-parts, which shall be bright.

The lamps to be designed to produce the best results when taking current as follows: 18-inch, 30 to 35 amperes; 24-inch, 50 to 60 amperes; 30-inch, 75 to 90 amperes.

The 18-inch projector shall project a beam of light of sufficient density to render plainly discernible, on a clear, dark night, a light-colored object 10 by 20 feet in size, at a distance of not less than 4,000 yards; the 24-inch projector, at a distance of not less than 5,000 yards; and the 30-inch projector, at a distance of not less than 6,000 yards.

The connections for the electrically controlled projectors as manufactured by the General Electric Company are shown in the diagram. The fields of the two training motors are in series with each other and connected across the 80-volt circuit. Both horizontal and vertical training can be simultaneously produced. The controller-handle when released, is brought to the off

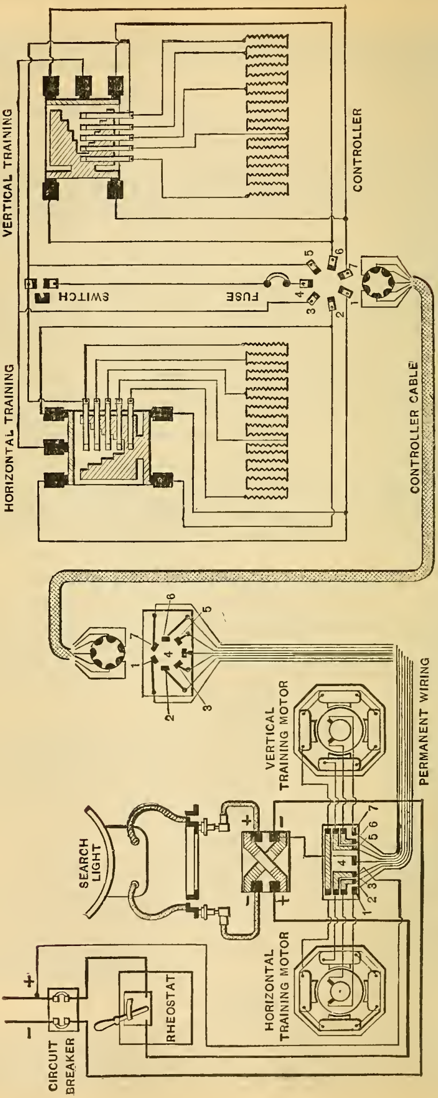


FIG. 1. Diagram of Connections for Electrically Controlled Searchlight.

position by springs and short circuits both motor armatures thus stopping all movement.

The horizontal training motor drives through a worm gear, and the vertical motor through a revolving nut on a vertical screw shaft: all gearing can be easily thrown out for quick hand control.

The highest speeds are 360° in 30 seconds horizontally, and 100° in 60 seconds vertically. The motors may also be operated at four lower speeds.

The lamp has a striking magnet in series with the arc and feeding magnet in shunt with the arc. When the arc becomes too long, sufficient current is forced through the shunt feeding magnet to cause it to make its armature vibrate back and forth, and thus move the carbons together through a ratchet which turns the feed screws. The point at which the magnet will begin to feed is adjustable by means of a spring attached to armature. The feed screws are so proportioned that the positive and negative carbons are each fed together at the same rate that they are consumed, thus keeping the arc always in the focus of the mirror. Sight holes are provided through which the arc may be watched. A permanent magnet, fastened to the inside of the projector and surrounding the arc on all sides but the top, causes the arc to burn steadily near the upper edge of the carbons and in focus with the mirror.

The rheostat is located near the switchboard, and after being once set for proper working does not need to be again changed. Double-pole circuit breakers are used at the switchboards for switches.

SIGNAL LIGHTS.

Ardois Signals.

The Ardois signals consist of four double lanterns, each containing a red and a white light, which are hung from the top of the mast, one under the other and several feet apart. By means of a special controller any number of lanterns may have either their red or white lamps lighted, thus producing combinations by which any code can be signaled. The lamps used are clear, and the color is produced by having the upper lens which forms the body of the lantern colored red ; the lower lens is clear.

The controller consists of eight semi-circular plates, with pieces of hard rubber set in the inner edges where needed, and a rotating center stud with eight plunger contacts rubbing on the edges of the plates. By suitably placing the pieces of hard rubber for any given position of the contacts, any desired combination of lights can be produced.

The operation consists in moving the arm carrying the contacts to the position desired (as shown by a pointer on an indicating dial) and closing the operating switch, when the proper lamps will light.

Truck Lights.

The truck lights are lanterns of construction similar to the Ardois lanterns, mounted, one on the top of both the fore and main masts. By means of a special controller the red or white light in either lantern can be lighted.

POWER SYSTEM.

Motors are kept entirely separate from lights by the use of different bus-bars on the generator switchboard and distribution boards. Each motor or group of motors is supplied by its own feeder running from the distribution board, where it has its own fused switch. A maximum drop of 5 per cent is allowed.

Principal Requirements of Specifications for Motors.

Motors to be wound for 80 volts direct current.

Sizes above 4 H. P. to be multipolar ; 4 H. P. and below may be bipolar.

Armatures to be of iron-clad type, and coils preferably to be separately wound and easily removable.

Band wires to be of non-magnetic material, and not more than three to be used under poles.

Commutator segments to be of pure copper, insulated with mica of such quality that it will wear evenly with the copper.

Carbon brushes to be used carrying not more than 30 amperes per square inch at full load.

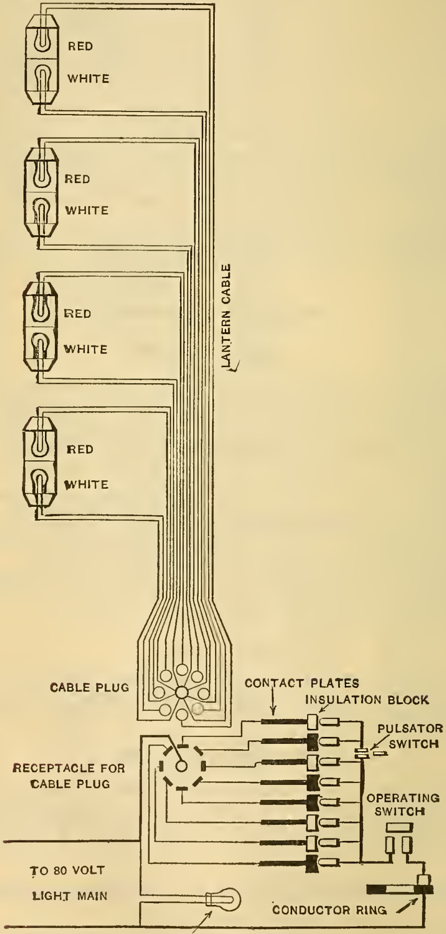


FIG. 2. Diagram of Ardois Signal Set.

No sparking to occur up to full load with no shifting of the brushes.

To prevent deterioration from rust and corrosion, such parts as bolts, nuts, screws, pins, and fittings of a light character, which if rusted or corroded would injure the operation, strength, ease of adjustment or taking apart, or appearance, are to be made of tobin bronze, or similar metal, and not of iron or steel.

No insulating substances to be used that can be injured by a temperature of 94° C. Test for dielectric strength to be made with a pressure of 1500 volts alternating for 60 seconds, using a transformer and generator of at least 5 k. w. capacity.

Allowed temperature rises above surrounding air are: —

Continuous running motors, open type, windings 35° C., commutator 40° C., after eight hour full-load run.

Same as above, but closed type, 50° C., for both winding and commutator.

Intermittent running motors have special requirements depending upon use; but nearly all require 45° C. for all parts after one hour at constant full-load.

Bearings of all motors 40° C.

Lubrication of continuous running motors is by oil rings or sight feed cups, the intermittent running motors by grease pockets.

Every motor to be protected by an automatic circuit-breaking device, capable of being set to 50 % above the normal full load.

Turret-Turning Gear.

The motors are controlled by the Ward-Leonard system, the principle of operation of which is illustrated by the elementary diagram on the diagram of generator switchboard and turret-turning system, page 738.

The motors are shunt wound, and have the fields constantly separately excited from the bus-bars of the ship's power system. A separate generator is required which cannot be used for any other purpose when used with the turret. The generator is also separately excited from the power bus-bars; but a variable rheostat, located in the turret, is connected in the shunt-field circuit. The brushes of the motor are directly connected to the brushes of the generator, and the generator is kept running at constant speed by its driving-engine. It is now evident that by varying the rheostat in the turret, the field excitation, and consequently the voltage produced by the generator, will be varied; and any variation in the voltage of the generator will produce a corresponding variation in the speed of the motor, which has a constant field from separate excitation. The direction of rotation of the motor is reversed by reversing the leads to the armature. The actual connections for the application of the above principles are shown in the main part of the diagram. Generator No. 4 is shown connected for operating the after-turret.

Closing the after-turret field switch and the center blades of the generator field switch, separately excites the fields of the motors and generator from the power bus-bars. The regular field rheostat of the generator is entirely disconnected, and a rheostat located in the turret and operated by the turret turning controller is used instead.

Closing the positive and negative single-pole switches on the after-turret bus-bars connects the generator armature to the motor armatures, through a circuit breaker, the reversing contacts of the controller, and separate armature switches for each of the two motors, which are operated in parallel.

The controller has one shaft, at the top of which are located the connections for the generator field rheostat, so arranged that as the controller is turned either way from the off position the rheostat is gradually cut out; below are located the reversing contacts, which reverse the connections between the generator armature and the motor armatures; these contacts are so arranged that at the off position the motor armatures are entirely disconnected from the generator, and are short-circuited through a low resistance called the "Brake resistance." The effect of this brake resistance is to bring the turret to a quick stop when the controller is brought to the off position, as the motor armatures revolving in a separately excited field generate a large current, which passes through the braking resistance, and thus absorbs the kinetic energy of the turret, giving a quick and

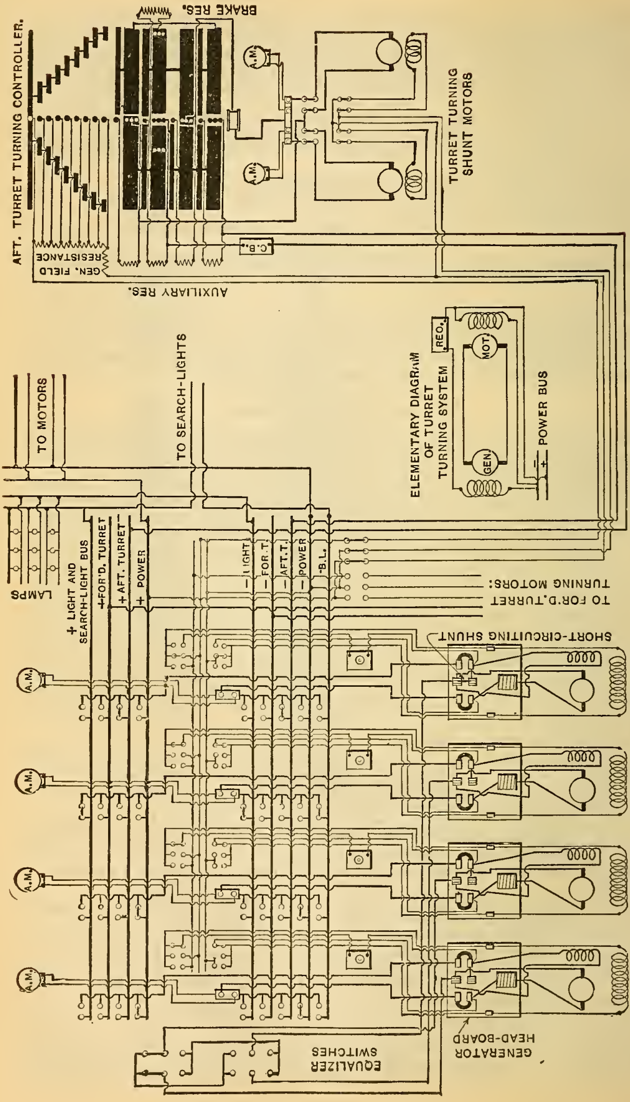


FIG. 3. Diagram of Generator Switchboard and Connections for Turret Turning System.

smooth stop. In parallel with each of the large main fingers of the reversing contacts is a small auxiliary finger and an auxiliary resistance connected to it. This auxiliary finger makes contact a little before and breaks it a little after the main finger, and thus reduces the sparking. The controller is also provided with a magnetic blow-out for reducing sparking at contacts.

When used on this system for operating a turret the generator has its series coil short circuited by a very low resistance shunt, so that it has very little effect on the field excitation, but this resistance is so proportioned that enough of the total current generated by the generator will pass through the series coil to give a quick and positive start of the turret; because if the series coil is absolutely short circuited, and only the separately excited shunt coil used, the time required for the field to build up is sufficient to make the starting of the turret very sluggish and irregular, and prevents very fine training from being obtained.

On the U.S.S. "Kearsarge" and "Kentucky," two 50 H. P. motors of 400 r.p.m. are used to turn each double turret, which weighs 710 tons and is mounted on 32-flanged conical rollers, 15½-inches diameter, running on a track 21 feet in diameter. Each motor drives through a worm and wheel, connected to a spur pinion meshing into a stationary circular rack. The motors are geared together by a cross shaft. Friction clutches are inserted in the transmission gearing to prevent sudden stops, firing the guns, or impact of shot, from breaking the gearing. Full speed of the turret is at the rate of one revolution per minute. The controller is provided with a mechanical automatic stop which brings it to the off position when the turret reaches the limit of its train at either side.

The following results were obtained on test of the four turrets of the two ships. The friction varied considerably for different turrets.

Forward turret of the "Kearsarge" gave: —

Turning at constant full speed,	
Input of motors	22 E.H.P.
Output of motors	13 H.P.
Maximum when accelerating at rate of attaining full speed in 10 seconds,	
Input of motors	44.5 E.H.P.
Output of motors	36.3 H.P.
This was the easiest running of the four turrets.	
The hardest running gave,	
Turning at constant full speed,	
Imput of motors	41 E.H.P.

The motors are seen to be greatly over-powered for the work, this to allow for overcoming any deformation of track, rollers, etc., which might occur during action.

Fineness of train obtained: —

The turrets were easily started and stopped with a resulting movement of 10 seconds of arc, which equals a movement of about 2 inches at 1,000 yards range.

This is a movement much smaller than the visual angle covered by the cross hair of the sighting telescope, so that the fineness of train is much greater than that of sighting.

A turret was turned through its extreme train from one side to the other 48 times in one hour, with a stop being made at each beam position during each trip.

The motors used were entirely inclosed and weighed 5,700 pounds.

Loading and Training Gear for Guns.

Guns of 12-inch and over are elevated and rammed by power, smaller guns have hand gear.

The elevating gear for 12-inch and 13-inch guns consists of a 2½ H.P., 80-volt, 300 r.p.m. series motor, geared to a revolving screw which raises or lowers a nut crosshead from which connecting rods go to the gun.

Ordinary rheostatic control is used with no braking appliance. To train a 13-inch gun at the rate of 30° per minute, an armature input of from 1.5 to

3 E.H.P. is required, depending upon the condition of the load and whether elevating or depressing. The motors used are entirely inclosed and weigh 550 pounds.

Rammers consist of a telescopic tube worked through spur and chain-gearing by a 5 H.P., 80-volt, 775 r.p.m. series motor. A friction slip clutch is inserted in the gearing to prevent damage when the shell seats itself in the breach. Ordinary rheostatic control is used.

When ramming a shell but little power is required, as the shell slides along the breech, but as it is being forced to its seat at the end of the breech chamber a sudden rush of current of from two to three times the full-load current of the motor is produced.

The motors used are similar to the elevating motors, except wound for higher speed.

AMMUNITION HOISTS.

Power ammunition hoists are of two kinds; first, those in which a car or cage is hoisted up and down by a line wound on a drum on the motor counter-shaft; and second, those in which the motor runs an endless chain provided with toes or buckets on which the ammunition is placed and conveyed up through a trunk.

Hoists for 12-inch and 13-inch Ammunition.

These hoists are of the first kind. The motor frame is provided with bearings for a counter-shaft, geared by a spur-gear and pinion to the armature shaft; on the counter-shaft is mounted a grooved drum for the hoisting-cable.

On the armature shaft is mounted a solenoid band-brake. The cores of the solenoid are weighted and attached to the brake-setting lever so that when free their weight is sufficient to hold the loaded car from falling; when the solenoids are energized the cores are drawn up and the brake released.

The controller is constructed so that on the off position the solenoids are not energized and the brake is set; but at all other points, both hoisting and lowering, the solenoids are energized and the brake released.

Shunt motors are used, and the control for hoisting is ordinary rheostatic; the resistance being put in series with the armature and gradually cut out, the field is always constantly excited as soon as the feeder-switch is closed. For lowering, the entire rheostat is thrown directly across the line, one armature lead connecting to one side of the line and the other lead gradually moved (as the motor is brought to full speed) from the condition of a short-circuited armature at the off position to direct connection to the other side of the line at the full on position; in all intermediate positions the armature is in shunt with a part of the rheostat. The object of this is to cause the armature to take current from the line and run as a motor when lowering a light load which will not overhaul, but to run as a generator and send current through the rheostat if the load is very heavy and overhauls the motor and gearing. In either case the speed will depend upon the amount of the rheostat that is in shunt across the armature. The off position of the controller short-circuits the armature, and since the fields are always excited, this gives a quick stop and also holds the load.

The 13-inch hoists of the U.S.S. "Kearsarge" and "Kentucky" used 20 H.P. motors running at 350 r.p.m., with a gearing ratio of 6.43 from armature to counter-shaft.

The load was, empty car 1,846 pounds, and full charge 1,628 pounds, or a total of 3,474 pounds.

The following average results were obtained when testing at hoisting full charge: —

Hoisting-speed, feet per minute	180
Mechanical H.P. in load	18.96
Input of motor, E.H.P.	28.5
Total efficiency	66.6%

Motors were designed to be suspended under the turret, were entirely inclosed, and weighed 3,000 pounds complete with brake.

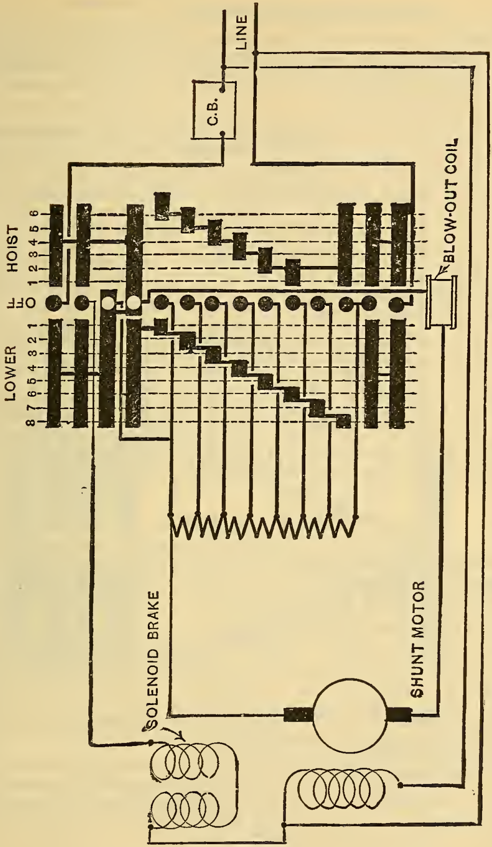


FIG. 4. Diagram of Connections for 13-inch Ammunition Hoist.

Hoists for 8-inch Ammunition.

Hoists for smaller ammunition are made and controlled in a similar manner as the above, except the solenoid brakes are replaced with an ordinary band-brake, operated by a foot or hand lever.

The 8-inch hoists used a 6 H.P., 375 r.p.m. shunt motor to hoist a total load of 910 pounds at 163 feet per minute.

Tests gave average results of, —

Mechanical H.P. in load	4.5
Input of motor, E.H.P	7.4
Total efficiency	60.8%

Endless Chain Ammunition Hoists.

These hoists run continuously, the ammunition being fed in as desired. The motor is geared to the chain sprockets by spur gearing, is shunt wound, and is started and stopped by a controlling panel, which is provided with no voltage and overload release, a field rheostat for varying the speed of the motor, and a reversing-switch.

A solenoid brake, similar to the one above described for the 13-inch hoist, is mounted on the armature shaft, and is set when the starting-arm is in the off position, but has its coils energized and is released when the arm makes the first contact in starting. At the full on position, part of the starting rheostat is in series with the brake, thus cutting down the current consumed by it. This does not affect the reliability of the brake, since the current required to hold up the cores is much less than that required to first start them, and at the start the full-line voltage is on the coils.

To lower ammunition the reversing-switch is thrown down, which reverses the connections to the motor armature, and puts in the armature circuit a safety switch. This safety switch is attached to the lever which operates the catch pawls in the hoist trunk. These pawls will allow ammunition to go up, but will catch and prevent it from going down, and are used to keep the ammunition from falling in case any part of the hoist should be shot away. When the pawl lever is thrown down it throws the pawls out of action, and allows ammunition to be lowered by reversing the motor; it also closes the safety switch which completes the armature circuit for the lowering position of the reversing-switch.

This style of hoist is used for all kinds of ammunition up to and including 6-inch. Packages are so made that they weigh about 100 pounds each. Motors rated at 3¾ H.P., continuous running, with speed variation of 360 to 475 r.p.m. are used; power required varies greatly with kind and style of hoist. Motors are entirely inclosed and weigh 980 pounds.

BOAT CRANES.

For handling steam cutters and other boats a revolving crane having the general shape of a davit is used; it extends down to the protective deck, and has a steady bearing at each deck passed through, and the weight is carried by a roller thrust bearing. The operating machinery is carried on a circular platform fastened to the crane.

The cranes for the U.S.S. "Kearsarge" and "Kentucky" have two motions; namely, rotating the entire crane, and raising or lowering the hook. One motor only is used for both motions, clutches and gearing being used to produce either at will. Two counter-shafts are driven by the motor, each having a worm at the end, one driving a worm wheel on the hoisting-drum and the other a worm wheel on the shaft of the rotating pinion. Each of the counter-shafts contains a friction clutch, so that it can be disconnected from its worm at will.

A band-brake is provided on the rotating-worm to hold the crane from rotating. A strap brake is provided on the hoisting-drum, which consists of a wrought-iron strap, one end of which is permanently fastened to the platform, wound three times around the hoisting-drum and the free end attached to a weighted lever which pulls it taut. This strap is wound around the drum in the direction it turns when lowering, so that any motion in this direction causes the friction to make the strap bind tighter and hold the drum from turning; but rotation of the drum in the hoisting direction causes the friction to make the strap loosen up and allow the drum to continue rotating. Thus the brake automatically holds the load from over-hauling the drum when the motor is disconnected. For lowering, the brake has its free end raised by a hand lever, thus loosening it, and allowing the drum to turn in the lowering direction.

The motor is shunt wound with field constantly excited as soon as the feeder switch is closed at the distribution board.

The controller cylinder gives ordinary rheostatic control with resistance in series with the armature, but there is a commutating switch which when closed gives the same kind of control as used for lowering with the 13-inch ammunition hoist described above; this control is used for lowering and rotating, since it gives a smoother stop, and the rheostatic control is used for hoisting. The off position of the controller short circuits the armature, giving a quick and positive stop.

A 40-foot steam cutter is the largest boat handled, and weighs complete 16,000 pounds.

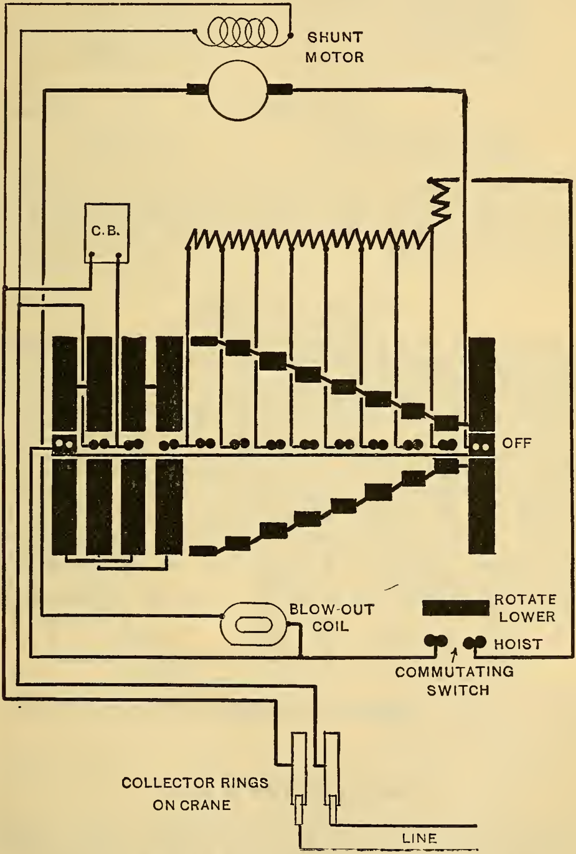


FIG. 5. Diagrams of Connections for Boat Crane Motors

The weight of the complete crane is 54,000 pounds.

Motor is 50 H.P., 400 r.p.m., is entirely inclosed and water-tight, and weighs 5,890 pounds. Current is supplied through collector rings mounted on the cranes. The controller is water-tight, and the circuit breaker is mounted in a water-tight iron box; all were tested for water-tightness by playing a stream of salt water on them from the fire-hose.

The following results were obtained on test: —

Load of	16,000	pounds
Hoisting-speed, feet per minute	25	
Mechanical H.P. in load	13.64	H.P.
Input of motor to hoist	30.6	E.H.P.
Total efficiency	44.5 %	
Rotating speed	1	r.p.m.
Imput of motor to rotate	14.8	E.H.P.

EMPTY HOOK.

Input of motor to hoist	7.3	E.H.P.
Input of motor to rotate	8.9	E.H.P.

It is seen that the motor is very much overpowered for the ordinary work required, but this is done to have a large margin to be able to handle boats in rough weather when the ship is rolling. Especial strain will be produced when rotating a boat in when the ship is heeled over, and also from the inertia effect of rolling.

DECK WINCHES.

The electric deck winches of the U.S.S. "Kearsarge" and "Kentucky" consist of a series motor geared through a system of spur-gearing to the shaft carrying the winch heads.

The control is ordinary rheostatic, with the controller suspended horizontally from the deck underneath the winch and operated by a vertical shaft and a pair of bevel gears. Braking is accomplished by a foot lever, operating a brake-band. For ordinary working the controller is turned to the full speed and the winch allowed to run continuously, the load being controlled by taking several turns of the hoisting-rope around the winch head. The maximum load can be very nicely controlled in this manner.

The capacity of the winches is 2,200 pounds at 300 feet per minute; and two winches are provided with a compound gear which can be thrown in to give a speed of 50 feet per minute with a corresponding pull of 13,000 pounds. The motors are 25 H.P., with a full-load speed of 320 r.p.m., but when the winch is allowed to run without load the speed of the motor increases to about 900 r.p.m.

When hoisting 2,200 pounds at 300 feet per minute, the average test results were: —

Mechanical H.P. in load	20 H.P.
Input of motor	34.3 E.H.P.
Total efficiency	58.4 %

Motors are entirely inclosed and water-tight, and were tested for water-tightness by playing a stream of salt water from the fire-hose on them without any water entering.

VENTILATION FANS.

Nearly all compartments of a ship have artificial ventilation by power fans; both exhaust and pressure systems being employed. Both steam and electric drive is used, steam being used almost entirely for forced draught in the boiler rooms, while electric predominates for all other places.

Shunt motors are used, started, and stopped by a controlling panel having "no voltage" and "overload" release. Speed variation is obtained by a field rheostat.

The following table gives results of tests on different sizes and styles of fans when run at full load and speed:

Fan.	Used as	Dia. at Tip of Blades.	Full Speed.	Air Pressure Oz.	Volume Delivered, Cubic Ft.	Motor Input, E.H.P.	Slow Speed by Field Rheostat.
Steel plate . .	Blower	50″	500	1⅝	12500	11.1	300
No. 6 Monogram, Sturtevant .	Exhauster	27½″	1030	1½	2580	2.7	810
No. 5 Monogram, Sturtevant .	Exhauster	24″	1220	1½	1460	1.43	910
No. 3 Monogram, Sturtevant .	Exhauster	14⅞″	1650	1½	835	.77	1196

STEERING-GEAR.

Electrical steering-gears are not at present used in the United States Navy, but are somewhat used in foreign navies. One method used is shown in the diagram of connections in which M is a shunt motor operated from the ship's mains and running continuously at constant speed; its shaft is directly coupled to G, a shunt generator, the two forming a motor generator set and located at any desired place, most conveniently in the dynamo room. P is a shunt motor geared by suitable gearing to the rudder post, and has its field constantly excited from the ship's mains, its brushes are directly connected to the brushes of the constantly running generator G. R and R′ are two equal and symmetrical rheostats, the contact arm of R being attached to the rudder post or any part of its gearing which has a similar rotation, and the contact arm R′ being attached by suitable gearing to the steering-wheel. The ends of the field of G are connected to these two contact arms, and the two rheostats are connected across the ship's mains.

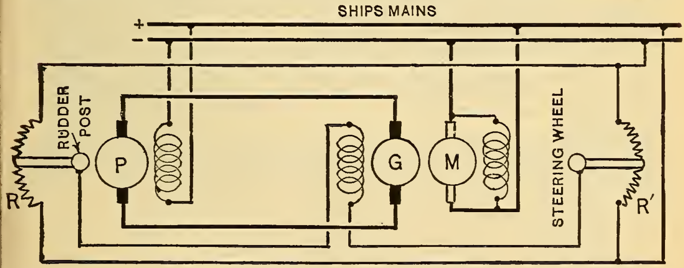


FIG. 6. Diagram of Steering-Gear.

It is now seen that the two rheostats and the field of G form a Wheatstone's bridge, the parts of the rheostat on each side of the contact arms being the four resistances, the field of G taking the place of the galvanometer and the line being the battery. This bridge is in balance, and no current will flow through the field of G whenever the two rheostant arms occupy similar positions on their respective rheostats; but if they do not occupy similar positions, then the bridge will be out of balance and current will flow through the field of G.

The operation is as follows: Starting with everything central as shown in the diagram, if the steering-wheel is turned, moving the arm of R′ a certain distance, the balance will be disturbed and current will flow through the field of G, causing it to generate an E.M.F. and start the motor P, which will continue to run until the arm of R has been moved a distance equal to the original movement made by the arm of R′, when the balance will be restored, no current will flow through the field of G, which will then develop no E.M.F., and the motor P will consequently stop. The gearing between P and the contact arm of R is so arranged that the movement of the arm will be in the proper direction to restore the balance. The direction of current flow in the field of G, and consequently the polarity of G and direction of rotation of P, will depend upon the direction of movement of the arm of R′. It is thus seen that the arm of R is given an exact copying motion of the arm of R′, both for distance moved and direction of rotation.

Instead of actually turning the rudder, the motor P can be made, if desired, to only operate the valve of a steam-steering engine; when this is done the device is called a "Telemotor."

Another method (which has only been applied for use as a telemotor) has the first movement of the steering-wheel connect the operating motor directly to the ship's mains, and the motion of the motor causes a step by step mechanism to disconnect it when it has moved the engine valve a distance proportional to the original movement of the steering-wheel. Both connection and disconnection of the operating motor are made by a switch at the steering-wheel, the interrupter of the step-by-step mechanism is at the operating motor and the mechanism itself at the steering-wheel. The mechanical arrangements are quite complicated.

Several ships of the Russian Navy have been fitted with direct acting steering-gears by the Electro-Dynamic Company, of Philadelphia, Pa., and work on the above first described bridge principle, with the addition of a small exciter for the generator mounted on the generator shaft, and the field of this exciter is connected with the bridge rheostats, instead of the main generator field itself. The motor of the motor-generator is rated at 70 H.P., the generator at 500 amperes and 100 volts, and the rudder motor at 50 H.P.; all being easily capable of standing 50% overloads for short periods of time. The motor-generator runs at 650 r.p.m. and weighs 11,000 pounds; the rudder motor runs at 400 r.p.m. and weighs 5,500 pounds; the accessory appliances weigh 1,500 pounds, making a total weight of 18,000 pounds.

Tests made on the Russian Cruiser "Variag" took 150 H.P. to move the rudder from hard-a-port to hard-a-starboard in 20 seconds, while going at a speed of 23 knots an hour. For ordinary steering at about 19 knots, readings taken every time the rudder was moved gave the following results: —

Amperes.	Volts.	K.W.
250	4	1.
250	10	2,5
150	14	2.1
180	30	5.4
200	40	8.
100	50	5.
100	55	5.5
50	5	.25
50	25	1.25
60	40	2.
100	22	2.2
100	25	2.5
50	15	.75
200	26	5.2
100	18	1.8
100	20	2.

Readings were taken for every movement occurring for a period of ½ hour, rudder was never moved more than 15 degrees.

WATER-TIGHT DOOR GEAR.

An arrangement for electrically operating sliding water-tight bulk-head doors has been experimentally tried and has given good results. The sliding door is provided with a rack and pinion, the shaft of the pinion being connected through a worm gear with a 1 H.P. motor, compound wound, of the short shunt type, the shunt coils being relatively weak. The circuits are so arranged that for raising the door, only the series coils are in circuit, giving quick and easy starting, while for closing the door where it may be necessary to cut through coal, the shunt and series coils are both in circuit.

The door can be opened or closed by a switch having a handle on both sides of the bulkhead. A limit switch is provided, which is opened by a bell crank when the door reaches either of its extreme positions. An emergency control is also provided by means of which all doors in the ship can be closed at the same time from any desired place, such as the conning-tower.

The diagram on the next page shows the connections for the control of one door, and the parts are as follows: —

S and S′ are two separate solenoids having attached to their cores, by insulating washers, cross contact arms, which make and break contact across the contact clips 1, 2, 3, 4, etc. When a solenoid is energized it draws up its core and the arms make contact across the two upper pairs of clips, and when it is not energized the weight of the core will cause it to drop and the arms make contact across the two lower pairs of clips.

L and L′ are the limit switches. L′ is opened when the door reaches its upper limit of travel, but is closed at all other positions. L opens its left hand pair of contacts and closes its right-hand pair of contacts at the extreme down position, but at all other positions it is closed at the left and open at the right. The left-hand contacts form the limit switch, the right-hand ones being used for signal connections described later

C is the local control switch at the door, and can be operated from either side of the bulkhead. It is provided with a spring which keeps it on the middle point when released.

E is the emergency control switch, and is located at any desired point on the ship.

D is a signal lamp located near E at the emergency station.

A and B are the ship's mains.

The operation is as follows: —

To Open Door. — Move local control switch C to its right-hand contact, which will energize solenoid S′, the circuit being from main A through arm of C, through L′, through S′, across contacts 2, to main B. This will raise the core of S′ and the arms will connect across contacts 5 and 7, and the motor will be connected to the mains as a series motor, the shunt coils being idle. The circuit is from main A through contacts 5, through the armature, across contact 7, through the series field to main B, and the motor will run in the raising direction until the switch C is released, or until the door reaches its upper limit and opens the limit switch L′, which will open the solenoid circuit and allow the core to fall, thus cutting off the motor.

To close Door. — Move switch C to its left-hand contact, which will energize solenoid S, the circuit being from main A through arm of C, through L, across contacts 8, through series field coil to main B. This will raise the core of S and connect across contacts 1 and 3, and the motor will be connected to the mains with both the shunt and series coils in use. The circuit is from main A through contacts 1, through armature, through contacts 3, through series coil to main B; and for the shunt field is from main A through shunt field to side of armature which connects to the series coil and through it to main B, giving a short shunt connection. This will cause the motor tc run in the lowering direction until C is released and the limit reached.

Whenever the motor is stopped both solenoids are released as drawn in the diagram, and the armature is short circuited through its series field, thus giving an electrical braking effect which absorbs the kinetic energy of the

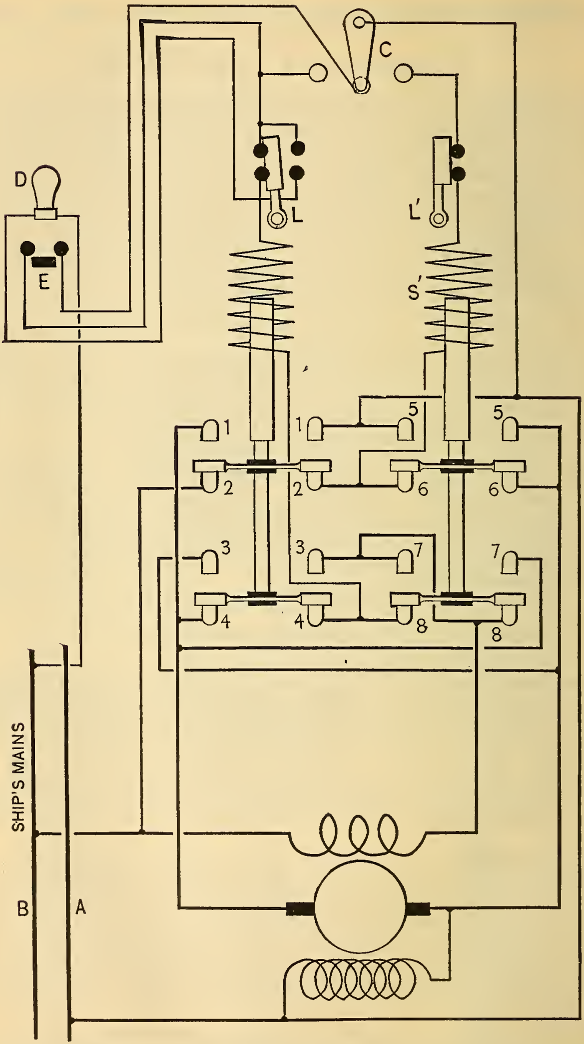


Fig. 7. Diagram of Connections for Electric Control of Watertight Sliding Doors.

armature and other moving parts, and gives a smooth and quick stop. The circuit is from right brush, through contacts 6 and 2, through series field, through contacts 8 and 4 to left brush.

The door can be closed from the distant emergency station by closing the switch E, which gives the same result as moving switch C to its left-hand point, since closing E connects the pivot of C to the left point, the circuit being through the center point on which C normally rests. It is thus seen that the closing of E does not affect the action of C, since as soon as C is moved from its center point E is cut out.

If the door is closed at the emergency station by means of E, the lamp D will light up as soon as the door is completely closed, for the closing of the door operates the lower limit switch L and closes its right-hand contacts. The circuit is from main B through lamp, through right contacts of L, through E, through C, to main A.

If desired all doors in the ship can be closed by one emergency switch, by having that switch operate a solenoid having a pair of contacts for each door, or the doors may be divided into sections, each section having a separate emergency switch and solenoid.

Since the motor takes its maximum current just at the instant of final closing of the door, the speed of the different motors on any one section is so adjusted that the doors will reach the end of their travel one after the other with a small time interval between each, thus preventing the sudden drain of current from the ship's generators that would occur if all shut exactly at the same instant. One-third k.w. of generator capacity is allowed per door for a system. This system is made by the "Long Arm" System Company, Cleveland, O.

The following results were obtained on test: —

	Amperes.	Volts.
To start the door down	13¼	115
Steadying while closing at	3¼	113
To start the door up	22	115
Steadying while opening at	11	113

With fine bituminous coal heaped against the back of the door to within six inches of the top: —

	Amperes.	Volts.
To start the door up	24½	115
Steadying while opening at	11	113

On opening the door wide the coal ran through the doorway, and the door was then closed through this coal lying eleven inches deep on the sill: —

	Amperes.	Volts.
To start the door down	14	115
	13.5	115
Cutting through coal and within an inch of seating, steadied at	3	113
	3	113
While driving loose coal through the hollow sill the ammeter jumped to	52	115
	49	113

INTERIOR COMMUNICATION SYSTEM.

The interior communication system of a ship consists of, as the name implies, the appliances for transmitting signals of all kinds from one part of the ship to another.

Order and Position Indicators.

Many devices have been tried for the electrical transmission of prearranged orders, or the position of a moving body, such as a rudder-head; but the most successful and the one generally installed consists at the receiving end of a number of small incandescent lamps, each mounted in a small separate light tight cell with a glass front, and the whole inclosed in a suitable case. On the glass front of each light cell is marked an order or number, or whatever particular information the particular device is to indicate. This receiver is connected to the transmitter by a cable having a separate wire for each lamp, and one wire for a common return. The transmitter consists of a switching device, by means of which any lamp or lamps in the receiver may be lighted, the current being taken from the lighting mains. As many receivers as desired can be operated from one transmitter, the receivers being connected in parallel.

Helm Angle Indicator.

When the above-described device is used to indicate in different parts of the ship the angle that the helm is turned, the transmitter switch consists of an arm, as shown in diagram No. 8 on the next page, fastened to the rudder stock, and moving over a series of contact pieces arranged in an arc in the same manner as an ordinary field rheostat. Each of the contact pieces is connected, through one wire of an interior communication table, to one side of one of the receiver lamps, which lamp has marked on its front the number of degrees that the given contact is situated from the center-line of the ship; the other side of the lamp is connected to the common return wire, which goes to the source of current and then to the contact arm. As the rudder turns, the contact arm makes connection with the different contact pieces, and as it touches each piece the corresponding lamp in the receiver lights up and indicates its position within the limits shown; when it is just midway between any two pieces it will touch both and light both corresponding lamps, which doubles the closeness with which the position is indicated.

As many receivers can be connected on as desired, all being operated in parallel.

Engine Telegraphs.

When used for engine order telegraphs the contact arm is mounted in a metal case and operated by a hand lever of the same construction as the hand lever of an ordinary mechanical ship's engine telegraph. The case contains indicator lamps in parallel with the lamps of the receiver at the engine-room, so that the operator on the bridge has visual evidence of the order sent. A small magnetto is geared to the transmitter handle, and rings a bell at the receiver whenever the handle is moved, thus calling attention to the change of order.

Battle Order Indicators.

The receiving indicators are of the same construction as above described for the Helm Indicators, but the transmitter consists of single-pole snap switches, connected up exactly like the lamps of the indicator, so that by turning the proper switches any desired number of lamps can be lighted, and of course any desired order can be marked in front of any lamp. Several indicators, located in different parts of the ship, are usually worked by each transmitter, all being connected in parallel.

The case which contains the transmitter switches also contains an indicator, thus always showing what orders are being indicated on the system.

Range Indicators.

Range indicators are exactly like the Battle Order Indicators, except that instead of having different orders marked before each lamp, a number representing the range in yards is marked.

A range indicator and a battle-order indicator are usually mounted together at desired stations, thus showing what kind of firing is to be done, and at what range.

Revolution Indicators.

To show on the bridge the direction and speed of rotation of the engines, several appliances have been devised. The one most generally used is shown in Fig. 9, and consists at the transmitter of a small gear *E*, mounted eccentrically upon the propeller shaft *S*, and meshing with a pinion *P*, which is carried on the lower end of an arm *A*. The arm *A* is slotted and mounted on a pivot as shown, and when *S* is rotating, *A* will be turned to one side or the other, depending upon the direction of rotation of *S*, until it hits on the stop *B*, and will then remain against the stop and reciprocate up and down from the eccentric action of *E*; on each up movement it will make contact with clip *C* or *C′*, depending upon which side it is turned.

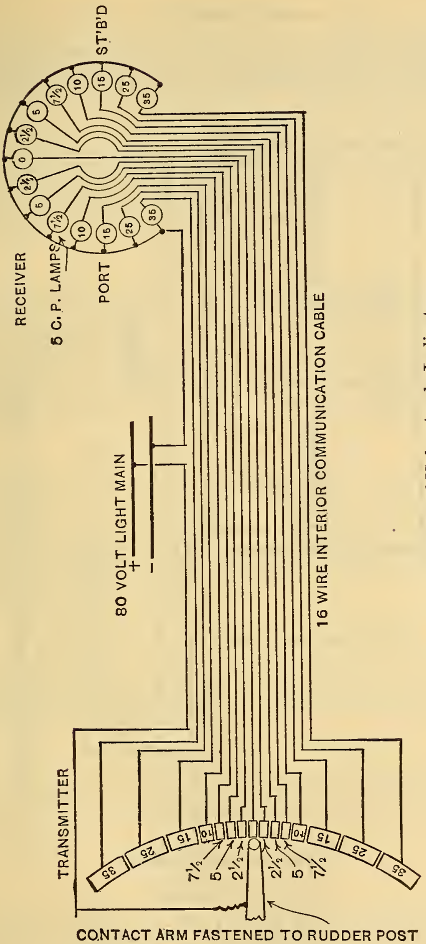


FIG. 8. Diagram of Helm Angle Indicator.

The receiver consists of two pivoted pointers, connected as shown to two electro-magnets and marked "Astern" and "Ahead."

From the connections shown, it is seen that at each rotation of the propeller shaft the pointer corresponding to the direction of rotation will make a movement, and at the same time the magnet armature will make a plainly audible click, thus indicating both visually and audibly the rotation. The other pointer corresponding to the direction in the opposite rotation will remain still. For twin screws a separate transmitter and receiver is installed for each.

A separate mechanical indicator is also usually installed, consisting of a small shaft geared to the propeller shaft, and running to the bridge (angles being turned by bevel gears), where it drives a pointer at the same rate as the main shaft.

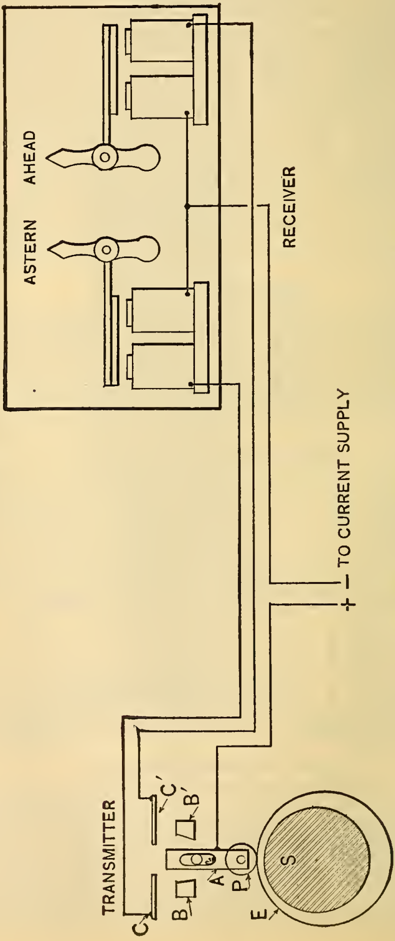


Fig. 9. Diagram of Connections for Revolution Indicator.

Telephones.

In the telephone system used there is no "Central" station; but each telephone is provided with a transfer switch, by means of which it can be directly connected with the other telephones. An annunciator is provided to show what station has made the call. The ringing and talking circuits are entirely separate, and ringing is done by battery current.

To make a call, the transfer switch is turned so that the pointer is over the name of the station desired, and a push-button pressed. This rings the bell, and causes the annunciator at the desired station to indicate the name of the station calling; then the person called turns his transfer switch to agree with the indication of the annunciator, which connects the two telephones directly with each other, and allows talking to proceed.

Bell Company's telephones are used, and are mounted in water-tight cases; all accessories are made water-tight.

Fire Alarms.

The fire-alarm system consists of mercurial thermostats, located in all parts of the ship, and connected to an annunciator in the captain's office.

The thermostats consist of a hermetically sealed metal tube containing mercury, and provided with an insulated platinum point, so adjusted that at a temperature of 200° F. the mercury will have expanded sufficiently to make contact with the platinum, thus completing the circuit, and indicating at the annunciator the location of the heated thermostat. The annunciator is provided with a bell which will ring continuously until a switch corresponding to the indicating drop is opened. Battery current is used.

Water-tight Door Alarms.

To give a general signal for the closing of all water-tight doors, a system of alarm whistles is used. The whistle consists of a solenoid which pulls its core down into an air chamber, and thus forces the air out through a small shrill whistle. The core is restored by spiral springs. All whistles are connected in parallel, and are operated by a make and break mechanism, which by the pulling of a lever will interrupt the circuit continuously for about 30 seconds, each interruption giving a blast from each whistle. Current from the lightning mains is used.

SOLENOID ALARM WHISTLE.

The construction is shown in Fig. 12. The clockworks for operating the contact maker is constructed so that by rotating an operating lever it is wound up, and upon releasing the lever it vibrates the contact while running down, thus giving periodical signals.

Call Bells.

An elaborate system of call bells, annunciators, electro-mechanical signal gongs, etc., is installed on all large ships. The main difference from ordinary commercial work is that all appliances are made water-tight.

MISCELLANEOUS.

Range-Finder.

The following is a brief outline of the principles employed in the instrument designed by Lieutenant Bradely Fiske of the United States Navy.

In Fig. 10 let A represent the target and BC a known base. Then

$$AC : BC :: \sin ABC : \sin BAC.$$

$$AC = BC \times \frac{\sin ABC}{\sin BAC}.$$

The angle ABC can be readily measured. The angle $BAC = DBE$, the line BE being parallel to AC.

The Fiske range-finder measures the angle *DBE* by the use of the Wheatstone bridge, as follows :

Suppose the two semi-circles in Fig. 10 replaced by two metallic arcs (Fig. 11). At the center of each of these arcs is pivoted a telescope, the pivot of which is connected to a battery *B*. The telescopes are in electrical contact with the arcs. These metallic arcs are connected at their extremities with a galvanometer, *c*, the whole forming a Wheatstone bridge, whose arms are *aa bb*.

When the telescopes are pointed at the object *A*, it is evident that the arms of the bridge are unequal, and hence do not balance ; and this fact is indicated by the deflection of the needle of the galvanometer. The arc *FD* is noted. By swinging the telescope at F around till the needle of the galvanometer indicates zero, the bridge balances, the telescope being parallel to the one at *C*, and the arc or angle *DF* – *FE* is equal to the angle at *A*. From this the distance *AC* can be calculated, or read off directly on a properly constructed scale.

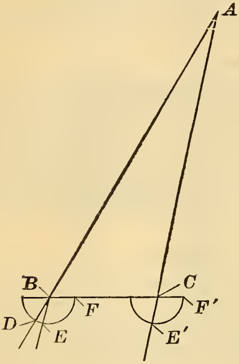


FIG. 10.

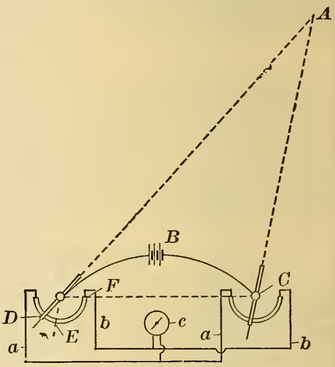


FIG. 11.

Generally, in using the instrument, the telescopes are mounted at a distance from the battery, where the view is uninterrupted, while the galvanometer is at the gun. The observers keep the telescopes constantly directed on the target, and the man at the gun balances the bridge by introducing a variable resistance into the circuit till the needle stands at zero. This variable resistance is graduated so as to indicate the range corresponding to the resistance introduced.

Firing Guns.

Large guns are arranged to use both percussion and electric primers for firing. The electric primer is of the same external shape as the percussion primers, and is exploded by a fine platinum wire, heated by current from the cells of a dry battery mounted near the gun. A ground return is used, and a safety switch is fastened to the breech plug, so that the circuit cannot be completed until the breech plug is closed. A push-button is used to complete the circuit and fire the gun.

Speed Recorder.

An instrument called the "Weaver Speed Recorder" is somewhat used for measuring the speed of ships when run on the measured mile, and while being launched ; also to measure the acceleration of turrets during test.

It consists essentially of a clock-works, which drives a paper tape over a set of five pens operated by electro-magnets, so that when any magnet is

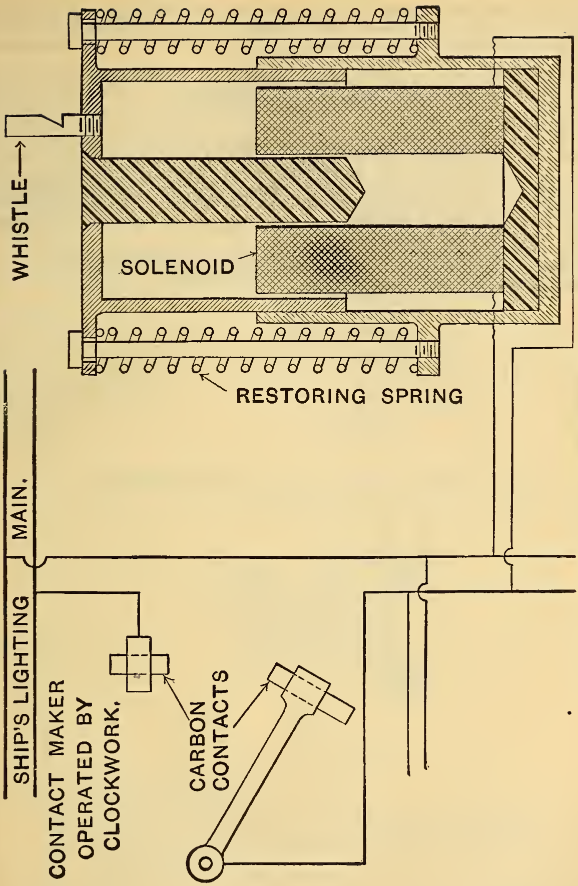


FIG. 12. Diagram of Connections of Electric Whistle.

excited it pulls its pen against the moving paper tape, and makes a dot thereon. The connecting levers between the magnet and pen are arranged something like a piano finger action, so that no matter how long the magnet is kept excited, the pen will only make a quick, short dot. All pens are located side by side in the same line, so that if they were all operated at the same instant, the result would be a line of dots across the tape.

When used for measuring mile runs, one pen is connected to a make and brake chronometer, so that it makes a dot on the tape every second; another pen is connected to a hand push-button, so that a dot can be made at the start and finish of the run, and at as many intermediate points as desired; the other three pens are connected to contact makers on the shafts of the main engines, so that a dot is made for every revolution of the engine. (If the ship has twin screws, of course only two of the remaining pens are used; and if single screw, only one.)

It is thus seen that by counting the number of second dots between the start and finish dots, the length of time to make the run is given, and by counting the number of revolution dots in any desired space, the speed of the engine is given. Fractional seconds or revolutions can easily be scaled.

When used to obtain launching curves, a long steel wire wound on a drum has one end attached to the ship, and a contact maker is fastened to this drum. As the ship slides out the drum is revolved and dots made on the tape at each revolution; knowing the diameter of the drum, the speed at any instant is found by comparison of the revolution dots with the second dots. The hand-push is used to mark the start, finish, instant of pivoting, and any other desired matters.

When used for acceleration runs on turrets, the same procedure as for launching curves is followed, except the contact maker is attached to some rotating part of the turret mechanism.

MISCELLANEOUS.

THERMO-ELECTRIC SCALE.

With respect to lead, at a mean temperature of 20° C. (Matthiessen.) The E.M.F.s are in micro-volts per degree centigrade:

Bismuth of commerce in wire	+97.0
" pure "	+89.0
" crystallized along axis	+65.0
" " normal to axis	+45.0
Cobalt	+22.0
German Silver	+11.75
Mercury	+0.418
Lead	0.
Tin	— 0.1
Copper of commerce	— 0.1
Platinum	— 0.9
Gold	— 1.2

Antimony, pure, in wire	— 3.8
Silver " "	— 3.0
Zinc " "	— 3.7
Copper, galvano-plastic	— 3.8
Antimony of commerce in wire	— 6.0
Arsenic	— 13.56
Iron, piano wire	— 17.50
Antimony, crystallized along axis	— 22.60
Antimony, normal to axis	— 26.40
Phosphorus (red)	— 29.70
Tellurium	—502.00
Selenium	—807.00

CONNECTIONS OF INDUCTION COIL.

(Ruhmkoff's.)

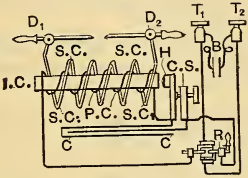


FIG. 1.

Index to Figure.

$T_1 T_2$ = Terminals to which wires from
B = Battery are attached.
R = Reverser or commutator for removing or cutting off current.
CS = Contact screw platinum-pointed (in primary circuit).
H = Hammer (soft iron), the movement of which completes and breaks circuit at CS.
C = Condenser for arresting the momentary direct induced current in
PC = Primary coil of thick wire, through which battery current passes.
SC = Secondary coil of fine wire (well insulated) in which sparking currents are induced.
$D_1 D_2$ = Spark dischargers fitted to ends of secondary coil.
IC = Iron core, being a bundle of very soft iron wires.

POWER REQUIRED FOR SEWING-MACHINES.

Light-running	20 machines	to	1 h.p.
Heavy work on same	15 "	"	"
Leather-sewing	12 "	"	"
Button-hole machines	8 to 12 "	"	"

PRONY BRAKE.

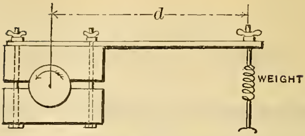


FIG. 2.

$$\text{Constant} = \frac{2\pi}{33000} = .0001904.$$

then

Horse-power = .0001904 × d × w × revolutions per minute.

POWER USED BY MACHINE-TOOLS.

(R. E. Dinsmore, from the *Electrical World.*)

1. Shop shafting $2\frac{3}{16}$ in. × 180 ft. at 160 revs., carrying 26 pulleys from 6 in. diam. to 36 in., and running 20 idle machine belts .	1.32 H. P.
2. Lodge-Davis upright back-geared drill-press with table, 28 in. swing, drilling $\frac{3}{8}$ in. hole in cast iron, with a feed of 1 in. per minute	0.78 H. P.
3. Morse twist-drill grinder No. 2, carrying 26 in. wheels at 3200 revs	0.29 H. P.
4. Pease planer 30 in. × 36 in., table 6 ft., planing cast iron, cut $\frac{1}{4}$ in. deep, planing 6 sq. in. per minute, at 9 reversals	1.06 H. P.
5. Shaping-machine 22 in. stroke, cutting steel die, 6 in. stroke, $\frac{1}{8}$ in. deep, shaping at rate of 1.7 square inch per minute . . .	0.37 H. P.
6. Engine-lathe 17 in. swing, turning steel shaft $2\frac{3}{8}$ in. diam., cut $\frac{3}{16}$ deep, feeding 7.92 in. per minute	0.43 H. P.
7. Engine lathe 21 in. swing, boring cast-iron hole 5 in. diam., cut $\frac{3}{16}$ diam., feeding 0.3 in. per minute	0.23 H. P.
8. Sturtevant No. 2, monogram blower at 1800 revs. per minute, no piping	0.8 H. P.
9. Heavy planer 28 in. × 28 in. × 14 ft. bed, stroke 8 in., cutting steel, 22 reversals per minute	3.2 H. P.

Horse-power in Machine-shops; Friction; Men Employed.

(Flather.)

Name of Firm.	Kind of Work.	Horse-power.				Number of Men.	No. of Men per Total H. P.	No. of Men per Effective H.P.
		Total.	Required to drive Shafting.	Required to drive Machinery.	Per Cent to drive Shafting.			
Lane & Bodley	E. & W.W.	58				132	2.27	
J. A. Fay & Co.	W. W.	100	15	85	15	300	3.00	3.53
Union Iron Works . .	E., M. M.	400	95	305	23	1600	4.00	5.24
Frontier Iron &Brass W'ks	M. E., etc.	25	8	17	32	150	6.00	8.82
Taylor Mfg. Co.	E.	95				230	2.42	
Baldwin Loco. Works .	L.	2500	2000	500	80	4100	1.64	8.20
W. Sellers & Co. (one department)	H. M.	102	41	61	40	300	2.93	4.87
Pond Machine Tool Co. .	M. T.	180	75	105	41	432	2.40	4.11
Pratt & Whitney Co. . .	"	120				725	6.04	
Brown & Sharpe Co. . .	"	230				900	3.91	

Horse-power in Machine-shops. — *Continued.*

Name of Firm.	Kind of Work.	Horse-power.				Number of Men.	No. of Men per Total H. P.	No. of Men per Effective H.P.
		Total.	Required to drive Shafting.	Required to drive Machinery.	Per cent to drive Shafting.			
Yale & Towne Co.	C. & L.	135	67	68	49	700	5.11	10.25
Ferracute Machine Co. .	P. & D.	35	11	24	31	90	2.57	3.75
T. B. Wood's Sons . . .	P. & S.	12				30	2.50	
Bridgeport Forge Co. .	H. F.	150	75	75	50	130	.86	1.73
Singer Mfg. Co.	S. M.	1300				3500	2.69	
Howe Mfg. Co.	“	350				1500	4.28	
Worcester Mach. Screw Co.	M. S.	40				80	2.00	
Hartford “ “ “	“	400	100	300	25	250	0.62	0.83
Nicholson File Co. . .	F.	350				400	1.14	
Averages	. . . . .	346.4			38.6%	818.3	2.96	5.13

Abbreviations: E., engine; W.W., wood-working machinery; M. M., mining machinery; M. E., marine engines; L., locomotives; H. M., heavy machinery; M. T., machine-tools; C. & L., cranes and locks; P. & D., presses and dies; P. & S., pulleys and shafting; H. F., heavy forgings; S. M., sewing-machines; M. S., machine-screws; F., files.

LIST OF TOOLS AND SUPPLIES USEFUL IN INSTALLING ELECTRIC LIGHTS AND DYNAMOS.

1 Tool chest.
1 Magneto and cable.
1 Speed indicator.
1 Tape line, 75 ft.
1 Rule, 2 ft.
1 Scraper, for bearings.
1 Blow lamp.
1 Clawhammer, No. 13.
1 Ball pein hammer, No. 24.
1 B. & S. pocket wrench, No. 4.
1 Monkey wrench, 10 inch.
1 Set (2) Champion screw-drivers.
1 Large screw-driver, 12-inch.
1 Off-set screw-driver.
1 Ratchet brace, No. 33.
Bits, ¼, ⅜, ½, ⅝, ¾, ⅞, 1 inch.
1 Clarke Expansive bit, ⅞ to 3 inch.
1 Screw-driver bit.
1 Gimlet bit.
1 Wood countersink.
1 Extension drill, ⅜ in. length, 24 in.
1 Long or extension gimlet.
1 Cold chisel, ¾ inch.
1 Half round cold chisel.
1 Cape chisel.
1 Wood chisel, firmer paring, ⅝ inch.
1 Brick drill.
Files, one each: round, flat, half-round and three-square.
1 Saw, 20 inch.
1 Hack-saw, 10 inch.
10 Extra saw blades.
1 Plumb bob.
1 Brad awl.
1 Pair carbon tongs.
1 Soldering copper, No. 3.
1 Pound of solder.
1 Pair of climbers.
1 Come-along.
1 Splicing-clamp.
1 Strap and vise.
1 Pair line pliers, 8 inch.
1 Pair of side-cutting pliers, 5 inch.
1 Pair of diagonal-cutting pliers, 5 in.
1 Pair of round-nose pliers, 5 inch.
1 Pair of flat-nose pliers, 5 inch.
1 Pair of burner pliers, 7 inch.
6 Sheets of emery cloth.
6 Sheets of crocus cloth.
2 Gross of assorted machine screws.
2 Gross of assorted wood screws.
150 Special screws.
Taps, 6–30, 10–24, 12–24, 18–18,
Drills, 34, 21, 9, 15–64,
Tap wrench,

TOOLS REQUIRED.

The following-named tools will probably be required in constructing lines for city or commercial lighting:

(Davis.)

Article.	Size.	Cost about
Stubs' pliers, plain	8 in.	$2.00
Climbers and straps	.....	3.00
Pulley-block and ecc. clamp	To No. 3 B. & S.	8.00
Come-along and strap		2.25
Splicing-clamps		2.50
Linemen's tool-bag and strap	.....	4.80
Soldering-furnace	.....	6.00
Gasoline blow-pipes	.....	6.00
Soldering coppers	2 lb.	.95
Pole-hole shovels	8 ft.	1.50
Pole-hole spoon, regular	7 ft.	1.25
Octagon digging-bars	8 ft.	3.50
Tamping-bars	7 ft.	2.60
Crowbar	10 lb.	.90
Pick-axe	.....	.75
Carrying-hook, heavy	.....	6.00
Cant-hook	4 ft.	2.00
Pike-poles	16 ft.	2.40
Pole-supporter	6 ft.	12.00
Comb, pay-out reel and straps	.....	20.00
Nail-hammer	1 lb.	1.00
Linemen's broad hatchets	6 in.	1.50
Drawing-knives	12 in.	2.10
Hand-saw	26 in.	1.50
Ratchet-brace, bits	10 in.	3.00
Screw-drivers	8 in.	.80
Wrench	12 in.	1.25
Bastard file	12 in.	.30

APPROXIMATE LIST OF SUPPLIES

REQUIRED IN INSTALLING 15 CITY LAMPS AND 20 COMMERCIAL LAMPS ON A FIVE-MILE CIRCUIT, SETTING POLES 132 FEET APART.

(Davis.)

Articles.	Size or Diameter.	Price about	Quantity.
Electric-light poles	30 ft., 6 in.	$2.40 each	180
Electric-light poles	35 ft., 7 in.	4.15 "	...
Electric-light poles	40 ft., 7 in.	5.50 "	40
Cross-arms, 4-pin	4 ft.	.30 "	200
Painted oak pins	1½ in.	.02 "	800
Oak pins and bolts	1½ in.	.07 "	24
Iron break-arms	......	.75 "	25
Lag-screws and washers	½ × 7 in.	.04 "	400
Glass insulators, D. G.	......	.07½ "	850
Pole steps	⅝ × 8 in.	.05 "	2500
Guy stranded cable	⅜ in.	.07 lb.	500 lbs.
Cross-arm brace and bolts	......	.20 each	40
Line wire	6 BS	125.00 mi.	6 miles

MATERIAL REQUIRED FOR CONNECTING IN LAMPS.

(Davis.)

Sleet-proof pulleys . . .	. . . . . .	$0.75 each.	30
Street-lamp cleats, iron .	. . . . . .	.25 "	15
Arc-lamp cordage	$\frac{3}{8}$ in.	1.25 hd. ft.	25
Suspension cable	$\frac{1}{4}$ in.	.02$\frac{1}{2}$ ft.	3000 ft.
Hard-rubber tube	$\frac{3}{8} \times \frac{5}{8}$ in.	1.50 lb.	5 lbs.
Soft-rubber tubing . . .	$\frac{3}{8}$ in.	.20 ft.	200 ft.
Arc cut-out	. . . . . .	3.50 each	20
Porcelain insulators and screws	. . . . . .	2.40 hd.	400
Oak brackets and spikes .	. . . . . .	2.50 "	150

"NATIONAL ELECTRICAL CODE."

RULES AND REQUIREMENTS OF THE NATIONAL BOARD OF FIRE UNDERWRITERS FOR THE INSTALLATION OF WIRING AND APPARATUS FOR ELECTRIC LIGHT, HEAT, AND POWER AS RECOMMENDED BY THE UNDERWRITERS' NATIONAL ELECTRIC ASSOCIATION.

EDITION OF 1901.

The National Electrical Code, as it is here presented, is the result of the united efforts of the various Electrical, Insurance, Architectural, and allied interests which have, through the National Conference on Standard Electrical Rules, composed of delegates from various National Associations, unanimously voted to recommend it to their respective Associations for approval or adoption.

The following is a list of the Associations represented in the Conference, all of which have approved of the Code :

American Institute of Architects.
American Institute of Electrical Engineers
American Society of Mechanical Engineers
American Street Railway Association
Factory Mutual Fire Insurance Companies
National Association of Fire Engineers
National Board of Fire Underwriters
National Electric Light Association
Underwriters' National Electric Association

GENERAL PLAN GOVERNING THE ARRANGEMENT OF RULES.

CLASS A.—**Central Stations, Dynamo, Motor, and Storage-Battery-Rooms, Transformer Substations, etc.** Rules 1 to 11.

CLASS B.—**Outside Work,** all systems and voltages. Rules 12 and 13.

CLASS C.—**Inside Work.** Rules 14 to 39. Subdivided as follows :
- **General Rules,** applying to all systems and voltages. Rules 14 to 17.
- **Constant-Current** systems. Rules 18 to 20.
- **Constant-Potential** systems.
  - All voltages. Rules 21 to 23.
  - Voltage not over 550. Rules 24 to 31.
  - Voltage between 550 and 3,500. Rules 32 to 37.
  - Voltage over 3,500. Rules 38 and 39.

CLASS D.—**Specification** for **Wires** and **Fittings.** Rules 40 to 63.

CLASS E.—**Miscellaneous.** Rules 64 to 67.

CLASS F.—**Marine Wiring.** Rules 68 to 80.

CLASS A.—STATIONS AND DYNAMO ROOMS.

INCLUDES CENTRAL STATIONS, DYNAMO, MOTOR, AND STORAGE-BATTERY ROOMS, TRANSFORMER SUBSTATIONS, ETC.

1. Generators—

a. Must be located in a dry place.

b. Must never be placed in a room where any hazardous process is carried on, nor in places where they would be exposed to inflammable gases or flyings of combustible materials.

c. Must be insulated on floors or base frames, which must be kept filled to prevent absorption of moisture, and also kept clean and dry. Where frame insulation is impracticable, the Inspection Department having jurisdiction may, in writing, permit its omission, in which case the frame must be permanently and effectively grounded.

A high-potential machine which, on account of great weight or for other reasons, cannot have its frame insulated from the ground, should be surrounded with an insulated platform. This may be made of wood, mounted on insulating supports, and so arranged that a man must always stand upon it in order to touch any part of the machine.

In case of a machine having an insulated frame, if there is trouble from static electricity due to belt friction, it should be overcome by placing near the belt a metallic comb connected with the earth, or by grounding the frame through a very high resistance of not less than 200 ohms per volt generated by the machine.

d. Every constant-potential generator must be protected from excessive current by a safety fuse, or equivalent device, of approved design in each lead wire.

These devices should be placed on the machine or as near it as possible.

Where the needs of the service make these devices impracticable, the Inspection Department having jurisdiction may, in writing, modify the requirements.

e. Must each be provided with a waterproof cover.

f. Must each be provided with a name-plate, giving the maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute.

2. Conductors —

From generators to switchboards, rheostats, or other instruments, and thence to outside lines.

a. Must be in plain sight or readily accessible.

b. Must have an *approved* insulating covering as called for by rules in Class "C" for similar work, except that in central stations, on exposed circuits, the wire which is used must have a heavy braided non-combustible outer covering.

Bus bars may be made of bare metal.

c. Must be kept so rigidly in place that they cannot come in contact.

d. Must in all other respects be installed under the same precautions as required by rules in Class "C" for wires carrying a current of the same volume and potential.

3. Switchboards —

a. Must be so placed as to reduce to a minimum the danger of communicating fire to adjacent combustible material.

Special attention is called to the fact that switchboards should not be built down to the floor, nor up to the ceiling, but a space of at least ten or twelve inches should be left between the floor and the board, and from eighteen to twenty-four inches between the ceiling and the board in order to prevent fire from communicating from the switchboard to the floor or ceiling, and also to prevent the forming of a partially concealed space very liable to be used for storage of rubbish and oily waste.

b. Must be made of non-combustible material or of hardwood in skeleton form filled to prevent absorption of moisture.

c. Must be accessible from all sides when the connections are on the back, but may be placed against a brick or stone wall when the wiring is entirely on the face.

d. Must be kept free from moisture.

e. Bus bars must be equipped in accordance with rules for placing conductors.

4. Resistance Boxes and Equalizers —

(For construction rules, see No. 60.)

a. Must be placed on a switchboard or, if not thereon, at a distance of a foot from combustible material, or separated therefrom by a non-inflammable, non-absorptive, insulating material.

5. Lightning Arresters—

(*For construction rules see No. 63.*)

a. Must be attached to each side of every overhead circuit connected with the station.

It is recommended to all electric light and power companies that arresters be connected at intervals over systems in such numbers and so located as to prevent ordinary discharges entering (over the wires) buildings connected to the lines.

b. Must be located in readily accessible places away from combustible materials, and as near as practicable to the point where the wires enter the building.

Station arresters should generally be placed in plain sight on the switch board.

In all cases, kinks, coils, and sharp bends in the wires between the arresters and the outdoor lines must be avoided as far as possible.

c. Must be connected with a thoroughly good and permanent ground connection by metallic strips or wires having a conductivity not less than that of a No. 6 B. & S. copper wire, which must be run as nearly in a straight line as possible from the arresters to the earth connection.

Ground wires for lightning arresters must not be attached to gas-pipes within the buildings.

It is often desirable to introduce a choke coil in circuit between the arresters and the dynamo. In no case should the ground wire from a lightning arrester be put into iron pipes, as these would tend to impede the discharge.

6. Care and Attendance.

a. A competent man must be kept on duty where generators are operating.

b. Oily waste must be kept in approved metal cans and removed daily.

Approved waste cans shall be made of metal, with legs raising can three inches from the floor, and with self-closing covers.

7. Testing of Insulation Resistance.

a. All circuits, except such as are permanently grounded in accordance with Rule 13 A, must be provided with reliable ground detectors. Detectors which indicate continuously, and give an instant and permanent indication of a ground, are preferable. Ground wires from detectors must not be attached to gas-pipes within the building.

b. Where continuously indicating detectors are not feasible, the circuits should be tested at least once per day, and preferably oftener.

c. Data obtained from all tests must be preserved for examination by the Inspection Department having jurisdiction.

These rules on testing to be applied at such places as may be designated by the Inspection Department having jurisdiction.

8. Motors—

a. Must be insulated on floors or base frames, which must be kept filled to prevent absorption of moisture; and must be kept clean and dry. Where frame insulation is impracticable the Inspection Department having jurisdiction may, in writing, permit its omission, in which case the frame must be permanently and effectively grounded.

A high-potential machine which, on account of great weight or for other reasons, cannot have its frame insulated, should be surrounded with an insulated platform. This may be made of wood mounted on insulating supports, and so arranged that a man must stand upon it in order to touch any part of the machine.

In case of a machine having an insulated frame, if there is trouble from static electricity due to belt friction, it should be overcome by placing near the belt a metallic comb connected to the earth, or by grounding the frame through a very high resistance of not less than 200 ohms per volt generated by the machine.

b. Must be wired under the same precautions as required by rules in class "C," for wires carrying a current of the same volume and potential.

The leads or branch circuits should be designed to carry a current at least fifty per cent greater than that required by the rated capacity of the motor to provide for the inevitable overloading of the motor at times without overfusing the wires.

c. The motor and resistance box must be protected by a cutout and controlled by a switch (see No. 17 *a*), said switch plainly indicating whether "on" or "off." Where one-fourth horse-power or less is used on low-tension circuits a single-pole switch will be accepted. The switch and rheostat must be located within sight of the motor, except in such cases where special permission to locate them elsewhere is given in writing by the Inspection Department having jurisdiction.

d. Must have their rheostats or starting-boxes located as to conform to the requirements of No. 4.

In connection with motors the use of circuit-breakers, automatic starting-boxes and automatic under-load switches is recommended, and they *must* be used when required.

e. Must not be run in series-multiple or multiple-series, except on constant-potential systems, and then only by special permission of the Inspection Department having jurisdiction.

f. Must be covered with a waterproof cover when not in use, and, if deemed necessary by the Inspection Department having jurisdiction, must be inclosed in an approved case.

From the nature of the question the decision as to what is an approved case must be left to the Inspection Department having jurisdiction to determine in each instance.

g. Must, when combined with ceiling fans, be hung from insulated hooks, or else there must be an insulator interposed between the motor and its support.

h. Must each be provided with a name-plate, giving the maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute.

9. Railway Power Plants.

a. Must be equipped in each feed wire before it leaves the station with an *approved* automatic circuit-breaker (see No. 52) or other device, which will immediately cut off the current in case of an accidental ground. This device must be mounted on a fireproof base, and in full view and reach of the attendant.

10. Storage or Primary Batteries.

a. When current for light and power is taken from primary or secondary batteries, the same general regulations must be observed as applied to similar apparatus fed from dynamo generators developing the same difference of potential.

b. Storage battery rooms must be thoroughly ventilated.

c. Special attention is directed to the rules for rooms where acid fumes exist (see No. 24, *j* and *k*).

d. All secondary batteries must be mounted on non-absorptive, non-combustible insulators, such as glass or thoroughly vitrified and glazed porcelain.

e. The use of any metal liable to corrosion must be avoided in cell connections of secondary batteries.

11. Transformers.

(*For construction rules, see No. 62.*)

a. In central or substations the transformers must be so placed that smoke from the burning out of the coils or the boiling over of the oil (where oil-filled cases are used) could do no harm.

CLASS B. — OUTSIDE WORK.

ALL SYSTEMS AND VOLTAGES.

12. Wires.

a. Service wires must have an *approved* rubber insulating covering (see No. 41). Line wires, other than services, must have an *approved* weatherproof, or rubber insulating covering (Nos. 41 and 44). All the wires must have an insulation equal to that of the conductors they confine.

b. Must be so placed that moisture cannot form a cross connection between them, not less than a foot apart, and not in contact with any substance other than their insulating supports. Service blocks must be covered over their entire surface with at least two coats of waterproof paint.

c. Must be at least seven feet above the highest point of flat roofs, and at least one foot above the ridge of pitched roofs over which they pass or to which they are attached.

d. Must be protected by dead insulated guard iron or wires from possibility of contact with other conducting wires or substances to which current may leak. Special precautions of this kind must be taken where sharp angles occur, or where any wires might possibly come in contact with electric light or power wires.

e. Must be provided with petticoat insulators of glass or porcelain. Porcelain knobs or cleats and rubber hooks will not be approved.

f. Must be so spliced or joined as to be both mechanically and electrically secure without solder. The joints must then be soldered, to insure preservation, and covered with an insulation equal to that on the conductors.

All joints must be soldered, even if made with some form of patent splicing device. This ruling applies to joints and splices in all classes of wiring covered by these rules.

g. Must, where they enter buildings, have drip loops outside, and the holes through which the conductors pass must be bushed with non-combustible, non-absorptive insulating tubes slanting upward toward the inside.

h. Telegraph, telephone, and similar wires must not be placed on the same cross-arm with electric light or power wires; and when placed on the same pole with such wires the distance between the two inside pins of each cross-arm must not be less than twenty-six inches.

i. The metallic sheaths to cables must be permanently and effectively connected to "earth."

TROLLEY WIRES.

j. Must not be smaller than No. 0 B. & S. copper or No. 4 B. & S. silicon bronze, and must readily stand the strain put upon them when in use.

k. Must have a double insulation from the ground. In wooden-pole construction the pole will be considered as one insulation.

l. Must be capable of being disconnected at the power plant, or of being divided into sections, so that, in case of fire on the railway route, the current may be shut off from the particular section and not interfere with the work of the firemen. This rule also applies to feeders.

m. Must be safely protected against accidental contact where crossed by other conductors.

Guard wires should be insulated from the ground, and should be electrically disconnected in sections of not more than 300 feet in length.

GROUND RETURN WIRES.

n. For the diminution of electrolytic corrosion of underground metal work, ground return wires must be so arranged that the difference of potential between the grounded dynamo terminal and any point on the return circuit will not exceed twenty-five volts.

It is suggested that the positive pole of the dynamo be connected to the trolley line, and that whenever pipes or other underground metal work are found to be electrically positive to the rails or surrounding earth, that they be connected by conductors arranged so as to prevent as far as possible current flow from the pipes into the ground.

13. Transformers.

(*For construction rules, see No. 62.*)

a. Must not be placed inside of any building, excepting central stations, unless by special permission of the Inspection Department having jurisdiction.

b. Must not be attached to the outside walls of buildings, unless separated therefrom by substantial supports.

13. A. Grounding Low Potential Circuits.

The grounding of low potential circuits under the following regulations is only allowed when so arranged that under normal conditions there will be no flow of current through the ground wire.

Direct Current 3-Wire Systems.

a. Neutral wire may be grounded, and when grounded the following rules must be complied with: —

1. Must be grounded at the Central Station on a metal plate buried in coke beneath permanent moisture level, and also through all available underground water- and gas-pipe systems.
2. In underground systems the neutral wire must also be grounded at each distributing-box through the box.
3. In overhead systems the neutral wire must be grounded every 500 feet, as provided in Sections *c*, *e*, and *f*.

The Inspection Department having jurisdiction may require grounding if they deem it necessary.

Two-wire direct current systems having no accessible neutral point are not to be grounded.

Alternating Current Secondary Systems.

b. The neutral point of transformers, or the neutral wire of distributing systems, may be grounded, and when grounded the following rules must be complied with: —

1. Transformers feeding 2-wire systems must be grounded at the center of the secondary coils.
2. Transformers feeding systems with a neutral wire must have the neutral wire grounded at the trausformer and at least every 250 feet beyond.

Inspection Department having jurisdiction may *require* grounding if they deem it necessary.

Ground Connections.

c. The ground wire in D. C. 3-wire systems must not at Central Stations be smaller than the neutral wire and not smaller than No. 6 B. & S. elsewhere.

d. The ground wire in A. C. systems must never be less than No. 6 B. & S., and must always have equal carrying capacity to the secondary lead of the transformer, or the combined leads where transformers are banked.

e. The ground wire must be kept outside of buildings, but may be directly attached to the building or pole. The wire must be carried in as nearly a straight line as possible, and kinks, coils and sharp bends must be avoided.

f. The ground connections for Central Stations, transformer substations, and banks of transformers must be made through metal plates buried in coke below permanent moisture level, and connections should also be made to all available underground piping systems. For individual transformers and building services the ground connection may be made as above, or may be made to water or other piping systems running into the buildings. This connection may be made by carrying the ground wire into the cellar and connecting on the street side of meters, main clocks, etc.

In connecting ground wires to piping systems, where possible the wires should be soldered into one or more brass plugs and the plugs forcibly screwed into a pipe-fitting, or where the pipes are cast iron into a hole tapped to the pipe itself. For large stations, where connecting to underground pipes with bell and spigot joints, it is well to connect to several lengths, as the pipe joints may be of rather high resistance. Where such plugs cannot be used the surface of the pipe may be filed or scraped bright, the wire wound around it, and a strong clamp put over the wire and firmly bolted together.

Where ground plates are used a No. 16 copper plate, about 3 x 6 feet in size, with about two feet of crushed coke or charcoal about pea size both under and over it, would make a ground of sufficient capacity for a moderate size station, and would probably answer for the ordinary sub-station or bank of transformers. For a large Central Station considerable more area might be necessary, depending upon the other underground connections available. The ground wire should be riveted to such a plate in a number of places, and soldered for its whole length. Perhaps even better than a copperplate is a cast-iron plate with projecting forks, the idea of the fork being to distribute the connection to the ground over a fairly broad area, and to give a large surface contact. The ground wire can probably best be connected to such a cast-iron plate by brass plugs screwed into the plate to which the wire is soldered. In all cases the joint between the plate and the ground wire should be thoroughly protected against corrosion by suitable painting with waterproof paint or some equivalent.

CLASS C.—INSIDE WORK.

ALL SYSTEMS AND VOLTAGES.

GENERAL RULES—ALL SYSTEMS AND VOLTAGES.

14. Wires.

(*For special rules, See Nos. 18, 24, 32, 38, and 39.*)

a. Must not be of smaller size than No. 14 B. & S., except as allowed under Rules 24 *t* and 45 *b*.

b. Tie wires must have an insulation equal to that of the conductors they confine.

c. Must be so spliced or joined as to be both mechanically and electrically secure without solder; they must be then soldered to insure preservation, and the joint covered with an insulation equal to that on the conductors.

Standard wires must be soldered before being fastened under clamps or binding screws; and, when they have a conductivity greater than No. 10 B. & S. copper wire, they will be soldered into lugs.

All joints must be soldered, even if made with some form of patent splicing device. This ruling applies to joints and splices in all classes of wiring covered by these rules.

d. Must be separated from contact with walls, floors, timbers, or partitions through which they may pass by non-combustible, non-absorptive insulating tubes, such as glass or porcelain.

Bushings must be long enough to bush the entire length of the hole in one continuous piece, or else the hole must first be bushed by a continuous waterproof tube, which may be a conductor, such as iron pipe; the tube then is to have a non-conducting bushing pushed in at each end so as to keep the wire absolutely out of contact with the conducting pipe.

e. Must be kept free from contact with gas, water, or other metallic piping, or any other conductors or conducting material which they may cross, by some continuous and firmly fixed non-conductor, creating a separation of at least one inch. Deviations from this rule may sometimes be allowed by special permission.

f. Must be so placed in wet places that an air space will be left between conductors and pipes in crossing, and the former must be run in such a way that they cannot come in contact with the pipe accidentally. Wires should be run over, rather than under, pipes upon which moisture is likely to gather or which, by leaking, might cause trouble on a circuit.

15. Underground Conductors—

a. Must be protected, when brought into a building, against moisture and mechanical injury, and all combustible material must be kept removed from the immediate vicinity.

b. Must not be so arranged as to shunt the current through a building around any catch-box.

16. Table Carrying Capacity of Wires.

Below is a table which must be followed in placing interior conductors, showing the allowable carrying capacity of wires and cables of ninety-eight per cent conductivity, according to the standard adopted by the American Institute of Electrical Engineers.

B. & S. G.	Table A. Rubber-Covered Wires. See No. 41. Amperes.	Table B. Weather-proof Wires. See No. 42 to 44. Amperes.	Circular Mils.	Circular Mils.	Table A. Rubber-Covered Wires. See No. 41. Amperes.	Table B. Weather-proof Wires. See No. 42 to 44. Amperes.
18	3	5	1,624	200,000	200	300
16	6	8	2,583	300,000	270	400
14	12	16	4,107	400,000	330	500
12	17	23	6,530	500,000	390	590
10	24	32	10,380	600,000	450	680
8	33	46	16,510	700,000	500	760
6	46	65	26,250	800,000	550	840
5	54	77	33,100	900,000	600	920
4	65	92	41,740	1,000,000	650	1,000
3	76	110	52,630	1,100,000	690	1,080
2	90	131	66,370	1,200,000	730	1,150
1	107	156	83,690	1,300,000	770	1,220
0	127	185	105,500	1,400,000	810	1,290
00	150	220	133,100	1,500 000	850	1,360
000	177	262	167,800	1,600,000	890	1,430
0000	210	312	211,600	1,700,009	930	1,490
				1,800,000	970	1,550
				1,900,000	1,010	1,610
				2,000,000	1,050	1,670

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

The carrying capacity of sixteen and eighteen wire is given, but no smaller than fourteen is to be used, except as allowed under Rules 24*t* and 45 *b*.

17. Switches, Cutouts, Circuit-Breakers, etc.—

(*For construction rules, see Nos. 51, 52, and 53.*)

a. Must, whenever called for, unless otherwise provided (for exceptions, see No. 8 *c* and No. 22 *c*), be so arranged that the cutouts will protect, and the opening of the switch or circuit-breaker will disconnect, all of the wires; that is, in a two-wire system the two wires, and in a three-wire system the three wires, must be protected by the cutout, and disconnected by the operation of the switch or circuit-breaker.

b. Must not be placed in the immediate vicinity of easily ignitible stuff or where exposed to inflammable gases or dust or to flyings of combustible material.

c. Must, when exposed to dampness, either be inclosed in a waterproof box or mounted on porcelain knobs.

CONSTANT CURRENT SYSTEMS.

PRINCIPALLY SERIES ARC LIGHTING.

18. Wires—

(*See also Nos. 14, 15, and 16.*)

a. Must have an *approved* rubber insulating covering (see No. 41).

b. Must be arranged to enter and leave the building through an *approved* double-contact service switch (see No. 51), mounted in a non-combustible case, kept free from moisture, and easy of access to police or firemen. So-called "snap switches" must not be used on high-potential circuits.

c. Must always be in plain sight, and never incased, except when *required* by the Inspection Department having jurisdiction.

d. Must be supported on glass or porcelain insulators, which separate the wire at least one inch from the surface wired over, and must be kept *rigidly* at least eight inches from each other, except within the structure of lamps, on hanger-boards, in cutout boxes, or like places, where a less distance is necessary.

e. Must, on side walls, be protected from mechanical injury by a substantial boxing, retaining an air space of one inch around the conductors, closed at the top (the wires passing through bushed holes), and extending not less than seven feet from the floor. When crossing floor-timbers in cellars or in rooms, where they might be exposed to injury, wires must be attached by their insulating supports to the underside of a wooden strip not less than one-half an inch in thickness.

19. Arc Lamps—

(*For construction rules, see No. 57.*)

a. Must be carefully isolated from inflammable material.

b. Must be provided at all times with a glass globe surrounding the arc, securely fastened upon a closed base. No broken or cracked globes to be used.

c. Must be provided with a wire netting (having a mesh not exceeding one and one-fourth inches) around the globe, and an *approved* spark arrester (see No. 58), when readily inflammable material is in the vicinity of the lamps, to prevent escape of sparks, melted copper or carbon. It is recommended that plain carbons, not copper-plated, be used for lamps in such places.

Arc lamps, when used in places where they are exposed to flyings of easily inflammable material, should have the carbons inclosed completely in a globe in such manner as to avoid the necessity for spark arresters.

For the present, globe and spark arresters will not be required on so-called "inverted arc" lamps, but this type of lamp must not be used where exposed to flyings of easily inflammable materials.

d. Where hanger-boards (see No. 56) are not used, lamps must be hung from insulating supports other than their conductors.

20. Incandescent Lamps in Series Circuits—

a. Must have the conductors installed as provided in No. 18, and each lamp must be provided with an automatic cutout.

b. Must have each lamp suspended from a hanger-board by means of rigid tube.

c. No electro-magnetic device for switches and no system of multiple-series or series-multiple lighting will be approved.

d. Under no circumstances can they be attached to gas fixtures.

CONSTANT POTENTIAL SYSTEMS.

GENERAL RULES, ALL VOLTAGES.

21. Automatic Cutouts (Fuses and Circuit-Breakers).

(*See No. 17, and for construction Nos. 52 and 53.*)

a. Must be placed on all service wires, either overhead or underground, as near as possible to the point where they enter the building and inside the walls, and arranged to cut off the entire current from the building.

Where the switch required by rule No. 22 is inside the building, the cutout required by this section must be placed so as to protect it.

b. Must be placed at every point where a change is made in the size of wire [unless the cutout in the larger wire will protect the smaller (see No. 16)].

c. Must be in plain sight, or inclosed in an *approved* box (see No. 54) and readily accessible. They must not be placed in the canopies or shells of fixtures.

d. Must be so placed that no set of incandescent lamps, whether grouped on one fixture or several fixtures or pendants, requiring more than 660 watts, shall be dependent upon one cutout. Special permission may be given in writing by the Inspection Department having jurisdiction for departure from this rule in case of large chandeliers, stage borders, and illuminated signs.

e. Must be provided with fuses, the rated capacity of which does not exceed the allowable carrying capacity of the wire; and, when circuit-breakers are used, they must not be set more than about thirty per cent above the allowable carrying capacity of the wire, unless a fusible cutout is also installed in the circuit (see No. 16).

22. Switches —

(*See No. 17, and for construction No. 51.*)

a. Must be placed on all service wires, either overhead or underground, in a readily accessible place, as near as possible to the point where the wires enter the building, and arranged to cut off the entire current.

b. Must always be placed in dry, accessible places, and be grouped as far as possible. Knife switches must be so placed that gravity will tend to open rather than close the switch.

c. Must not be single-pole, except when the circuits which they control supply not more than six 16-candle power lamps or their equivalent.

d. Where flush-switches are used, whether with conduit systems or not, the switches must be inclosed in boxes constructed of or lined with fire-resisting material. No push-buttons for bells, gas-lighting circuits or the like shall be placed in the same wall-plate with switches controlling electric light or power wiring.

23. Electric Heaters —

a. Must, if stationary, be placed in a safe situation, isolated from inflammable materials, and be treated as sources of heat.

b. Must each have a cutout and *indicating*-switch (see No. 17 *a*).

c. Must have the attachments of feed wires to the heaters in plain sight, easily accessible, and protected from interference, accidental or otherwise.

d. The flexible conductors for portable apparatus, such as irons, etc., must have an *approved* insulating covering (see No. 45 *h*).

e. Must each be provided with name-plate, giving the maker's name and the normal capacity in volts and amperes.

LOW POTENTIAL SYSTEMS.

550 VOLTS OR LESS.

Any circuit attached to any machine, or combination of machines, which develops a difference of potential, between any two wires, of over ten volts and less than 550 volts, shall be considered as a low-potential circuit, and as coming under this class, unless an approved transforming device is used, which cuts the difference of potential down to ten volts or less. The primary circuit not to exceed a potential of 3,500 volts.

24. Wires —

GENERAL RULES.

(*See also Nos. 14, 15, and 16.*)

a. Must not be laid in plaster, cement, or similar finish.

b. Must never be fastened with staples.

c. Must not be fished for any great distance, and only in places where the inspector can satisfy himself that the rules have been complied with.

d Twin wires must never be used, except in conduits, or where flexible conductors are necessary.

c. Must be protected on side walls from mechanical injury. When crossing floor-timbers in cellars or in rooms, where they might be exposed to injury, wires must be attached by their insulating supports to the under side of a wooden strip, not less than one-half inch in thickness, and not less than three inches in width.

Suitable protection on side walls may be secured by a substantial boxing, retaining an air space of one inch around the conductor, closed at the top (the wires passing through bushed holes), and extending not less than five feet from the floor; or by an iron-armored or metal-sheathed insulating conduit sufficiently strong to withstand the strain it will be subjected to; or plain metal pipe, lined with insulating tubing which must extend one-half inch beyond the end of the metal tube.

The pipe must extend not less than five feet above the floor, and may extend through the floor in place of a floor bushing.

If iron pipes are used with alternating currents, the two or more wires of a circuit *must* be placed in the same conduit. In this case the insulation of each wire must be reinforced by a tough conduit tubing projecting beyond the ends of the iron pipe at least two inches.

f. When run immediately under roofs, or in proximity to water tanks or pipes, will be considered as exposed to moisture.

SPECIAL RULES.

For open work:

In dry places:

g. Must have an *approved* rubber or "slow-burning" waterproof insulation (see Nos. 41 and 42).

h. Must be rigidly supported on non-combustible, non-absorptive insulators, which separate the wires from each other and from the surface wired over in accordance with following table:

VOLTAGE.	DISTANCE FROM SURFACE.	DISTANCE BETWEEN WIRES.
0 to 225	½ inch.	2½ inches.
225 " 550	1 "	4 "

Rigid supporting requires under ordinary conditions, where wiring along flat surfaces, supports at least every four and one-half feet. If the wires are liable to be disturbed, the distance between supports should be shortened. In buildings of mill construction, mains of No. 8 B. & S. wire or over, where not liable to be disturbed, may be separated about four inches, and run from timber to timber, not breaking around, and may be supported at each timber only.

This rule will not be interpreted to forbid the placing of the neutral of a three-wire system in the center of a three-wire cleat, provided the outside wires are separated in accordance with above table.

In damp places, such as Breweries, Sugar Houses, Packing Houses, Stables, Dye Houses, Paper or Pulp Mills, or buildings specially liable to moisture, or acid, or other fumes liable to injure the wires or their insulation, except where used for pendants:

i. Must have an *approved* rubber insulating covering (see No. 41).

j. Must be rigidly supported on non-combustible, non-absorptive insulators, which separate the wire at least one inch from the surface wired over, and they must be kept apart at least two and one-half inches.

Rigid supporting requires under ordinary conditions, where wiring over flat surfaces, supports at least every four and one-half feet. If the wires are liable to be disturbed, the distance between supports should be shortened. In buildings of mill construction, mains of No. 8 B. & S. wire or over, where not liable to be disturbed, may be separated about four inches, and run from timber to timber, not breaking around, and may be supported at each timber only.

k. Must have no joints or splices.

For molding work:

l. Must have *approved* rubber insulation covering (see No. 41).

m. Must never be placed in molding in concealed or damp places.

For conduit work:

n. Must have an *approved* rubber insulating covering (see No. 47).

o. Must not be drawn in until all mechanical work on the building has been, as far as possible, completed.

p. Must, for alternating systems, have the two or more wires of a circuit drawn in the same conduit.

It is advised that this be done for direct-current systems also, so that they may be changed to alternating systems at any time, induction troubles preventing such a change unless this construction is followed.

For concealed "knob and tube" work:

q. Must have an *approved* rubber insulating covering (see No. 41).

r. Must be rigidly supported on non-combustible, non-absorptive insulators which separate the wire at least one inch from the service wired over, and must be kept at least ten inches apart, and, when possible, should be run singly on separate timbers or studding.

Rigid supporting requires under ordinary conditions, where wiring along flat surfaces, supports at least every four and one-half feet. If the wires are liable to be disturbed, the distance between supports should be shortened.

s. When, from the nature of the case, it is impossible to place concealed wiring on non-conbustible, insulating supports of glass or porcelain, an *approved* armored cable with single or twin conductors (see No. 48) may be used where the difference of potential between wires is not over 300 volts, provided it is installed without joints between outlets, and the cable armor properly enters all fittings and is rigidly secured in place; or, if the difference of potential between wires is not over 300 volts, and if wires are not exposed to moisture, they may be fished on the loop system if separately incased throughout in approved flexible tubing or conduits.

For fixture work:

t. Must have an *approved* rubber insulating covering (see No. 46), and shall not be less in size than No. 18 B. & S.

u. Supply conductors, and especially the splices to fixtures wires, must be kept clear of the grounded part of gas-pipes; and, where shells are used, the latter must be constructed in a manner affording sufficient area to allow this requirement.

v. Must, when fixtures are wired outside, be so secured as not to be cut or abraded by the pressure of the fastenings or motion of the fixture.

25. Interior Conduits.

(*See also Nos. 24 n to p, and 49.*)

The object of a tube or conduit is to facilitate the insertion or extraction of the conductors to protect them from mechanical injury and, as far as possible, from moisture. Tubes or conduits are to be considered merely as raceways, and are not to be relied upon for insulation between wire and wire, or between the wire and the ground.

a. No conduit tube having an internal diameter of less than five-eights of an inch shall be used. (If conduit is lined, measurement to be taken inside of lining.)

b. Must be continuous from one junction box to another or to fixtures, and the conduit tube must properly enter all fittings.

c. Must be first installed as a complete conduit system, without the conductors.

d. Must be equipped at every outlet with an *approved* outlet box.

e. Metal conduits, where they enter junction boxes, and at all other outlets, etc., must be fitted with a capping of *approved* insulating material, fitted so as to protect wire from abrasion.

f. Must have the metal of the conduit permanently and effectively grounded.

26. Fixtures—

(*See also No. 24 t to v.*)

a. Must, when supported from the gas-piping of a building, be insulated from the gas-pipe system by means of *approved* insulating joints (see No. 59) placed as close as possible to the ceiling.

It is recommended that the gas outlet pipe be protected above the insulating joint by a non-combustible, non-absorptive insulating tube, having a flange at the lower end where it comes in contact with the insulating joint;

and that, where outlet tubes are used, they be of sufficient length to extend below the insulating joint, and that they be so secured that they will not be pushed back when the canopy is put in place. Where iron ceilings are used, care must be taken to see that the canopy is thoroughly and permanently insulated from the ceiling.

b. Must have all burs, or fins, removed before the conductors are drawn into the fixture.

c. The tendency to condensation within the pipes should be guarded against by sealing the upper end of the fixture.

d. No combination fixture in which the conductors are concealed in a space less than one-fourth inch between the inside pipe and the outside casing will be approved.

e. Must be tested for "contacts" between conductors and fixture, for "short circuits," and for ground connections before it is connected to its supply conductors.

f. Ceiling blocks for fixtures should be made of insulating material ; if not the wires in passing through the plate must be surrounded with non-combustible non-absorptive, insulating material, such as glass or porcelain.

g. Under no conditions shall there be a difference of potential of more than 300 volts between wires contained in or attached to the same fixture.

27. Sockets.

(*For construction rules, see No. 55.*)

a. In rooms where inflammable gases may exist the incandescent lamp and socket must be inclosed in a vapor-tight globe, and supported on a pipe hanger, wired with *approved* rubber-covered wire (see No. 41) soldered directly to the circuit.

b. In damp or wet places, or over specially inflammable stuff, waterproof sockets must be used.

When waterproof sockets are used, they should be hung by separate stranded rubber-covered wires, not smaller than No. 14 B. & S., which should preferably be twisted together when the drop is over three feet. These wires should be soldered direct to the circuit wires, but supported independently of them.

28. Flexible Cord —

a. Must have an *approved* insulation and covering (see No. 45).

b. Must not be used where the difference of potential between the two wires is over 300 volts.

c. Must not be used as a support for clusters.

d. Must not be used except for pendants, wiring of fixtures, and portable lamps or motors.

e. Must not be used in show windows.

f. Must be protected by insulating bushings where the cord enters the socket.

g. Must be so suspended that the entire weight of the socket and lamp will be born by knots under the bushing in the socket, and above the point where the cord comes through the ceiling-block or rosette, in order that the strain may be taken from the joints and binding screws.

29. Arc Lights on Low-Potential Circuits —

a. Must have a cutout (see No. 17*a*) for each lamp of each series of lamps.

The branch conductors should have a carrying capacity about fifty per cent in excess of the normal current required by the lamp to provide for heavy current required when lamp is started or when carbons become stuck without overfusing the wires.

b. Must only be furnished with such resistances or regulators as are inclosed in non-combustible material, such resistances being treated as sources of heat. Incandescent lamps must not be used for resistance devices.

c. Must be supplied with globes and protected by spark arresters and wire netting around globe, as in the case of arc lights on high-potential circuits (see Nos. 19 and 58).

30. Economy Coils.

a. Economy and compensator coils for arc lamps must be mounted on non-conbustible, non-absorptive insulating supports, such as glass or porcelain, allowing an air space of at least one inch between frame and support, and in general to be treated like sources of heat.

31. Decorative Series Lamps.

a. Incandescent lamps run in series shall not be used for decorative purposes inside of buildings, except by special permission in writing from the Inspection Department having jurisdiction.

32. Car-Wiring—

a. Must be always run out of reach of the passengers, and must have an *approved* rubber-insulating covering (see No. 41).

33. Car-Houses—

a. Must have the trolley wires securely supported on insulating hangers.

b. Must have the trolley hangers placed at such distance apart that, in case of a break in the trolley wire, contact cannot be made with the floor.

c. Must have cutout switch located at a proper place outside of the building, so that all trolley circuits in the building can be cut out at one point, and line circuit-breakers must be installed, so that when this cutout switch is open the trolley wire will be dead at all points within 100 feet of the building. The current must be cut out of the building whenever the same is not in use or the road not in operation.

d. Must have all lamps and stationary motors installed in such a way that one main switch can control the whole of each installation — lighting or power — independently of main feeder-switch. No portable incandescent lamps or twin wire allowed, except that portable incandescent lamps may be used in the pits, connections to be made by two *approved* rubber-covered flexible wires (see No. 41), properly protected against mechanical injury; the circuit to be controlled by a switch placed outside of the pit.

e. Must have all wiring and apparatus installed in accordance with rules under Class "C" for constant potential systems.

f. Must not have any system of feeder distribution centering in the building.

g. Must have the rails bonded at each joint with no less than No. 2 B. & S. annealed copper wire, also a supplementary wire to be run for each track.

h. Must not have cars left with trolley in electrical connection with the trolley wire.

34. Lighting and Power from Railway Wires—

a. Must not be permitted, under any pretense, in the same circuit with trolley wires with a ground return, except in electric railway cars, electric car houses and their power stations; nor shall the same dynamo be used for both purposes.

HIGH-POTENTIAL SYSTEMS.

550 TO 3,500 VOLTS.

Any circuit attached to any machine, or combination of machines, which develops a difference of potential, between any two wires, of over 300 volts and less than 3,500 volts, shall be considered as a high-potential circuit, and as coming under that class, unless an approved transforming device is used, which cuts the difference of potential down to 300 volts or less.

35. Wires—

(*See also Nos. 14, 15, and 16.*)

a. Must have an *approved* rubber-insulating covering (see No. 41).

b. Must be always in plain sight and never incased, except where required by the Inspection Department having jurisdiction *c.* Must be rigidly supported on glass or porcelain insulators, which raise the wire at least one inch from the surface wired over, and must be kept apart at least four inches for voltages up to 750 and at least eight inches for voltages over 750.

Rigid supporting requires under ordinary conditions, where wiring along flat surfaces, supports at least about every four and one-half feet. If the wires are unusually liable to be disturbed, the distance between supports should be shortened.

In buildings of mill construction, mains of No. 8 B. & S. wire or over, where not liable to be disturbed, may be separated about six inches for voltages up to 750 and about ten inches for voltages above 750; and run from timber to timber, not breaking around, and may be supported at each timber only.

d. Must be protected on side walls from mechanical injury by a substantial boxing, retaining an air space of one inch around the conductors, closed at the top (the wires passing through bushed holes) and extending not less than seven feet from the floor. When crossing floor-timbers, in cellars or in rooms, where they might be exposed to injury, wires must be attached by their insulating supports to the under side of a wooden strip not less than one-half an inch in thickness.

36. Transformers (when permitted inside buildings, see No. 13)—

(*For construction rules, see No. 62.*)

a. Must be located at a point as near as possible to that at which the primary wires enter the building.

b. Must be placed in an inclosure constructed of or lined with fire-resisting material: the inclosure to be used only for this purpose, and to be kept securely locked, and access to the same allowed only to responsible persons.

c. Must be effectually insulated from the ground, and the inclosure in which they are placed must be practically air-tight, except that it shall be thoroughly ventilated to the outdoor air, if possible, through a chimney or flue. There should be at least six inches air space on all sides of the transformer.

37. Series Lamps.

a. No system of multiple-series or series-multiple for light or power will be approved.

b. Under no circumstances can lamps be attached to gas fixtures.

EXTRA HIGH POTENTIAL SYSTEMS.

OVER 3,500 VOLTS.

Any circuit attached to any machine or combination of machines, which develops a difference of potential, between any two wires, of over 3,500 volts, shall be considered as an extra high-potential circuit, and as coming under that class, unless an approved transforming device is used, which cuts the difference of potential down to 3,500 volts or less.

38. Primary Wires—

a. Must not be brought into or over building, except power and sub-stations.

39. Secondary Wires—

a. Must be installed under rules for high-potential systems, when their immediate primary wires carry a current of over 3,500 volts, unless the primary wires are entirely underground, within city and village limits.

The presence of wires carrying a current with a potential of over 3,500 volts in the streets of cities, towns, and villages is considered to increase the fire hazard. Extra high potential circuits are also objectionable in any location where telephone, telegraph, and similar circuits run in proximity to them. As the underwriters have no jurisdiction over streets and roads they can only take this indirect way of discouraging such systems; but further, it is strongly urged that municipal authorities absolutely refuse to grant any franchise for right of way for overhead wires carrying a current of extra high potential through streets or roads which are used to any great extent for public travel or for trunk-line, telephone, or telegraph circuits.

CLASS D. FITTINGS, MATERIALS, AND DETAILS OF CONSTUCTION.

ALL SYSTEMS AND VOLTAGES. INSULATED WIRES — RULES 40 to 48.

40. General Rules.

a. Copper for insulated conductors must never vary in diameter so as to be more than two one-thousandths of an inch less than the specified size.

b. Wires and cables of all kinds designed to meet the following specifications must be plainly tagged or marked as follows:

1. The maximum voltage at which the wire is designed to be used.
2. The words "National Electrical Code Standard."
3. Name of the manufacturing company, and, if desired, trade-name of the wire.
4. Month and year when manufactured.

41. Rubber-Covered.

a. Copper for conductors must be thoroughly tinned.

Insulation for voltages between 0 and 600.

b. Must be of rubber or other approved substance, and be of a thickness not less than that given in the following table for B. & S. gauge sizes:

From	18 to	16,	inclusive,	$\frac{1}{32}''$
"	14 to	8,	"	$\frac{3}{64}''$
"	7 to	2,	"	$\frac{1}{16}''$
"	1 to	0000,	"	$\frac{5}{64}''$
"	0000 to	500,000,	C. M.	$\frac{3}{32}''$
"	500,000 to	1,000,000,	"	$\frac{7}{64}''$
Larger than		1,000,000,	"	$\frac{1}{8}''$

Measurements of insulating wall are to be made at the thinnest portion of the dielectric.

c. The completed coverings must show an insulation resistance of at least 100 megohms per mile during thirty days' immersion in water at seventy degrees Fahrenheit.

d. Each foot of the completed covering must show a dieletric strength sufficient to resist throughout five minutes the application of an electromotive force of 3,000 volts per one-sixty-fourth of an inch thickness of insulation under the following conditions:

The source of alternating electro-motive force shall be a transformer of at least one kilowatt capacity. The application of the electro-motive force shall first be made at 4,000 volts for five minutes, and then the voltage increased by steps of not over 3,000 volts, each held for five minutes, until the rupture of the insulation occurs. The tests for dielectric strength shall be made on a sample of wire which has been immersed for seventy-two hours in water, one foot of which is submerged in a conducting liquid held in a metal trough, one of the transformer terminals being connected to the wire and the other to the metal of the trough.

Insulations for voltages between 600 and 3,500:

e. The thickness of the insulating walls must not be less than those given in the following table for B. & S. gauge sizes:

From 14 to 1, inclusive, $\frac{3}{32}''$

From 0 to 500,000, C. M., $\frac{3}{32}''$ covered by a tape or a braid.

Larger than 500,000, C. M., $\frac{4}{32}''$ covered by a tape or a braid

f. The requirements as to insulation and break-down resistance for wires for low potential systems shall apply, with the exception that an insulation resistance of not less than 300 megohms per mile shall be required.

g. Wire for arc-light circuits exceeding 3,500 volts potential shall have an insulating wall not less than six-thirty-seconds of an inch in thickness, and shall withstand a break-down test of at least 30,000 volts, and have an insulation of at least 500 megohms per mile.

The tests on this wire to be made under the same conditions as for low-potential wires.

Specifications for insulations for alternating currents exceeding 3,500 volts have been considered, but on account of the somewhat complex conditions in such work it has so far been deemed inexpedient to specify general insulations for this use.

h. All of the above insulations must be protected by a substantial braided covering properly saturated with a preservative compound and sufficiently strong to withstand all the abrasion likely to be met with in practice, and sufficiently elastic to permit all wires smaller than No. 7 B. & S. gauge to be bent around a cylinder with twice the diameter of the wire, without injury to the braid.

42. Slow-burning Weatherproof.

a. The insulation shall consist of two coatings, the inner one to be fireproof in character, the outer to be weatherproof. The inner fireproof coating must comprise at least six-tenths of the total thickness of the wall. The completed covering must be of a thickness not less than that given in the following table for B. & S. gauge sizes:

From	14 to	8, inclusive,	$\frac{3}{64}''$
"	7 to	2,	$\frac{1}{16}''$
"	2 to	0000,	$\frac{5}{64}''$
"	0000 to	500,000, C. M.,	$\frac{3}{32}''$
"	500,000 to	1,000,000, "	$\frac{7}{64}''$
Larger than		1,000,000, "	$\frac{1}{8}''$

Measurements of insulating wall are to be made at the thinnest portion of the dielectric.

b. The inner fireproof coating shall be layers of cotton or other thread, the outer one of which must be braided. All the interstices of these layers are to be filled with the fireproofing compound. This is to be material whose solid constituent is not susceptible to moisture, and which will not burn even when ground in an oxidizable oil, making a compound which, while proof against fire and moisture, at same time has considerable elasticity, and which when dry will suffer no change at a temperature of 250 degrees Fahrenheit, and which will not burn at even higher temperature.

c. The weatherproof coating shall be a stout braid thoroughly saturated with a dense moistureproof compound thoroughly slicked down, applied in such manner as to drive any atmospheric moisture from the cotton braiding, thereby securing a covering to a greater degree waterproof and of high insulating power. This compound to retain its elasticity at zero Fahrenheit, and not to drip at 160 degrees Fahrenheit.

This wire is not as burnable as the old "weatherproof," nor as subject to softening under heat, but still is able to repel the ordinary amount of moisture found indoors. It would not usually be used for outside work.

43. Slow-burning.

a. The insulation shall be the same as the "slow-burning weatherproof," except that the outer braiding shall be impregnated with a fireproofing compound similar to that required for the interior layers, and with the outer surface finished smooth and hard.

This "slow-burning" wire shall only be used with special permission of the Inspection Department having jurisdiction.

This is practically the old "Underwriters'" insulation. It is specially useful in hot, dry places where ordinary insulations would perish, also where wires are bunched, as on the back of a large switchboard or in a wire tower so that the accumulation of rubber or weatherproof insulation would result in an objectionably large mass of highly inflammable material.

Its use is restricted, as its insulating qualities are not high and are damaged by moisture.

44. Weatherproof.

a. The insulating covering shall consist of at least three braids thoroughly impregnated with a dense moisture repellent, which will not drip at a temperature lower than 180 degrees Fahrenheit. The thickness of insulation shall be not less than that of "slow-burning weatherproof." The outer surface shall be thoroughly slicked down."

This wire is for outdoor use where moisture is certain and where fireproof qualities are not necessary.

45. Flexible Cord —

a. Must be made of stranded copper conductors, each strand to be not larger than No. 26 or smaller than No. 30 B. & S. gauge, and each stranded conductor must be covered by an approved insulation and protected from mechanical injury by a tough braided outer covering.

For pendent lamps:

In this class is to be included all flexible cord which under usual conditions hangs freely in air, and which is not likely to be moved sufficiently to come in contact with surrounding objects.

b. Each stranded conductor must have a carrying capacity equivalent to not less than a No. 18 B. & S. gauge wire.

c. The covering of each stranded conductor must be made up as follows:

1. A tight, close wind of fine cotton.
2. The insulation proper, which shall be either waterproof or slow-burning.
3. An outer cover of silk or cotton.

The wind of cotton tends to prevent a broken strand puncturing the insulation and causing a short circuit. It also keeps the rubber from corroding the copper.

d. Waterproof insulation must be solid, at least one-thirty-second of an inch thick, and must show an insulation resistance of fifty megohms per mile throughout two weeks' immersion in water at 70 degrees Fahrenheit, and stand the test prescribed for low-tension wires as far as they apply.

e. Slow-burning insulation must be at least one-thirty-second of an inch in thickness, and composed of substantial, elastic, slow-burning materials, which will suffer no damage at a temperature of 250 degrees Fahrenheit.

f. The outer protecting braiding should be so put on and sealed in place that when cut it will not fray out, and where cotton is used, it should be impregnated with a flameproof paint, which will not have an injurious effect on the insulation.

For portables:

In this class is included all cord used on portable lamps, small portable motors, etc.

g. Flexible cord for portable use must have waterproof insulation as required in section *d* for pendent cord, and in addition be provided with a reinforcing cover especially designed to withstand the abrasion it will be subject to in the uses to which it is to be put.

For portable heating apparatus:

h. Must be made up as follows: —

1. A tight, close wind of fine cotton.
2. A thin layer of rubber about one-one-hundredth of an inch thick, or other cementing material.
3. A layer of asbestos insulation at least three-sixty-fourths of an inch thick.
4. A stout braid of cotton.
5. An outer reinforcing cover especially designed to withstand abrasion.

This cord is in no sense waterproof, the thin layer of rubber being specified in order that it may serve merely as a seal to help hold in place the fine cotton and asbestos, and it should be so put on as to accomplish this.

46. Fixture Wire —

a. Must have a solid insulation, with a slow-burning, tough, outer covering, the whole to be at one-thirty-second of an inch in thickness, and show an insulation resistance between conductors, and between either conductor and the ground, of at least one megohm per mile, after one week's submersion in water at seventy degrees Fahrenheit, and after three minutes' electrification with 550 volts.

47. Conduit Wire —

Must comply with the following specifications:

a. For metal conduits, having a lining of insulating material, single wires must comply with No. 41, and all duplex, twin, and concentric conductors must comply with No. 41, and must also have each conductor separately braided or taped and a substantial braid covering the whole.

b. For unlined metal conduits, conductors must conform to the specifications given for lined conduits, and in addition have a second outer fibrous covering at least one-thirty-second of an inch in thickness, and sufficiently tenacious to withstand the abrasion of being hauled through the metal conduit.

The braid required around each conductor in duplex, twin, and concentric cables is to hold the rubber insulation in place and prevent jamming and flattening.

48. Armored Cable.

a. The armor of such cables must be at least equal in thickness and of equal strength to resist penetration by nails, etc., as the armor of metal covering of metal conduits (see No. 49 *b*).

b. The conductors in same, single wire or twin conductors, must have an insulating covering as required by No. 41, any filler used to secure a round exterior must be impregnated with a moisture repellent, and the whole bunch of conductors and fillers must have a separate exterior covering of insulating material at least one-thirty-second of an inch in thickness, conforming to the insulation standard given in No. 41, and covered with a substantial braid.

Very reliable insulation is specified, as such cables are liable to hard usage, and in part of their length may be subject to moisture, while they may not be easily removable, so that a breakdown of insulation is likely to be expensive.

49. Interior Conduits.

(*For wiring rules, see Nos. 24 and 25.*)

a. Each length of conduit, whether insulated or uninsulated, must have the maker's name or initials stamped in the metal or attached thereto in a satisfactory manner, so that the inspectors can readily see the same.

METAL CONDUITS WITH LINING OF INSULATING MATERIAL.

b. The metal covering or pipe must be equal in strength to the ordinary commercial forms of gas-pipe of the same size, and its thickness must be not less than that of standard gas-pipe, as shown by the following table :

Size. Inches.	Thickness of Wall — Inches.	Size. Inches.	Thickness of Wall — Inches.
$\frac{1}{2}$	.109	$1\frac{1}{4}$	.140
$\frac{5}{8}$	.111	$1\frac{1}{2}$	.145
$\frac{3}{4}$	.113	2	.154
1	.134		

An allowance of two one-hundredths of an inch for variation in manufacturing and loss of thickness by cleaning will be permitted.

c. Must not be seriously affected externally by burning out a wire inside the tube when the iron pipe is connected to one side of the circuit.

d. Must have the insulating lining firmly secured to the pipe.

e. The insulating lining must not crack or break when a length of the conduit is uniformly bent at temperature of 212 degrees Fahrenheit to an angle of ninety degrees, with a curve having a radius of fifteen inches, for pipes of one inch and less, and fifteen times the diameter of pipe for larger pipes.

f. The insulating lining must not soften injuriously at a temperature below 212 degrees Fahrenheit, and must leave water in which it is boiled practically neutral.

g. The insulating lining must be at least one-thirty-second of an inch in thickness ; and the materials of which it is composed must be of such a nature as will not have a deteriorating effect on the insulation of the conductor, and be sufficiently tough and tenacious to withstand the abrasion test of drawing long lengths of conductors in and out of same.

h. The insulating lining must not be mechanically weak after three days' submersion in water, and when removed from the pipe entire must not absorb more than ten per cent of its weight of water during 100 hours of submersion.

i. All elbows or bends must be so made that the conduit or lining of same will not be injured. The radius of the curve of the inner edge of any elbow not to be less than three and one-half inches. Must have not more than the equivalent of four quarter bends from outlet to outlet, the bends at the outlets not being counted.

UNLINED METAL CONDUITS.

j. Plain iron or steel pipes of equal thickness and strengths specified for lined conduits in No. 49 *b* may be used as conduits, provided their interior surfaces are smooth and free from burs; pipe to be galvanized, or the interior surfaces coated or enameled, to prevent oxidation, with some substance which will not soften so as to become sticky and prevent wire from being withdrawn from the pipe.

k. All elbows or bends must be so made that the conduit will not be injured. The radius of the curve of the inner edge of any elbow not to be less than three and one-half inches. Must have not more than the equivalent of four quarter bends from outlet to outlet, the bends at the outlet not being counted.

50. Wooden Moldings —

(*For wiring rules, see No. 24.*)

a. Must have, both outside and inside, at least two coats of waterproof paint, or be impregnated with a moisture repellent.

b. Must be made of two pieces, a backing and capping, so constructed as to thoroughly incase the wire, and provide a one-half inch tongue between the conductors, and a solid backing, which, under grooves, shall not be less than three-eighths of an inch in thickness, and must afford suitable protection from abrasion.

It is recommended that only hardwood molding be used.

51. Switches —

(*See Nos. 17 and 22.*)

a. Must be mounted on non-combustible, non-absorptive, insulating bases, such as slate or porcelain.

b. Must have carrying capacity sufficient to prevent undue heating,

c. Must, when used for service switches, indicate, on inspection, whether the current be "on" or "off."

d. Must be plainly marked, where it will always be visible, with the name of the maker and the current and voltage for which the switch is designed.

e. Must, for constant potential systems, operate successfully at fifty per cent overload in amperes, with twenty-five per cent excess voltage under the most severe conditions they are liable to meet with in practice.

f. Must, for constant potential systems, have a firm and secure contact; must make and break readily, and not stop when motion has once been imparted by the handle.

g. Must, for constant current systems, close the main circuit and disconnect the branch wires when turned "off"; must be so constructed that they shall be automatic in action, not stopping between points when started, and must prevent an arc between the points under all circumstances. They must indicate, upon inspection, whether the currents be "on" or "off."

52. Cutouts and Circuit-Breakers —

(*For installation rules, see Nos. 17 and 21.*)

a. Must be supported on bases of non-combustible, non-absorptive insulating material.

b. Cutouts must be provided with covers, when not arranged in approved cabinets, so as to obviate any danger of the melted fuse metal coming in contact with any substance which might be ignited thereby.

c. Cutouts must operate successfully, under the most severe conditions they are liable to meet with in practice, on short circuits with fuses rated at fifty per cent above, and with a voltage twenty-five per cent above the current and voltage for which they are designed.

d. Circuit-breakers must operate successfully, under the most severe conditions they are liable to meet with in practice, on short circuits when set at fifty per cent above the current, and with a voltage twenty-five per cent above that for which they are designed.

e. Must be plainly marked, where it will always be visible, with the name of the maker, and current and voltage for which the device is designed.

53. Fuses —

(*For installation rules, see Nos. 17 and 21.*)

a. Must have contact surfaces or tips of harder metal having perfect electrical connection with the fusible part of the strip.

b. Must be stamped with about eighty per cent of the maximum current they can carry indefinitely, thus allowing about twenty-five per cent overload before fuse melts.

With naked open fuses, of ordinary shapes and not over 500 amperes capacity, the *maximum* current which will melt them in about five minutes may be safely taken as the melting point, as the fuse practically reaches its maximum temperature in this time. With larger fuses a longer time is necessary.

Inclosed fuses where the fuse is often in contact with substances having good conductivity to heat and often of considerable volume, require a much longer time to reach a maximum temperature, on account of the surrounding material which heats up slowly.

These data are given to facilitate testing.

c. Fuse terminals must be stamped with the maker's name, initials, or some known trade-mark.

54. Cutout Cabinets —

a. Must be so constructed, and cutouts so arranged, as to obviate any danger of the melted fuse metal coming in contact with any substance which might be ignited thereby.

A suitable box can be made of marble, slate, or wood, strongly put together, the door to close against a rabbet so as to be perfectly dust-tight; and it should be hung on strong hinges, and held closed by a strong hook or catch. If the box is wood, the inside should be lined with sheets of asbestos board about one-sixteenth of an inch in thickness, neatly put on, and firmly secured in place by shellac and tacks. The wire should enter through holes bushed with porcelain bushings; the bushings tightly fitting the holes in the box, and the wires tightly fitting the bushings (using tape to build up the wire, if necessary) so as to keep out the dust.

55. Sockets.

(*See No.* 27.)

Sockets of all kinds, including wall receptacles, must be constructed in accordance with the following specifications: —

a. STANDARD SIZES. — The standard lamp socket shall be suitable for use on any voltage not exceeding 250 and with any size lamp up to fifty candle-power. For lamps larger than fifty candle-power a standard keyless socket may be used; or if a key is required, a special socket designed for the current to be used must be made. Any special sockets must follow the general spirit of these specifications.

b. MARKING. — The standard socket must be plainly marked fifty candle-power, 250 volts, and with either the manufacturer's name or registered trademark. Special large sockets must be marked with the current and voltage for which they are designed.

c. SHELL. — Metal used for shells must be moderately hard, but not hard enough to be brittle or so soft as to be easily dented or knocked out of place. Brass shells must be at least 0.013 inch in thickness, and shells of any other material must be thick enough to give the same stiffness and strength as brass.

d. LINING. — The inside of the shells must be lined with insulating material, which shall absolutely prevent the shell from becoming a part of the circuit, even though the wires inside the socket should start from their position under binding screws.

The material used for lining must be at least one thirty-second of an inch in thickness, and must be tough and tenacious. It must not be injuriously affected by the heat from the largest lamp permitted in the socket, and must leave the water in which it is boiled practically neutral. It must be so firmly secured to the shell that it will not fall out with ordinary handling of the socket. It is preferable to have the lining in one piece.

e. CAP. — Caps when of sheet brass must be at least 0.013 inch in thickness, and when cast or made of other metals must be of equivalent strength. The inlet piece, except for special sockets, must be tapped and threaded for ordinary one-eighth-inch pipe. It must contain sufficient metal for a full strong thread, and, when not of the same piece as the cap, must be joined to it in a way to give the strength of a single piece.

There must be sufficient room in the cap to enable the ordinary wireman to easily and quickly make a knot in the cord, and push it into place in cap without crowding. All parts of the cap upon which the knot is likely to bear must be smooth and well insulated.

f. FRAME AND SCREWS. — The frame holding moving parts must be sufficiently heavy to give ample strength and stiffness.

Brass pieces containing screw threads must be at least 0.06 of an inch in thickness.

Binding-post screws must not be smaller than No. 5 wire and about forty threads per inch.

g. SPACING. — Points of opposite polarity must everywhere be kept not less than three sixty-fourths of an inch apart unless separated by a reliable insulation.

h. CONNECTIONS. — The connecting points for the flexible cord must be made to very securely grip a No. 16 or 18 B. & S. conductor. A turned-up lug, arranged so that the cord may be gripped between the screw and the lug in such a way that it cannot possibly come out, is strongly advised.

i. LAMP-HOLDER. — The socket must firmly hold the lamp in place so that it cannot be easily jarred out, and must provide a contact good enough to prevent undue heating with maximum current allowed. The holding-pieces, springs and the like, if a part of the circuit, must not be sufficiently exposed to allow them to be brought in contact with anything outside of lamp and socket.

j. BASE. — The inside parts of the socket, which are of insulating material, except the lining, must be made of porcelain.

k. KEY. — The socket key-handle must be of such a material that it will not soften from the heat of a fifty candle-power lamp hanging downwards in air at seventy degrees Fahrenheit from the socket, and must be securely, but not necessarily rigidly, attached to the metal spindle it is designed to turn.

l. SEALING. — All screws in porcelain pieces, which can be firmly sealed in place, must be so sealed by a waterproof compound which will not melt below 200 degrees Fahrenheit.

m. PUTTING TOGETHER. — The socket must, as a whole, be so put together that it will not rattle to pieces. Bayonet joints or equivalent are recommended.

n. TEST. — The socket when slowly turned "on and off," at the rate of about two or three times per minute, must "make and break" the circuit 6,000 times before failing, when carrying a load of one ampere at 220 volts.

o. KEYLESS SOCKETS. — Keyless sockets of all kinds must comply with requirements for key sockets as far as they apply.

p. SOCKETS OF INSULATING MATERIALS. — Sockets made of porcelain or other insulating material must conform to the above requirements as far as they apply, and all parts must be strong enough to withstand a moderate amount of hard usage without breaking.

q. INLET BUSHING. — When the socket is not attached to fixtures the threaded inlet must be provided with a strong insulating bushing, having a *smooth* hole of at least fifteen sixty-fourths of an inch in diameter. The corners of the bushing must be rounded, and all inside fins removed, so that in no place will the cord be subjected to the cutting or wearing action of a sharp edge.

56. Hanger-boards.

a. Hanger-boards must be so constructed that all wires and current-carrying devices thereon shall be exposed to view, and thoroughly insulated by being mounted on a non-combustible, non-absorptive insulating substance. All switches attached to the same must be so constructed that they shall be automatic in their action, cutting off both poles to the lamp, not stopping between points when started, and preventing an arc between points under all circumstances.

57. Arc Lamps.

(*For installation rules, see No. 19.*)

a. Must be provided with reliable stops to prevent carbons from falling out in case the clamps become loose.

b. Must be carefully insulated from the circuit in all their exposed parts.

c. Must, for constant-current systems, be provided with an *approved* hand switch, also an automatic switch that will shunt the current around the carbons, should they fail to feed properly.

The hand switch to be approved, if placed anywhere except on the lamp itself, must comply with requirements for switches on hanger-boards as laid down in No. 56.

58. Spark Arresters.

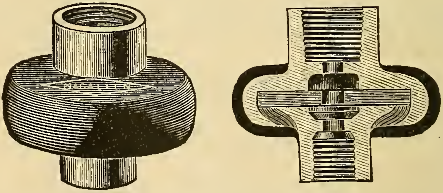
(*See No. 19 c.*)

a. Spark arresters must so close the upper orifice of the globe that it will be impossible for any sparks thrown off by the carbons to escape.

59. Insulating Joints –

(*See No. 26 a.*)

a. Must be entirely made of material that will resist the action of illuminating gases, and will not give way or soften under the heat of an ordinary gas-flame, or leak under a moderate pressure. They shall be so arranged that a deposit of moisture will not destroy the insulating effect, and shall have an insulating resistance of at least 250,000 ohms between the gas-pipe attachments, and be sufficiently strong to resist the strain they will be liable to be subjected to in being installed.



Insulating Joint for Gas Pipes.

b. Insulating joints having soft rubber in their construction will not be approved.

60. Resistance Boxes and Equalizers—

(*For installation rules, see No. 4.*)

a. Must be equipped with metal or with other non-combustible frames.

The word "frame" in this section relates to the entire case and surroundings of the rheostat, and not alone to the upholding supports.

61. Reactive Coils and Condensers.

a. Reactive coils must be made of non-combustible material, mounted on non-combustible bases, and treated, in general, like sources of heat.

b. Condensers must be treated like apparatus operating with equivalent voltage and currents. They must have non-combustible cases and supports, and must be isolated from all combustible materials, and, in general, treated like sources of heat.

62. Transformers —

(*For installation rules, see Nos. 11, 13, and 33.*)

a. Must not be placed in any but metallic or other non-combustible cases.

b. Must be constructed to comply with the following tests:

1. Shall be run for eight consecutive hours at a full load in watts under conditions of service, and at the end of that time the rise in temperature, as measured by the increase of resistance of the primary coil, shall not exceed 135 degrees Fahrenheit.
2. The insulation of transformers when heated shall withstand continuously for five minutes a difference of potential of 10,000 volts (alternating) between primary and secondary coils and core, and between the primary coils and core and a no-load "run" at double voltage for thirty minutes.

63. Lightning Arresters.

(*For installation rules, see No. 5.*)

a. Must be mounted on non-combustible bases, and must be so constructed as not to maintain an arc after the discharge has passed, and must have no moving parts.

CLASS E. — MISCELLANEOUS.

64. Signaling Systems (governing wiring for telephone, telegraph, district messenger, and call-bell circuits, fire and burglar alarms, and all similar systems) —

a. Outside wires should be run in underground ducts or strung on poles and, as far as possible, kept off of buildings, and must not be placed on the same cross-arm with electric light or power wires.

b. When outside wires are run on same pole with electric light or power wires, the distance between the two inside pins of each cross-arm must not be less than twenty-six inches.

c. All aerial conductors and underground conductors which are directly connected to aerial wires must be provided with some approved protective device, which shall be located as near their point of entrance to the building as possible, and not less than six inches from curtains or other inflammable material.

d. If the protector is placed inside of building, wires, from outside supports to binding-posts of protector, shall comply with the following requirements:

1. Must be of copper, and not smaller than No. 16 B. & S. gauge.
2. Must have an *approved* rubber insulating covering (see No. 41).
3. Must have drip loops in each wire immediately outside the building.
4. Must enter buildings through separate holes sloping upward from the outside; when practicable, holes to be bushed with non-absorptive, non-combustible insulating tubes extending through their entire length. Where tubing is not practicable, the wires shall be wrapped with two layers of insulating tape.
5. Must be supported on porcelain insulators, so that they will not come in contact with anything other than their designed supports.
6. A separation between wires of at least two and one-half inches must be maintained.

In case of crosses these wires may become a part of a high-voltage circuit, so that similar care to that given high-voltage circuits is needed in placing them. Reliable porcelain bushings at the entrance holes are desirable, and are only waved under adverse conditions, because the state of the art in this type of wiring makes an absolute requirement inadvisable.

e. The ground wire of the protective device shall be run in accordance with the following requirements :

1. Shall be of copper, and not smaller than No. 16 B. & S.
2. Must have an *approved* rubber insulating covering (See No. 41).
3. Shall run in as straight a line as possible to a good permanent ground, to be made by connecting to water- or gas-pipe, preferably water-pipe. If gas-pipe is used, the connection, in all cases, must be made between the meter and service pipes. In the absence of other good ground, the ground shall be made by means of a metallic plate or bunch of wires buried in permanently moist earth.
4. Shall be kept at least three inches from all other conductors, and supported on porcelain insulators so as not to come in contact with anything other than its designated supports.

In attaching a ground wire to a pipe, it is often difficult to make a thoroughly reliable solder joint. It is better, therefore, where possible, to carefully solder the wire to a brass plug, which may then be firmly screwed into a pipe fitting.

Where such joints are made under ground, they should be thoroughly painted and taped to prevent corrosion.

f. The protector to be approved must comply with the following requirements :

1. Must be mounted on non-combustible, non-absorptive insulating bases, so designed that when the protector is in place, all parts which may be alive will be thoroughly insulated from the wall holding the protector.
2. Must have the following parts :

   A lightning arrester which will operate with a difference of potential between wires of not over 500 volts, and so arranged that the chance of accidental grounding is reduced to a minimum.

   A fuse designed to open the circuit in case the wires become crossed with light or power circuits. The fuse must be able to open the circuit without arcing or serious flashing when crossed with any ordinary commercial light or power circuit.

   A heat coil which will operate before a sneak current can damage the instrument the protector is guarding.

   The heat coil is designed to warm up and melt out with a current large enough to endanger the instruments if continued for a long time, but so small that it would not blow the fuses ordinarily found necessary for such instruments. These smaller currents are often called " sneak " currents.
3. The fuses must be so placed as to protect the arrester and heat coils, and the protector terminals must be plainly marked " line," " instrument," " ground."

g. Wires beyond the protector, except where bunched, must be neatly arranged and securely fastened in place in any convenient, workmanlike manner. They must not come nearer than six inches to any electric light or power wire in the building, unless incased in approved tubing so secured as to prevent its slipping out of place.

The wires would ordinarily be insulated, but the kind of insulation is not specified, as the protector is relied upon to stop all dangerous currents. Porcelain tubing or circular loom conduit may be used for incasing wires where required as above.

h. Wires connected with outside circuits, where bunched together within any building, or inside wires, where laid in conduits or ducts, with electric light or power wires, must have fire-resisting coverings, or else must be inclosed in an air-tight tube or duct.

It is feared that if a burnable insulation were used, a chance spark might ignite it and cause a serious fire, for many installations contain a large amount of very readily burnable matter.

65. Electric Gas Lighting.

Where electric gas lighting is to be used on the same fixture with the electric light :

a. No part of the gas-piping or fixture shall be in electric connection with the gas-lighting circuit.

b. The wires used with the fixtures must have a non-inflammable insulation, or, where concealed between the pipe and shell of the fixture, the insulation must be such as required for fixture wiring for the electric light.

c. The whole installation must test free from "grounds."

d. The two installations must test perfectly free from connection with each other.

66. Insulation Resistance.

The wiring in any building must test free from grounds; i. e., the complete installation must have an insulation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.) of not less than the following:

Up to	5 amperes	4,000,000 ohms.
"	10 "	2,000,000 "
"	25 "	800,000 "
"	50 "	400,000 "
"	100 "	200,000 "
"	200 "	100,000 "
"	400 "	25,000 "
"	800 "	25,000 "
"	1,600 "	12,500 "

All cutouts and safety devices in place in the above.

Where lamp sockets, receptacles, and electroliers, etc., are connected, one-half of the above will be required.

67. Soldering Fluid.

a. The following formula for soldering fluid is suggested:

Saturated solution of zinc chloride	5 parts
Alcohol	4 parts
Glycerine	1 part

CLASS F. — MARINE WORK.

68. Generators —

a. Must be located in a dry place.

b. Must have their frames insulated from their bed-plates.

c. Must each be provided with a waterproof cover.

d. Must each be provided with a name-plate, giving the maker's name, the capacity in voltage and amperes and normal speed in revolutions per minute —

69. Wires —

a. Must have an *approved* insulating covering.

The insulation for all conductors, except for portables, to be approved, must be at least one-eighth-inch in thickness and be covered with a substantial waterproof and flameproof braid. The physical characteristics shall not be affected by any change in temperature up to 200 degrees Fahrenheit. After two weeks' submersion in salt water at seventy degrees Fahrenheit it must show an insulation resistance of one megohm per mile after three minutes' electrification, with 550 volts.

b. Must have no single wire larger than No. 12 B. & S. Wires to be stranded when greater carrying capacity is required. No single solid wire smaller than No. 14 B. & S., except in fixture wiring, to be used.

Stranded wires must be soldered before being fastened under clamps or binding screws, and when they have a conductivity greater than No. 10 B. & S. copper wire they must be soldered into lugs.

c. Must be supported in approved molding, except at switchboards and portables.

Special permission may be given for deviation from this rule in dynamo-rooms.

d. Must be bushed with hard-rubber tubing one-eighth of an inch in thickness when passing through beams and non-water-tight bulkheads.

e. Must have, when passing through water-tight bulkheads and through all decks, a metallic stuffing-tube lined with hard rubber. In case of deck tubes they shall be boxed near deck to prevent mechanical injury.

f. Splices or taps in conductors must be avoided as far as possible. Where it is necessary to make them they must be so spliced or joined as to be both mechanically and electrically secure without solder. They must then be soldered, to insure preservation, covered with an insulating compound equal to the insulation of the wire, and further protected by a waterproof tape. The joint must then be coated or painted with a waterproof compound.

70. Portable Conductors—

a. Must be made of two stranded conductors, each having a carrying capacity equivalent to not less than No. 14 B. & S. wire, and each covered with an approved insulation and covering.

Where not exposed to moisture or severe mechanical injury, each stranded conductor must have a solid insulation at least one-thirty-second of an inch in thickness, and must show an insulation resistance between conductors, and between either conductor and the ground, of at least one megohm per mile after one week's submersion in water at seventy degrees Fahrenheit and after three minutes' electrification, with 590 volts, and be protected by a slow-burning, tough-braided outer covering.

Where exposed to moisture and mechanical injury—as for use on decks, holds, and fire-rooms—each stranded conductor shall have a solid insulation to be approved, of at least one-thirty-second of an inch in thickness and protected by a tough braid. The two conductors shall then be stranded together, using a jute filling. The whole shall then be covered with a layer of flax, either woven or braided, at least one-thirty-second of an inch in thickness, and treated with a non-inflammable waterproof compound. After one week's submersion in water at seventy degrees Fahrenheit, at 550 volts and a three minutes' electrification, must show an insulation between the two conductors, or between either conductor and the ground, of one megohm per mile.

71. Bell or Other Wires—

a. Shall never run in same duct with lightning or power wires.

72. Table of Capacity of Wires.

B. & S. G.	Area Actual C. M.	No. of Strands.	Size of Strands B. & S. G.	Amperes.
19	1,288	..	..	..
18	1,624	..	..	3
17	2,048	..	..	..
16	2,583	..	..	6
15	3,257	..	..	..
14	4,107	..	..	12
12	6,530	..	..	17
..	9,016	7	19	21
..	11,368	7	18	25
..	14,336	7	17	30
..	18,081	7	16	35
..	22,799	7	15	40
..	30,856	19	18	50
..	38,912	19	17	60
..	49,077	19	16	70
..	60,088	37	18	85
..	75,776	37	17	100
..	99,064	61	18	120
..	124,928	61	17	145
..	157,563	61	16	170
..	198,677	61	15	200
..	250,527	61	14	235
..	296,387	91	15	270
..	373,737	91	14	320
..	413,639	127	15	340

When greater conducting area than that of a single wire is required, the conductor shall be stranded in a series of **7**, **19**, **37**, **61**, **91**, or **127**, wires as may be required; the strand consisting of one central wire, the remainder laid around it concentrically, each layer to be twisted in the opposite direction from the preceding

73. Switchboards —

a. Must be made of non-combustible, non-absorbtive insulating material, such as marble or slate.

b. Must be kept free from moisture, and must be located so as to be accessible from all sides.

c. Must have a main switch, main cutout, and ammeter for each generator.

Must also have a voltmeter and ground detector.

d. Must have a cutout and switch for each side of each circuit leading from board.

74. Resistance Boxes —

a. Must be made of non-combustible material.

b. Must be located on switchboard or away from combustible material. When not placed on switchboard they must be mounted on non-inflammable, non-absorptive insulating material.

c. Must be so constructed as to allow sufficient ventilation for the uses to which they are put.

75. Switches —

a. Must have non-combustible, non-absorptive insulating bases.

b. Must operate successfully at fifty per cent overload in amperes with twenty-five per cent excess voltage under the most severe conditions they are liable to meet with in practice, and must be plainly marked, where they will always be visible, with the name of the maker and the current and voltage for which the switch is designed.

c Must be double pole when circuits which they control supply more than six sixteen-candle-power lamps or their equivalent.

d. When exposed to dampness, they must be inclosed in a water-tight case.

76. Cutouts —

a. Must have non-combustible, non-absorptive insulating bases.

b. Must operate successfully, under the most severe conditions they are liable to meet with in practice, on short circuit with fuse rated at fifty per cent above, and with a voltage twenty-five per cent above the current and voltage they are designed for, and must be plainly marked, where they will always be visible, with the name of the maker and current and voltage for which the device is designed.

c. Must be placed at every point where a change is made in the size of the wire (unless the cutout in the larger wire will protect the smaller).

d. In places such as upper decks, holds, cargo spaces, and fire-rooms a water-tight and fireproof cutout may be used, connecting directly to mains when such cutout supplies circuits requiring not more than 660 watts energy.

e. When placed anywhere except on switchboards and certain places, as cargo spaces, holds, fire-rooms, etc., where it is impossible to run from center of distribution, they shall be in a cabinet lined with fire-resisting material.

f. Except for motors, searchlights, and diving-lamps shall be so placed that no group of lamps, requiring a current of more than six amperes, shall ultimately be dependent upon one cutout.

A single-pole covered cutout may be placed in the molding when same contains conductor supplying circuits requiring not more than 220 watts energy.

77. Fixtures —

a. Shall be mounted on blocks made from well-seasoned lumber treated with two coats of white lead or shellac.

b. Where exposed to dampness, the lamp must be surrounded by a vapor-proof globe.

c. Where exposed to mechanical injury the lamp must be surrounded by a globe protected by a stout wire guard.

d. Shall be wired with same grade of insulation as portable conductors which are not exposed to moisture or mechanical injury.

78. Sockets.

a. No portion of the lamp socket or lamp base exposed to contact with outside objects shall be allowed to come into electrical contact with either of the conductors.

79. Wooden Mouldings —

a. Must be made of well-seasoned lumber and be treated inside and out with at least two coats of white lead or shellac.

b. Must be made of two pieces, a backing and a capping, so constructed as to thoroughly incase the wire, and provide a one-half inch tongue between the conductors, and a solid backing which, under grooves, shall not be less than three-eighths of an inch in thickness.

c. Where molding is run over rivets, beams, etc., a backing strip must first be put up and the molding secured to this.

d. Capping must be secured by brass screws.

80. Motors —

a. Must be wired under the same precautions as with a current of same volume and potential for lighting. The motor and resistance box must be protected by a double-pole cutout, and controlled by a double-pole switch, except in cases where one-quarter horse-power or less is used.

The leads or branch circuits should be designed to carry a current at least fifty per cent greater than that required by the rated capacity of the motor to provide for the inevitable overloading of the motor at times.

b. Must be thoroughly insulated. Where possible, should be set on base frames made from filled, hard, dry, wood, and raised above surrounding deck. On hoists and winches they shall be insulated from bed-plates by hard rubber, fiber, or similar insulating material.

c. Shall be covered with a waterproof cover when not in use.

d. Must each be provided with a name-plate giving maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute.

GENERAL SUGGESTIONS.

In all electric work conductors, however well insulated, should always be treated as bare, to the end that under no conditions, existing or likely to exist, can a grounding or short circuit occur, and so that all leakage from conductor to conductor, or between conductor and ground, may be reduced to the minimum.

In all wiring special attention must be paid to the mechanical execution of the work. Careful and neat running, connecting, soldering, taping of conductors and securing and attaching of fittings, are specially conducive to security and efficiency, and will be strongly insisted on.

In laying out an installation, except for constant-current systems, the work should, if possible, be started from a center of distribution, and the switches and cutouts, controlling and connected with the several branches, be grouped together in a safe and easily accessible place, where they can be readily got at for attention or repairs. The load should be divided as evenly as possible among the branches, and all complicated and unnecessary wiring avoided.

The use of wire-ways for rendering concealed wiring permanently accessible is most heartily indorsed and recommended; and this method of accessible concealed construction is advised for general use.

Architects are urged, when drawing plans and specifications, to make provision for the channeling and pocketing of buildings for electric light or power wires, and in specifications for electric gas lighting to require a two-wire circuit, whether the building is to be wired for electric lighting or not, so that no part of the gas fixtures or gas-piping be allowed to be used for the gas-lighting circuit.

FOUNDATIONS AND STRUCTURAL MATERIALS.

POWER STATION CONSTRUCTION.

Chart.

(By E. P. Roberts & Co.)

- STATION
  - Steam Plant
    - Boilers
      - Foundation
      - Setting
      - Stack
      - Water. .
        - Source
        - Pumps and injectors, valves and gauges
        - Heaters
        - Sediment
          - Blow off
          - Mud drum
        - Steam
          - Steam pipe and valve to heater
          - Entrained water, separator
      - Fuel . .
        - Placing in building
        - Placing in boiler
        - Removal of coke and ashes
        - Removal of soot
      - Air . . . . Supply to surface
    - Link
      - Piping and valves
      - Coverings
      - Drains and drips
      - Supports
    - Engines
      - Foundation
      - Steam to cylinder
      - Oil to cylinder
      - Steam from cylinder
      - Water from cylinder
      - Oil to engine
      - Oil from engine
      - Engine indicator
        - Steam to condenser
        - Water to condenser
        - Water from condenser
  - Connecting links . . .
    - Belts
    - Shafts
    - Pulleys
      - Foundations
      - Lubrication
  - Electrical plant
    - Dynamos . .
      - Foundation
      - Lubrication
      - Insulation
      - Governing devices
      - Measuring devices
      - Safety devices
    - Wire . . . . .
      - Dynamos to switchboard
      - Switchboards to line
      - Track to dynamo
    - Switchboard
      - Distribution devices
      - Dynamo governing devices
      - Dynamo measuring devices
      - Feeder to measuring devices
      - Safety devices
      - Cut-out and lightning arrester
  - Building
    - Weatherproof
    - Fireproof
    - Ventilated
    - Light
    - Provisions for cranes or other strains foreign to its functions as a shelter.

FOUNDATIONS.

The term *foundation* designates the portion of a structure used as a base on which to erect the superstructure, and must be so solid that no movement of the superstructure can take place after its erection.

As all foundations or structures of coarse masonry, whether of brick or stone, will settle to some extent, and as nearly all soils are compressible under heavy weight, care must be taken that the settlement be even all over the structure in order to avoid cracks or other flaws. Although it is quite general to make the excavation for all the sub-foundation without predetermining in more than a general way the nature of the subsoil, and then adapting the base of the foundation to the nature of soil found; yet in large undertakings, where there may be question as to the bearing, borings are made and samples brought up in order to determine the different strata and distance of rock below the surface. Where foundations are not to be deep, or the soil is of good quality, a trench or pit is often sunk alongside the location of the proposed foundation, and the quality of the soil determined in that way.

Foundations on Rock.

The surface of rock should be cleaned and dressed, all decayed portions removed, crevices filled with *grouting* or *concrete*, and where the surface is inclined, it should be cut into a series of level steps before commencing the structure. In such cases of irregular levels, all mortar joints must be kept as close as possible, in order to prevent unequal settlement. A still better way is to bring all such uneven surfaces to a common level with a good thick bed of concrete, which, if properly made, will become as incompressible as stone or brick.

The load on rock foundation should never exceed one-eighth its crushing-load. Baker says " the safe bearing power of rock is certainly *not less* than one-tenth of the ultimate crushing strength of *cubes*. That is to say, the safe bearing power of solid rock is *not less* than 18 tons per square foot for the softest rock, and 180 for the strongest. It is safe to say that almost any rock, from the hardness of granite to that of a soft crumbling stone easily worn by exposure to the weather or to running water, when well bedded will bear the heaviest load that can be brought upon it by any masonry construction." Rankine gives the average of ordinary cases as 20,000 pounds per square foot on rock foundations. Later in this chapter (page 824) will be found a table that gives the crushing load in pounds per square inch for most of the substances used in foundations and building-walls.

Foundations on Sand or Gravel.

Strong gravel makes one of the best bottoms to build on; it is easily leveled, is almost incompressible, and is not affected by exposure to the atmosphere.

Sand confined so that it cannot escape forms an excellent foundation, and is nearly incompressible. It has no cohesion, and great care must be used in preparing it for a foundation. Surface water must be kept from running into earth foundation beds, and the beds themselves must be well-drained and below frost-line. Baker says that a rather thick bed of sand or gravel, well protected from running water, will safely bear a load of 8 to 10 tons per square foot. Of course the area of the surface must be proportioned to the weight of the superstructure, and to the bearing resistance of the material, and for this reason it is common practice to spread the subfoundation to give it the proper area. Rankine gives 2,500 to 3,500 lbs. per square foot as the greatest allowable pressure on firm earths.

Foundation on Clay.

A good stiff clay makes a very good foundation bed, and will support great weight if care is taken in its preparation. Water must be kept away from it, and the foundation level must be below the frost-line. The less clay is exposed to the atmosphere the better will be the result. Baker gives as safe bearing power for clay 3,000 or 4,000 pounds per square foot. Gaudard says a stiff clay will support in safety 5,500 to 11,000 pounds per square foot.

Foundation on Soft Earth.

Where the earth is too soft to support the superstructure, the trench is excavated to a considerable width, and to a considerable depth below the frost-line; then a bed is prepared of stones, sand, or concrete, the latter being most in use to-day. In fact, it is a common thing to cover the whole area of the basement of large power stations with a heavy layer of concrete, of a thickness sufficient to sustain not only the building-walls, but all machine foundations.

Sand makes a good foundation bed over soft earth, if the earth is of a quality that will retain the sand in position. Sand may be rammed in 9-inch layers in a soft earth trench, or it can be used as *piles* instead of wooden ones, by boring holes 6 or 8 inches in diameter and say six feet deep, and ramming the sand in wet. It is necessary to cover the surfaçe with planking or concrete to prevent the earth pressing upward. Alluvial soils are considered by Baker safe under a load of one-half to one ton per square foot.

Foundation on Piles.

When the earth is unsuitable in nature to support foundations, it is common to drive piles, on the tops of which the foundation is then built. When possible the piles are driven to bed rock, otherwise they are made of such length and used in such number as to support the superstructure by reason of the friction of their surfaces in the soil. Where the soil is quite soft it is also common to drive piles in large number all over the basement area in order to consolidate the earth, and make all parts of a better bearing quality.

Piles must be driven and cut off below the water level, and a grillage of heavy timbers or a layer of broken stone and a capping of concrete must be placed on top of them for supporting the foundation.

The woods most used for piles are spruce and hemlock in soft or medium-soft soils, or when they are to be always under water, hard pine, elm, and beech in firmer soils, and oak in compact soils. When piles are liable to be alternately wet and dry, white oak or yellow pine should be employed.

Piles should not be less than 10 inches in diameter at the small end, nor more than 14 inches at the large end. They should be straight-grained, and have the bark removed. The point is frequently shod with an iron shoe, to prevent the pile from splitting, and the head is hooped with an iron band to prevent splitting or brooming.

Safe Load on Piles.

Rankine gives as safe loads on piles 1,000 pounds per square inch of head, if driven to firm ground; 200 pounds, if in soft earth, and supported by friction.

Major Sanders, U. S. Engineers, gives the following rule for finding the safe load for a wooden pile driven until each blow drives it short and nearly equal distances:

$$\text{Safe load in pounds} = \frac{\text{Weight of hammer in pounds} \times \text{fall in inches}}{8 \times \text{inches driven by last blow}}.$$

Trautwine's rule is as follows:

$$\text{Extreme load in gross tons} = \frac{\sqrt[3]{\text{Fall in feet}} \times \text{Lbs. wgt. of hammer} \times .023}{\text{inches driven by last blow} + 1}.$$

He recommends as safe load one-half the extreme load where driven in firm soils, and one-sixth when driven in soft earths or mud. The last blow should be delivered on solid wood, and not on the "broomed" head.

Piles under Trinity Church, Boston, support two tons each.

Piles under the bridge over the Missouri River at Bismarck, Dakota, were driven into sand to a depth of 32 feet, and each sustained a load of 20 tons.

A pile under an elevator at Buffalo, N. Y., driven into the soil to a depth of 18 feet, sustained a load of 35 tons.

Arrangement of Piles.

Under walls of a building piles are arranged in rows of two or three, spaced 24 inches or 30 inches on centers. Under piers or machine foundations they are arranged in groups, the distance apart being determined by the weight to be supported, but usually, as above, from two to three feet apart on centers.

Concrete Foundation Bed.

As mentioned in a previous paragraph, concrete is now used to a very great extent for foundation beds, not only in soft earths, but to level up all kinds of foundation beds.

Good proportions are by measure, using Portland cement:

Cement, 1 part,
Coarse sand, 2 parts,
Broken stone, 5 parts.

Only hard and sharp broken stone that will pass through a 1½- or 2-inch ring should be used; and the ingredients should be thoroughly mixed dry, and after mixing, add just as little water as will fully wet the material.

Concrete should be placed carefully. It is never at its best when dropped any distance into place. It should be thoroughly rammed in six- or nine-inch layers, and after setting the top of each layer should be cleaned, wet, and roughened before depositing another layer over it. It is common practice to place side-boards in trenches and foundation excavations in order to save concrete. This is economical, but not good practice, if the earth is even moderately firm, as filling out the inequalities makes the foundation much firmer and steady in place. Weight of good concrete per cubic foot is 130 to 160 lbs. dry.

Permissible Loads on Foundation Beds.

Piles, in firm soil, each pile	30,000 to 140,000	lbs.
Piles in made ground, each pile,	4,000	"
Clay,	4,000	"
Coarse gravel and sand,	2,500 to 3,500	"
Rock foundations, average,	20,000	"
Concrete,	8,000	"
New York City laws, no pile to be weighted with a load exceeding,	40,000	"
New York City rule for solid natural earth per superficial foot,	8,000	"

Concrete Foundations.

One of the best foundations for engines or other heavy machinery is constructed wholly of concrete, rammed in a mold of planking. The mould can be made of any desired shape; the holding-down bolts placed by template, and the material rammed in layers not exceeding 12 inches thick.

Brick Foundations.

Only the best hard-burned brick should be used for foundations, and they should be thoroughly wet before laying. To insure a thorough wetting, the bricks should be deposited in a tub of water. Bricks should be *push placed* in a good rich cement mortar. Grouting should never be used, as it takes too long to dry. Joints should be very small. A well constructed brick foundation will break as easily in the brick as at the joints after it has been built for some time.

Stone Foundations.

Rubble stone foundations should start with large flat stones on the bottom. Care must be taken that all are well bedded in mortar, and that the work is well tied together by headers.

Dimension stone foundations are always laid out with the heavy and thick stones at the bottom, and gradually decreasing in height, layer by layer, to the top. A large cap-stone, or several if the size is too great for one, is often placed on top of the foundation. Care must be taken to bed each stone in cement mortar, so that the joints will be thin and yet leave all the spaces between the stones completely filled with mortar to prevent any unequal strains on the stone. In all large foundations use plenty of headers; and if the backing or center is of rubble, see that all stones are well bedded, and the crevices filled with spawls and cement.

I-Beam Foundations.

One of the best and now most common methods of constructing foundations for piers, walls, columns, etc., is the use of steel I-beams set in concrete. Knowing the weight to be supported and the bearing value of the soil, excavation is made of the right dimensions to get the proper area of bearing, then I-beams of predetermined dimensions are laid parallel along the bottom, and held in place with bolts from one beam to the next. Concrete is rammed in all the spaces to a level with the top of the beams. Another similar layer of beams is then laid on top of the first, and at right angles thereto, and the spaces also filled with concrete. The column base, or footing course, is then set on the structure ready to receive the column.
For method of calculation of dimensions of I-beams for use in foundations for piers and walls, the reader can consult the hand-book of the Carnegie Steel Company, and those of other Steel Companies.

MORTARS.

Lime Mortar.

Good proportions are: 1 measure or part quicklime, 3 measures of sand, well mixed, or tempered with clean water.

Quantity required. — Trautwine. 20 cu. ft. sand and 4 cu. ft. of lime, making about 22½ cu. ft. mortar, will lay 1,000 bricks with average coarse joints.

Weight. — 1 bbl. weighs 230 lbs. net, or 250 lbs. gross; 1 heaped bushel of lump lime weighs about 75 lbs.; 1 struck bushel ground quick lime, loose, weighs about 70 lbs. Average hardened mortar weighs about 105 to 115 lbs. per cu. ft.

Tenacity. — Ordinary good lime mortar 6 months old has cohesive strength of from 15 to 30 lbs. per square inch.

Adhesion to common bricks or rubble. — At 6 months old, 12 to 24 lbs. per sq. inch.

Cement Mortar.

Good proportions are: 1 measure cement, 2 measures sand, ½ measure water. The above is rich and strong, and for ordinary work will allow increase of sand to 3 or 4 measures.

Quantity required. — Trautwine. 1 bbl. cement, 2 bbls. sand, will lay 1 cu. yd. of bricks with ⅜ inch joints or 1 cu. yard rubble masonry.

Weight. —

American Rosendale, ground, loose, average,	56	lbs. per cu. ft.
" " U. S. struck bushel,	70	" " " "
English Portland,	81 to 102	" " " "
" " per struck bushel,	100 to 128	" " " "
" " per bbl.,	400 to 430	" " " "

Average Strength of Neat Cement after 6 Days in Water.

	Tensile, Lbs. per sq. in.	Compress, Lbs. per sq. in.	Compress, Tons per sq. ft.
Portland, artificial . . .	200 to 350	1400 to 2400	90 to 154
" Saylor's natural	170 to 370	1100 to 1700	71 to 109
U. S. common hydraulic .	40 to 70	250 to 450	16 to 29

Cements are weakened by the addition of sand somewhat as shown in the following table: calling neat cement 1.

Sand.	0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	3	4	5	6
Strength.	1	$\frac{2}{3}$	$\frac{1}{2}$	.4	$\frac{1}{3}$	.3	$\frac{1}{4}$	$\frac{1}{5}$	$\frac{1}{6}$

Adhesion to Bricks or Rubble.

Adhesion of cement, either neat or mixed with sand, will average about three-fourths the tensile strength of the mortar at the same age.

SAND AND CEMENT.

Recommendations of Am. Soc. Civil Engineers.

Sand. — To be crushed quartz only. To pass,
1st sieve, 400 meshes per square inch.
2d " 900 " " " "

Sand to pass the 400 mesh, but be caught by the 900 mesh, all finer particles to be rejected.

Portland Cement. — For fineness, to pass,
1st sieve, 2500 meshes per square inch.
2d " 5476 " " " "
3d " 10000 " " " "

Should be stored in bulk for at least 21 days to air-slake and free it from lime, as lime swells the bulk, and if not removed is apt to crack the work.

IRON AND STEEL.

Iron, weight of:	**cu. in.**	**cu. ft.**
Cast,	.2604 Lbs.	450 Lbs.
Wrought,	.2777 "	480 "

a = sectional area wrought-iron bar.
x = weight per foot " " "

$$a = \frac{3x}{10} \qquad x = \frac{10a}{3}.$$

Steel, weight of:	**cu. in.**	**cu. ft.**
	.2831 Lbs.	489.3 Lbs.

Cast Iron. Test.

Bar an inch square, supported on edges 1 foot apart, must sustain 1 ton at center.

WEIGHT OF FLAT ROLLED IRON IN POUNDS PER LINEAL FOOT.

Widths from 1 in. to 12 in.

Iron weighing 480 lbs. per cubic foot. For steel add 2 per cent.

Thickness in Inches.	Widths.															
	1 in.	$1\frac{1}{4}$ in.	$1\frac{1}{2}$ in.	$1\frac{3}{4}$ in.	2 in.	$2\frac{1}{4}$ in.	$2\frac{1}{2}$ in.	$2\frac{3}{4}$ in.	3 in.	$3\frac{1}{4}$ in.	$3\frac{1}{2}$ in.	$3\frac{3}{4}$ in.	4 in.	$4\frac{1}{4}$ in.	$4\frac{1}{2}$ in.	$4\frac{3}{4}$ in
$\frac{1}{16}$	.208	.260	.313	.365	.417	.469	.521	.573	.625	.677	.729	.781	.833	.885	.938	.990
$\frac{1}{8}$	.417	.521	.625	.729	.833	.938	1.04	1.15	1.25	1.35	1.46	1.56	1.67	1.77	1.88	1.98
$\frac{3}{16}$	.625	.781	.938	1.09	1.25	1.41	1.56	1.72	1.88	2.03	2.19	2.34	2.50	2.66	2.81	2.97
$\frac{1}{4}$	.833	1.04	1.25	1.46	1.67	1.88	2.08	2.29	2.50	2.71	2.92	3.13	3.33	3.54	3.75	3.96
$\frac{5}{16}$	1.04	1.30	1.56	1.82	2.08	2.34	2.60	2.86	3.13	3.39	3.65	3.91	4.17	4.43	4.69	4.95
$\frac{3}{8}$	1.25	1.56	1.88	2.19	2.50	2.81	3.13	3.44	3.75	4.06	4.38	4.69	5.00	5.31	5.63	5.94
$\frac{7}{16}$	1.46	1.82	2.19	2.55	2.92	3.28	3.65	4.01	4.38	4.74	5.10	5.47	5.83	6.20	6.56	6.93
$\frac{1}{2}$	1.67	2.08	2.50	2.92	3.33	3.75	4.17	4.58	5.00	5.42	5.83	6.25	6.67	7.08	7.50	7.92
$\frac{9}{16}$	1.88	2.34	2.81	3.28	3.75	4.22	4.69	5.16	5.63	6.09	6.56	7.03	7.50	7.97	8.44	8.91
$\frac{5}{8}$	2.08	2.60	3.13	3.65	4.17	4.69	5.21	5.73	6.25	6.77	7.29	7.81	8.33	8.85	9.38	9.90
$\frac{11}{16}$	2.29	2.86	3.44	4.01	4.58	5.16	5.73	6.30	6.88	7.45	8.02	8.59	9.17	9.74	10.31	10.89
$\frac{3}{4}$	2.50	3.13	3.75	4.38	5.00	5.63	6.25	6.88	7.50	8.13	8.75	9.38	10.00	10.63	11.25	11.88
$\frac{13}{16}$	2.71	3.39	4.06	4.74	5.42	6.09	6.77	7.45	8.13	8.80	9.48	10.16	10.83	11.51	12.19	12.86
$\frac{7}{8}$	2.92	3.65	4.38	5.10	5.83	6.56	7.29	8.02	8.75	9.48	10.21	10.94	11.67	12.40	13.13	13.85
$\frac{15}{16}$	3.13	3.91	4.69	5.47	6.25	7.03	7.81	8.59	9.38	10.16	10.94	11.72	12.50	13.28	14.06	14.84
1	3.33	4.17	5.00	5.83	6.67	7.50	8.33	9.17	10.00	10.83	11.67	12.50	13.33	14.17	15.00	15.83
$1\frac{1}{16}$	3.54	4.43	5.31	6.20	7.08	7.97	8.85	9.74	10.63	11.51	12.40	13.28	14.17	15.05	15.94	16.82
$1\frac{1}{8}$	3.75	4.69	5.63	6.56	7.50	8.44	9.38	10.31	11.25	12.19	13.13	14.06	15.00	15.94	16.88	17.81
$1\frac{3}{16}$	3.96	4.95	5.94	6.93	7.92	8.91	9.90	10.89	11.88	12.86	13.85	14.84	15.83	16.82	17.81	18.80
$1\frac{1}{4}$	4.17	5.21	6.25	7.29	8.33	9.38	10.42	11.46	12.50	13.54	14.58	15.63	16.67	17.71	18.75	19.79
$1\frac{5}{16}$	4.37	5.47	6.56	7.66	8.75	9.84	10.94	12.03	13.13	14.22	15.31	16.41	17.50	18.59	19.69	20.78
$1\frac{3}{8}$	4.58	5.73	6.88	8.02	9.17	10.31	11.46	12.60	13.75	14.90	16.04	17.19	18.33	19.48	20.63	21.77
$1\frac{7}{16}$	4.79	5.99	7.19	8.39	9.58	10.78	11.98	13.18	14.38	15.57	16.77	17.97	19.17	20.36	21.56	22.76
$1\frac{1}{2}$	5.00	6.25	7.50	8.75	10.00	11.25	12.50	13.75	15.00	16.25	17.50	18.75	20.00	21.25	22.50	23.75
$1\frac{9}{16}$	5.21	6.51	7.81	9.11	10.42	11.72	13.02	14.32	15.63	16.93	18.23	19.53	20.83	22.14	23.44	24.74
$1\frac{5}{8}$	5.42	6.77	8.13	9.48	10.83	12.19	13.54	14.90	16.25	17.60	18.96	20.31	21.67	23.02	24.38	25.73
$1\frac{11}{16}$	5.63	7.03	8.44	9.84	11.25	12.66	14.06	15.47	16.88	18.28	19.69	21.09	22.50	23.91	25.31	26.72
$1\frac{3}{4}$	5.83	7.29	8.75	10.21	11.67	13.13	14.58	16.04	17.50	18.96	20.42	21.88	23.33	24.79	26.25	27.71
$1\frac{13}{16}$	6.04	7.55	9.06	10.57	12.08	13.59	15.10	16.61	18.13	19.64	21.15	22.66	24.17	25.68	27.19	28.70
$1\frac{7}{8}$	6.25	7.81	9.38	10.94	12.50	14.06	15.63	17.19	18.75	20.31	21.88	23.44	25.00	26.56	28.13	29.69
$1\frac{15}{16}$	6.46	8.07	9.69	11.30	12.92	14.53	16.15	17.76	19.38	20.99	22.60	24.22	25.83	27.45	29.06	30.68
2	6.67	8.33	10.00	11.67	13.33	15.00	16.67	18.33	20.00	21.67	23.33	25.00	26.67	28.33	30.00	31.67

WEIGHT OF FLAT ROLLED IRON IN POUNDS PER LINEAL FOOT. Continued.

Thickness in Inches.	Widths.															
	5 in.	$5\frac{1}{4}$ in.	$5\frac{1}{2}$ in.	$5\frac{3}{4}$ in.	6 in.	$6\frac{1}{4}$ in.	$6\frac{1}{2}$ in.	$6\frac{3}{4}$ in.	7 in.	$7\frac{1}{2}$ in.	8 in.	$8\frac{1}{2}$ in.	9 in.	10 in.	11 in.	12 in.
$\frac{1}{16}$	1.04	1.09	1.15	1.20	1.25	1.30	1.35	1.41	1.46	1.56	1.67	1.77	1.88	2.08	2.29	2.50
$\frac{1}{8}$	2.08	2.19	2.29	2.40	2.50	2.60	2.71	2.81	2.92	3.13	3.33	3.54	3.75	4.17	4.58	5.00
$\frac{3}{16}$	3.13	3.28	3.44	3.59	3.75	3.91	4.06	4.22	4.38	4.69	5.00	5.31	5.63	6.25	6.88	7.50
$\frac{1}{4}$	4.17	4.38	4.58	4.79	5.00	5.21	5.42	5.63	5.83	6.25	6.67	7.08	7.50	8.33	9.17	10.00
$\frac{5}{16}$	5.21	5.47	5.73	5.99	6.25	6.51	6.77	7.03	7.29	7.81	8.33	8.85	9.38	10.42	11.46	12.50
$\frac{3}{8}$	6.25	6.56	6.88	7.19	7.50	7.81	8.13	8.44	8.75	9.38	10.00	10.63	11.25	12.50	13.75	15.00
$\frac{7}{16}$	7.29	7.66	8.02	8.39	8.75	9.11	9.48	9.84	10.21	10.94	11.67	12.40	13.13	14.58	16.04	17.50
$\frac{1}{2}$	8.33	8.75	9.17	9.58	10.00	10.42	10.83	11.25	11.67	12.50	13.33	14.17	15.00	16.67	18.33	20.00
$\frac{9}{16}$	9.38	9.84	10.31	10.78	11.25	11.72	12.19	12.66	13.13	14.06	15.00	15.94	16.88	18.75	20.63	22.50
$\frac{5}{8}$	10.42	10.94	11.46	11.98	12.50	13.02	13.54	14.06	14.58	15.63	16.67	17.71	18.75	20.83	22.92	25.00
$\frac{11}{16}$	11.46	12.03	12.60	13.18	13.75	14.32	14.90	15.47	16.04	17.19	18.33	19.48	20.63	22.92	25.21	27.50
$\frac{3}{4}$	12.50	13.13	13.75	14.38	15.00	15.63	16.25	16.88	17.50	18.75	20.00	21.25	22.50	25.00	27.50	30.00
$\frac{13}{16}$	13.54	14.22	14.90	15.57	16.25	16.93	17.60	18.28	18.96	20.31	21.67	23.02	24.38	27.08	29.79	32.50
$\frac{7}{8}$	14.58	15.31	16.04	16.77	17.50	18.23	18.96	19.69	20.42	21.88	23.33	24.79	26.25	29.17	32.08	35.00
$\frac{15}{16}$	15.63	16.41	17.19	17.97	18.75	19.53	20.31	21.09	21.88	23.44	25.00	26.56	28.13	31.25	34.38	37.50
1	16.67	17.50	18.33	19.17	20.00	20.83	21.67	22.50	23.33	25.00	26.67	28.33	30.00	33.33	36.67	40.00
$1\frac{1}{8}$	18.75	19.69	20.63	21.56	22.50	23.44	24.38	25.31	26.25	28.13	30.00	31.88	33.75	37.50	41.25	45.00
$1\frac{1}{4}$	20.83	21.88	22.92	23.96	25.00	26.04	27.08	28.13	29.17	31.25	33.33	35.42	37.50	41.67	45.83	50.00
$1\frac{3}{8}$	22.92	24.06	25.21	26.35	27.50	28.65	29.79	30.94	32.08	34.38	36.67	38.96	41.25	45.83	50.42	55.00
$1\frac{1}{2}$	25.00	26.25	27.50	28.75	30.00	31.25	32.50	33.75	35.00	37.50	40.00	42.50	45.00	50.00	55.00	60.00
$1\frac{5}{8}$	27.08	28.44	29.79	31.15	32.50	33.85	35.21	36.56	37.92	40.63	43.33	46.04	48.75	54.17	59.58	65.00
$1\frac{3}{4}$	29.17	30.63	32.08	33.54	35.00	36.46	37.92	39.38	40.83	43.75	46.67	49.58	52.50	58.33	64.17	70.00
$1\frac{7}{8}$	31.25	32.81	34.38	35.94	37.50	39.06	40.63	42.19	43.75	46.88	50.00	53.13	56.25	62.50	68.75	75.00
2	33.33	35.00	36.67	38.33	40.00	41.67	43.33	45.00	46.67	50.00	53.33	56.67	60.00	66.67	73.33	80.00

Other Sizes. — Weight of other sizes can easily be obtained from the above table by means of combinations or divisions. Thus, for example,

Weight of 12 × $1\frac{1}{4}$ equals weight of 12 × 1 plus weight of 12 × $\frac{1}{4}$ 50.00
Or, twice weight of 12 × $\frac{5}{8}$, as it is twice as thick 50.00
Weight of 6 × $1\frac{15}{16}$ equals midway weight between 6 × $1\frac{7}{8}$ and 6 × 2 . . . . . 38.75
Weight of 24 × $\frac{15}{16}$, being twice as wide as 12 × $\frac{15}{16}$, weighs 75.00

WEIGHTS OF SQUARE AND ROUND BARS OF WROUGHT IRON IN POUNDS PER LINEAL FOOT.

Iron weighing 480 lbs. per cubic foot. For steel add 2 per cent.

Thickness or Diameter in Inches.	Weight of Square Bar One Foot Long.	Weight of Round Bar One Foot Long.	Thickness or Diameter in Inches.	Weight of Square Bar One Foot Long.	Weight of Round Bar One Foot Long.	Thickness or Diameter in Inches.	Weight of Square Bar One Foot Long.	Weight of Round Bar One Foot Long.
0			$\frac{11}{16}$	24.08	18.91	$\frac{3}{8}$	96.30	75.64
$\frac{1}{16}$	.013	.010	$\frac{3}{4}$	25.21	19.80	$\frac{7}{16}$	98.55	77.40
$\frac{1}{8}$	.052	.041	$\frac{13}{16}$	26.37	20.71	$\frac{1}{2}$	100.8	79.19
$\frac{3}{16}$	.117	.092	$\frac{7}{8}$	27.55	21.64	$\frac{9}{16}$	103.1	81.00
$\frac{1}{4}$	.208	.164	$\frac{15}{16}$	28.76	22.59	$\frac{5}{8}$	105.5	82.83
$\frac{6}{16}$	.326	.256	3	30.00	23.56	$\frac{11}{16}$	107.8	84.69
$\frac{3}{8}$	.469	.368	$\frac{1}{16}$	31.26	24.55	$\frac{3}{4}$	110.2	86.56
$\frac{7}{16}$	.638	.501	$\frac{1}{8}$	32.55	25.57	$\frac{13}{16}$	112.6	88.45
$\frac{1}{2}$	.833	.654	$\frac{3}{16}$	33.87	26.60	$\frac{7}{8}$	115.1	90.36
$\frac{9}{16}$	1.055	.828	$\frac{1}{4}$	35.21	27.65	$\frac{15}{16}$	117.5	92.29
$\frac{5}{8}$	1.302	1.023	$\frac{5}{16}$	36.58	28.73	6	120.0	94.25
$\frac{11}{16}$	1.576	1.237	$\frac{3}{8}$	37.97	29.82	$\frac{1}{8}$	125.1	98.22
$\frac{3}{4}$	1.875	1.473	$\frac{7}{16}$	39.39	30.94	$\frac{1}{4}$	130.2	102.3
$\frac{13}{16}$	2.201	1.728	$\frac{1}{2}$	40.83	32.07	$\frac{3}{8}$	135.5	106.4
$\frac{7}{8}$	2.552	2.004	$\frac{9}{16}$	42.30	33.23	$\frac{1}{2}$	140.8	110.6
$\frac{16}{16}$	2.930	2.301	$\frac{5}{8}$	43.80	34.40	$\frac{5}{8}$	146.3	114.9
1	3.333	2.618	$\frac{11}{16}$	45.33	35.60	$\frac{3}{4}$	151.9	119.3
$\frac{1}{16}$	3.763	2.955	$\frac{3}{4}$	46.88	36.82	$\frac{7}{8}$	157.6	123.7
$\frac{1}{8}$	4.219	3.313	$\frac{13}{16}$	48.45	38.05	7	163.3	128.3
$\frac{3}{16}$	4.701	3.692	$\frac{7}{8}$	50.05	39.31	$\frac{1}{8}$	169.2	132.9
$\frac{1}{4}$	5.208	4.091	$\frac{16}{16}$	51.68	40.59	$\frac{1}{4}$	175:2	137.6
$\frac{5}{16}$	5.742	4.510	4	53.33	41.89	$\frac{3}{8}$	181.3	142.4
$\frac{3}{8}$	6.302	4.950	$\frac{1}{16}$	55.01	43.21	$\frac{1}{2}$	187.5	147.3
$\frac{7}{16}$	6.888	5.410	$\frac{1}{8}$	56.72	44.55	$\frac{5}{8}$	193.8	152.2
$\frac{1}{2}$	7.500	5.890	$\frac{3}{16}$	58.45	45.91	$\frac{3}{4}$	200.2	157.2
$\frac{9}{16}$	8.138	6.392	$\frac{1}{4}$	60.21	47.29	$\frac{7}{8}$	206.7	162.4
$\frac{5}{8}$	8.802	6.913	$\frac{5}{16}$	61.99	48.69	8	213.3	167.6
$\frac{11}{16}$	9.492	7.455	$\frac{3}{8}$	63.80	50.11	$\frac{1}{4}$	226.9	178.2
$\frac{3}{4}$	10.21	8.018	$\frac{7}{16}$	65.64	51.55	$\frac{1}{2}$	240.8	189.2
$\frac{13}{16}$	10.95	8.601	$\frac{1}{2}$	67.50	53.01	$\frac{3}{4}$	255.2	200.4
$\frac{7}{8}$	11.72	9.204	$\frac{9}{16}$	69.39	54.50	9	270.0	212.1
$\frac{15}{16}$	12.51	9.828	$\frac{5}{8}$	71.30	56.00	$\frac{1}{4}$	285.2	224.0
2	13.33	10.47	$\frac{11}{16}$	73.24	57.52	$\frac{1}{2}$	300.8	236.3
$\frac{1}{16}$	14.18	11.14	$\frac{3}{4}$	75.21	59.07	$\frac{3}{4}$	316.9	248.9
$\frac{1}{8}$	15.05	11.82	$\frac{13}{16}$	77.20	60.63	10	333.3	261.8
$\frac{3}{16}$	15.95	12.53	$\frac{7}{8}$	79.22	62.22	$\frac{1}{4}$	350.2	275.1
$\frac{1}{4}$	16.88	13.25	$\frac{15}{16}$	81.26	63.82	$\frac{1}{2}$	367.5	288.6
$\frac{5}{16}$	17.83	14.00	5	83.33	65.45	$\frac{3}{4}$	385.2	302.5
$\frac{3}{8}$	18.80	14.77	$\frac{1}{16}$	85.43	67.10	11	403.3	316.8
$\frac{7}{16}$	19.80	15.55	$\frac{1}{8}$	87.55	68.76	$\frac{1}{4}$	421.9	331.3
$\frac{1}{2}$	20.83	16.36	$\frac{3}{16}$	89.70	70.45	$\frac{1}{2}$	440.8	346.2
$\frac{9}{16}$	21.89	17.19	$\frac{1}{4}$	91.88	72.16	$\frac{3}{4}$	460.2	361.4
$\frac{5}{8}$	22.97	18.04	$\frac{6}{16}$	94.08	73.89	12	480.	377.

WEIGHT OF PLATE IRON, PER LINEAL FOOT, IN POUNDS.

(Based on 480 lbs. per Cubic Foot. For Steel add 2 per cent.)

Width in Inches.	Thickness in Inches.															
	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1
12	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50	40.00
13	2.71	5.42	8.13	10.83	13.54	16.25	18.96	21.67	24.38	27.08	29.79	32.50	35.21	37.92	40.63	43.33
14	2.92	5.83	8.75	11.67	14.58	17.50	20.42	23.33	26.25	29.17	32.08	35.00	37.92	40.83	43.75	46.67
15	3.13	6.25	9.38	12.50	15.63	18.75	21.88	25.00	28.13	31.25	34.38	37.50	40.63	43.75	46.88	50.00
16	3.33	6.67	10.00	13.33	16.67	20.00	23.33	26.67	30.00	33.33	36.67	40.00	43.33	46.67	50.00	53.33
17	3.54	7.08	10.63	14.17	17.71	21.25	24.79	28.33	31.88	35.42	38.96	42.50	46.05	49.59	53.13	56.67
18	3.75	7.50	11.25	15.00	18.75	22.50	26.25	30.00	33.75	37.50	41.25	45.00	48.75	52.50	56.25	60.00
19	3.96	7.92	11.87	15.83	19.79	23.75	27.71	31.67	35.67	39.58	43.54	47.50	51.45	55.41	59.37	63.33
20	4.17	8.33	12.50	16.67	20.83	25.00	29.17	33.33	37.50	41.67	45.83	50.00	54.17	58.33	62.50	66.67
21	4.38	8.75	13.13	17.50	21.88	26.25	30.63	35.00	39.38	43.75	48.13	52.50	56.88	61.25	65.63	70.00
22	4.58	9.17	13.75	18.33	22.92	27.50	32.08	36.67	41.25	45.83	50.42	55.00	59.58	64.17	68.75	73.33
23	4.79	9.58	14.38	19.17	23.96	28.75	33.54	38.33	43.13	47.92	52.71	57.50	62.30	67.09	71.88	76.67
24	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	55.00	60.00	65.00	70.00	75.00	80.00
25	5.21	10.42	15.62	20.83	26.04	31.25	36.46	41.67	46.88	52.08	57.29	62.50	67.70	72.91	78.13	83.33
26	5.42	10.83	16.25	21.67	27.08	32.50	37.92	43.33	48.75	54.17	59.58	65.00	70.42	75.83	81.25	86.67
27	5.63	11.25	16.88	22.50	28.13	33.75	39.38	45.00	50.63	56.25	61.88	67.50	73.13	78.75	84.38	90.00
28	5.83	11.67	17.50	23.33	29.17	35.00	40.83	46.67	52.50	58.33	64.17	70.00	75.84	81.67	87.50	93.33
29	6.04	12.08	18.13	24.17	30.21	36.25	42.29	48.33	54.38	60.42	66.46	72.50	78.55	84.59	90.63	96.67
30	6.25	12.50	18.75	25.00	31.25	37.50	43.75	50.00	56.25	62.50	68.75	75.00	81.25	87.50	93.75	100.0
32	6.67	13.33	20.00	26.67	33.33	40.00	46.67	53.33	60.00	66.67	73.33	80.00	86.67	93.33	100.0	106.7
34	7.08	14.17	21.25	28.33	35.42	42.50	49.58	56.67	63.75	70.83	77.91	85.00	92.08	99.17	106.3	113.3
36	7.50	15.00	22.50	30.00	37.50	45.00	52.50	60.00	67.50	75.00	82.50	90.00	97.50	105.0	112.5	120.0
38	7.92	15.83	23.75	31.67	39.59	47.50	55.42	63.33	71.25	79.17	87.09	95.00	102.9	110.8	118.8	126.7
40	8.33	16.67	25.00	33.33	41.67	50.00	58.33	66.67	75.00	83.33	91.67	100.0	108.3	116.7	125.0	133.3
42	8.75	17.50	26.25	35.00	43.75	52.50	61.25	70.00	78.75	87.50	96.25	105.0	113.7	122.5	131.3	140.0
44	9.17	18.33	27.50	36.67	45.84	55.00	64.17	73.33	82.50	91.67	100.8	110.0	119.2	128.3	137.5	146.7
46	9.58	19.17	28.75	38.33	47.92	57.50	67.08	76.67	86.25	95.83	105.4	115.0	124.6	134.2	143.8	153.3
48	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.0	110.0	120.0	130.0	140.0	150.0	160.0
50	10.42	20.83	31.25	41.67	52.08	62.50	72.91	83.33	93.75	104.2	114.6	125.0	135.4	145.8	156.3	166.7
52	10.83	21.67	32.50	43.33	54.17	65.00	75.83	86.67	97.50	108.3	119.2	130.0	140.8	151.7	162.5	173.3
54	11.25	22.50	33.75	45.00	56.25	67.50	78.75	90.00	101.3	112.5	123.8	135.0	146.3	157.5	168.8	180.0
56	11.67	23.33	35.00	46.67	58.33	70.00	81.66	93.33	105.0	116.7	128.3	140.0	151.7	163.3	175.0	186.7
58	12.08	24.17	36.25	48.33	60.42	72.50	84.58	96.67	108.8	120.8	132.9	145.0	157.1	169.2	181.3	193.3
60	12.50	25.00	37.50	50.00	62.50	75.00	87.50	100.00	112.5	125.0	137.5	150.0	162.5	175.0	187.5	200.0

U. S. STANDARD GAUGE FOR SHEET AND PLATE IRON AND STEEL. 1893.

Number of Gauge.	Approximate Thickness in Fractions of an Inch.	Approximate Thickness in Decimal Parts of an Inch.	Approximate Thickness in Millimeters.	Weight per Sq. Ft. in Ounces Avoirdupois.	Weight per Sq. Ft. in Pounds Avoirdupois.	Weight per Sq. Ft. in Kilograms.	Weight per Square Meter in Kilograms.	Weight per Square Meter in Pounds Avoirdupois.
0000000	1–2	0.5	12.7	320	20.	9.072	97.65	215.28
000000	15–32	0.46875	11.90625	300	18.75	8.505	91.55	201.82
00000	7–16	0.4375	11.1125	280	17.50	7.938	85.44	188.37
0000	13–32	0.40625	10.31875	260	16.25	7.371	79.33	174.91
000	3–8	0.375	9.525	240	15.	6.804	73.24	161.46
00	11–32	0.34375	8.73125	220	13.75	6.237	67.13	148.00
0	5–16	0.3125	7.9375	200	12.50	5.67	61.03	134.55
1	9–32	0.28125	7.14375	180	11.25	5.103	54.93	121.09
2	17–64	0.265625	6.746875	170	10.625	4.819	51.88	114.37
3	1–4	0.25	6.35	160	10.	4.536	48.82	107.64
4	15–64	0.234375	5.953125	150	9.375	4.252	45.77	100.91
5	7–32	0.21875	5.55625	140	8.75	3.969	42.72	94.18
6	12–64	0.203125	5.159375	130	8.125	3.685	39.67	87.45
7	3–16	0.1875	4.7625	120	7.5	3.402	36.62	80.72
8	11–64	0.171875	4.365625	110	6.875	3.118	33.57	74.00
9	5–32	0.15625	3.96875	100	6.25	2.835	30.52	67.27
10	9-64	0.140625	3.571875	90	5.625	2.552	27.46	60.55
11	1–8	0.125	3.175	80	5.	2.268	24.41	53.82
12	7–64	0.109375	2.778125	70	4.375	1.984	21.36	47.09
13	3–32	0.09375	2.38125	60	3.75	1.701	18.31	40.36
14	5–64	0.078125	1.984375	50	3.125	1.417	15.26	33.64
15	9–128	0.0703125	1.7859375	45	2.8125	1.276	13.73	30.27
16	1–16	0.0625	1.5875	40	2.5	1.134	12.21	26.91
17	9–160	0.05625	1.42875	36	2.25	1.021	10.99	24.22
18	1–20	0.05	1.27	32	2.	0.9072	9.765	21.53
19	7–160	0.04375	1.11125	28	1.75	0.7938	8.544	18.84
20	3–80	0.0375	0.9525	24	1.50	0.6804	7.324	16.15
21	11–320	0.034375	0.873125	22	1.375	0.6237	6.713	14.80
22	1–32	0.03125	0.793750	20	1.25	0.567	6.103	13.46
23	9–320	0.028125	0.714375	18	1.125	0.5103	5.493	12.11
24	1–40	0.025	0.635	16	1.	0.4536	4.882	10.76
25	7–320	0.021875	0.555625	14	0.875	0.3969	4.272	9.42
26	3–160	0.01875	0.47625	12	0.75	0.3402	3.662	8.07
27	11–640	0.0171875	0.4365625	11	0.6875	0.3119	3.357	7.40
28	1–64	0.015625	0.396875	10	0.625	0.2835	3.052	6.73
29	9–640	0.0140625	0.3571875	9	0.5625	0.2551	2.746	6.05
30	1–80	0.0125	0.3175	8	0.5	0.2268	2.441	5.38
31	7–640	0.0109375	0.2778125	7	0.4375	0.1984	2.136	4.71
32	13–1280	0.01015625	0.25796875	6½	0.40625	0.1843	1.983	4.37
33	3–320	0.009375	0.238125	6	0.375	0.1701	1.831	4.04
34	11–1280	0.00859375	0.21828125	5½	0.34375	0.1559	1.678	3.70
35	5–640	0.0078125	0.1984375	5	0.3125	0.1417	1.526	3.36
36	9–1280	0.00703125	0.17859375	4½	0.28125	0.1276	1.373	3.03
37	17–2560	0.006640625	0.168671875	4¼	0.265625	0.1205	1.297	2.87
38	1–160	0.00625	0.15875	4	0.25	0.1134	1.221	2.69

COLUMNS, PILLARS, OR STRUTS.

Hodgkinson's Formula for Columns.

P = crushing weight in pounds ; d = exterior diameter in inches ; d_1 = interior diameter in inches ; L = length in feet.

Kind of Columns.	Both ends rounded, the length of the column exceeding 15 times its diameter.	Both ends flat, the length of the column exceeding 30 times its diameter.
Solid cylindrical columns of cast iron .	$P = 33{,}380 \frac{d^{3 \cdot 76}}{L^{1 \cdot 7}}$	$P = 98{,}920 \frac{d^{3 \cdot 55}}{L^{1 \cdot 7}}$
Hollow cylindrical columns of cast iron	$P = 29{,}120 \frac{d^{3 \cdot 76} - d_1^{3 \cdot 76}}{L^{1 \cdot 7}}$	$P = 99{,}320 \frac{d^{3 \cdot 55} - d_1^{3 \cdot 55}}{L^{1 \cdot 7}}$
Solid cylindrical columns of wrought iron	$P = 95{,}850 \frac{d^{3 \cdot 76}}{L^2}$	$P = 299{,}600 \frac{d^{3 \cdot 55}}{L^2}$
Solid square pillar of Dantzic oak (dry) .	. . . .	$P = 24{,}540 \frac{d^4}{L^2}$

These formulæ apply only to cases of breakage caused by bending rather than mere crushing. Where the column is short, or say five times its diameter in length, then the following formula applies.

Let

P = value given in preceding formulæ,
K = transverse section of column in square inches,
C = ultimate compressive resistance of the material,
W = crushing strength of the column.

Then

$$W = \frac{P\,C\,K}{P + \frac{3}{4}\,C\,K}.$$

Hodgkinson's experiments were made upon columns the longest of which for cast iron was $60\frac{1}{2}$ inches, and for wrought iron $90\frac{3}{4}$ inches.

The following are some of his conclusions :

1. In all long pillars of the same dimensions, when the force is applied in the direction of the axis, the strength of one which has flat ends is about three times as great as one with rounded ends.

2. The strength of a pillar with one end rounded and the other flat is an arithmetical mean between the two given in the preceding case of the same dimensions.

3. The strength of a pillar having both ends firmly fixed is the same as one of half the length with both ends rounded.

4. The strength of a pillar is not increased more than one-seventh by enlarging it at the middle.

Gordon's formulæ, deduced from Hodgkinson's experiments, are more generally used than Hodgkinson's own. They are :

Columns with both ends fixed or flat $P = \frac{fS}{1 + a\frac{l^2}{r^2}}$;

Columns with one end flat, the other end round, $P = \frac{fS}{1 + 1.8a\frac{l^2}{r^2}}$

Columns with both ends round or hinged, $P = \frac{fS}{1 + 4a\frac{l^2}{r^2}}$;

$S =$ area of cross-section in inches;
$P =$ ultimate resistance of column in pounds;
$f =$ crushing strength of the material in pounds per square inch;
$r =$ least radius of gyration, in inches, $r^2 = \dfrac{\text{Moment of inertia}}{\text{area of section}}$;
$l =$ length of column in inches;
$a =$ a coefficient depending upon the material;

f and a are usually taken as constants; they are really empirical variables, dependent upon the dimensions and character of the column as well as upon the material. (Burr.)

For solid wrought-iron columns, values commonly taken are: $f = 36{,}000$ to $40{,}000$; $a = \dfrac{1}{36{,}000}$ to $\dfrac{1}{40{,}000}$.

New York City Building Laws 1897–1898 give the following values for f:

Cast iron	$f = 80{,}000$ lbs.
Rolled steel	$f = 48{,}000$ lbs.
Wrought or rolled iron	$f = 40{,}000$ lbs.
American oak . . .	$f = 6{,}000$ lbs.
Pitch or Georgia pine .	$f = 5{,}000$ lbs.
White pine and spruce	$f = 3{,}500$ lbs.

For solid cast-iron columns, $f = 80{,}000$, $a = \dfrac{1}{6400}$.

For hollow cast-iron columns, fixed ends, $p = \dfrac{80{,}000}{1 + 800\dfrac{l^2}{d^2}}$, $l =$ length and $d =$ diameter in the same unit, and $p =$ strength in lbs. per square inch.

Sir Benjamin Baker gives,

$$\text{For mild steel} \quad f = 67{,}000 \text{ lbs.}, a = \frac{1}{22{,}400}.$$

$$\text{For strong steel} \quad f = 114{,}000 \text{ lbs.}, a = \frac{1}{14{,}400}.$$

STRENGTH OF MATERIALS.

The terms *stress* and *strain* are generally used synonymously, authorities differing as to which is the proper use. Merriman defines *stress* as a force which acts in the interior of a body, and resists the external forces which tend to change its shape. A *deformation* is the amount of change of shape of a body caused by the stress. The word *strain* is often used as synonymous with *stress*, and sometimes it is also used to designate the deformation. Merriman gives the following general laws for simple tension or compression, as having been established by experiment.

a. When a small stress is applied to a body, a small deformation is produced, and on the removal of the stress the body springs back to its original form. For small stresses, then, materials may be regarded as perfectly elastic.

b. Under small stresses the deformations are approximately proportional to the forces or stresses which produce them, and also approximately proportional to the length of the bar or body.

c. When the stress is great enough, a deformation is produced which is partly permanent; that is, the body does not spring back entirely to its original form on removal of the stress. This permanent part is termed a set. In such cases the deformations are not proportional to the stress.

d. When the stress is greater still, the deformation rapidly increases, and the body finally ruptures.

e. A sudden shock or stress is more injurious than a steady stress, or than a stress gradually applied.

ELASTIC LIMIT.

The *elastic limit* of a material under test for tensile strength is defined as the point where the rate of stretch begins to increase, or where the deformations cease to be proportional to the stresses, and the body loses its power to return completely to its former dimensions when the stress is removed.

Modulus of Elasticity.

The *modulus* or *coefficient* of *elasticity* is the term expressing the relation of the amount of extension or compression of a material under stress to the load producing that stress or deformation. It is the load per unit of section divided by the extension per unit of length.

If $P =$ applied load,
$k =$ sectional area of piece,
$l =$ length of the part extended,
$\lambda =$ amount of extension,
$M =$ modulus of elasticity,

$$M = \frac{P}{k} \div \frac{\lambda}{l} = \frac{Pl}{k\lambda}.$$

Following are the *Moduli* of elasticity for various materials.

Brass, cast	9,170,000			
" wire	14,230,000			
Copper	15,000,000	to	18,000,000.	
Lead	1,000,000			
Tin, cast	4,600,000			
Iron, cast	12,000,000	to	27,000,000 (?)	
Iron, wrought	22,000,000	to	29,000,000	
Steel	26,000,000	to	32,000,000	
Marble	25,000,000			
Slate	14,500,000			
Glass	8,000,000			
Ash	1,600,000			
Beech	1,300,000			
Birch	1,250,000	to	1,500,000	
Fir	869,000	to	2,191,000	
Oak	974,000	to	2,283,000	
Teak	2,414,000			
Walnut	306,000			
Pine, long-leaf (butt-logs)	1,119,200	to	3,117,000	Average, 1,926,00

Factor of Safety.

This may be defined as the factor by which the breaking strength of a material is divided to obtain a safe working-stress. The factor of safety is sometimes a rather indefinite quantity, owing to lack of information as to the strength of materials, and it is now becoming common to name a definite stress which is substantially the result of dividing the average strengths by a factor.

The following factors are found in the "Laws Relating to Building in New York City," 1897–1898.

For beams, girders, and pieces subject to transverse strains, factor of safety = 4.

For wrought-iron or rolled-steel posts, columns, or other vertical supports, 4.

For other materials subject to a compressive strain, 5.

For tie-rods, tie-beams, and other pieces subject to tensile strain, 6.

MOMENT OF INERTIA.

The moment of inertia of a body about any axis, is the sum of the products of the mass of each particle of the body, into the square of its (least) distance from the axis.

RADIUS OF GYRATION.

The radius of gyration of a section is the square root of the quotient of the *moment of inertia*, divided by the area of the section, or

$$\text{Radius of gyration} = \sqrt{\frac{\text{Moment of inertia}}{\text{Area of section.}}}$$

The radius of gyration of a solid about an axis is equal to the

$$\sqrt{\frac{\text{Moment of Inertia}}{\text{Mass of the Solid}}}$$

Use in the Formulæ for Strength of Girders and Columns.

The strength of sections to resist strains, either as girders or as columns, depends on the form of the section and its area, and the property of the section which forms the basis of the constants used in the formulæ for strength of girders and columns to express the effect of the form, is its moment of inertia about its neutral axis. Thus the moment of resistance of any section to transverse bending is its moment of inertia divided by the distance from the neutral axis to the fibers farthest removed from the axis; or

$$\text{Moment of resistance} = \frac{\text{Moment of inertia}}{\text{Distance of extreme fiber from axis}}. \quad M = \frac{I}{e}.$$

Moment of Inertia of Compound Shapes.

(Pencoyd Iron Works.)

The moment of inertia of any section about any axis is equal to the I about a parallel axis passing through its center of gravity + (the area of the section × the square of the distance between the axes).

By this rule, the moments of inertia or radii of gyration of any single sections being known, corresponding values may be obtained for any combination of these sections.

Radius of Gyration of Compound Shapes.

In the case of a pair of any shape without a web the value of R can always be found without considering the moment of inertia.

The radius of gyration for any section round an axis parallel to another axis passing through its center of gravity is found as follows:

Let $r =$ radius of gyration around axis through center of gravity; $R =$ radius of gyration around another axis parallel to above; $d =$ distance between axes:

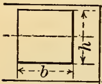
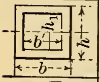
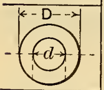
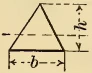
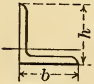
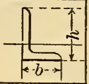
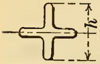
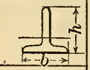
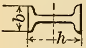
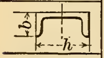
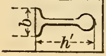
$$R = \sqrt{d^2 + r^2}$$

When r is small, R may be taken as equal to d without material error.

ELEMENTS OF USUAL SECTIONS.

Moments refer to horizontal axis through center of gravity. This table is intended for convenient application where extreme accuracy is not important. Some of the terms are only approximate; those marked * are correct. Values for radius of gyration in flanged beams apply to standard minimum sections only.

$A =$ area of section;
$b =$ breadth;
$h =$ depth;
$D =$ diameter.

Shape of Section.		Moment of Inertia.	Moment of Resistance.	Square of Least Radius of Gyration.	Least Radius of Gyration.
	Solid Rectangle.	$\frac{bh^2}{12}$ *	$\frac{bh^2}{6}$ *	$\frac{\left(\text{Least Side}\right)^{2}}{12}$ *	$\frac{\text{Least side}}{3.46}$ *
	Hollow Rectangle.	$\frac{bh^3-b_1h_1^3}{12}$ *	$\frac{bh^2-b_1h_1^2}{6h}$ *	$\frac{h^2+h_1^2}{12}$ *	$\frac{h+h^1}{4.89}$
	Solid Circle.	$\frac{AD^2}{16}$ *	$\frac{AD}{8}$ *	$\frac{D^2}{16}$ *	$\frac{D}{4}$ *
	Hollow Circle *A*, area of large section; *a*, area of small section.	$\frac{AD^2-ad^2}{16}$	$\frac{AD^2-ad^2}{8D}$	$\frac{D^2+d^2}{16}$ *	$\frac{D+d}{5.64}$
	Solid Triangle.	$\frac{bh^3}{36}$	$\frac{bh^2}{24}$	The least of the two: $\frac{h^2}{18}$ or $\frac{b^2}{24}$	The least of the two: $\frac{h}{4.24}$ or $\frac{b}{4.9}$
	Even Angle.	$\frac{Ah^2}{10.2}$	$\frac{Ah}{7.2}$	$\frac{b^3}{25}$	$\frac{b}{5}$
	Uneven Angle	$\frac{Ah^2}{9.5}$	$\frac{Ah}{6.5}$	$\frac{(hb)^2}{13(h^2+b^2)}$	$\frac{hb}{2.6\,(h+b)}$
	Even Cross.	$\frac{Ah^2}{19}$	$\frac{Ah}{9.5}$	$\frac{h^2}{22.5}$	$\frac{h}{4.74}$
	Even Tee.	$\frac{Ah^2}{11.1}$	$\frac{Ah}{8}$	$\frac{b^2}{22.5}$	$\frac{b}{4.74}$
	I-Beam.	$\frac{Ah^2}{6.66}$	$\frac{Ah}{3.2}$	$\frac{b^2}{21}$	$\frac{b}{4.58}$
	Channel.	$\frac{Ah^2}{7.34}$	$\frac{Ah}{3.67}$	$\frac{b^2}{12.5}$	$\frac{b}{3.54}$
	Deck Beam.	$\frac{Ah^2}{6.9}$	$\frac{Ah}{4}$	$\frac{b^2}{36.5}$	$\frac{b}{6}$

Distance of base from center of gravity, solid triangle, $\frac{h}{3}$; even angle, $\frac{h}{3.3}$; uneven angle, $\frac{h}{3.5}$; even tee, $\frac{h}{3.3}$; deck beam, $\frac{h}{2.3}$; all other shapes given in the table, $\frac{h}{2}$ or $\frac{D}{2}$.

Solid Cast-iron Columns.

Table, based on Hodgkinson's formula (gross tons).

The figures are one-tenth of the breaking weight in tons, for solid columns, ends flat and fixed.

Diam. in Inches.	Length of Column in Feet.								
	6.	8.	10.	12.	14.	16.	18.	20.	25.
1½	.82	.50	.34	.25	.19	.15	.13	.11	.07
1¾	1.43	.87	.60	.44	.34	.27	.22	.18	.13
2	2.31	1.41	.97	.71	.55	.44	.36	.30	.20
2¼	3.52	2.16	1.48	1.08	.83	.67	.54	.46	.31
2½	5.15	3.16	2.16	1.58	1.22	.97	.80	.66	.56
2¾	7.26	4.45	3.05	2.23	1.72	1.37	1.12	.94	.64
3	9.93	6.09	4.17	3.06	2.35	1.87	1.53	1.28	.88
3½	17.29	10.60	7.26	5.32	4.10	3.26	2.67	2.23	1.53
4	27.96	17.15	11.73	8.61	6.62	5.28	4.32	3.61	2.47
4½	42.73	26.20	17.93	13.15	10.12	8.07	6.60	5.52	3.78
5	62.44	38.29	26.20	19.22	14.79	11.79	9.65	8.06	5.52
5½	88.00	53.97	36.93	27.09	20.84	16.61	13.60	11.37	7.78
6	120.4	73.82	50.51	37.05	28.51	22.72	18.60	15.55	10.64
6½	160.6	98.47	67.38	49.43	38.03	30.31	24.81	20.74	14.19
7	209.7	128.6	87.98	64.53	49.66	39.57	32.30	27.08	18.53
7½	268.8	164.8	112.8	82.73	63.66	50.73	41.53	34.72	23.76
8	339.1	207.9	142.3	104.4	80.31	64.00	52.39	43.80	29.97
8½	421.8	258.6	177.0	129.8	99.90	79.61	65.16	54.48	37.28
9	518.2	317.7	217.4	159.5	122.7	97.80	80.05	66.92	45.80
9½	629.5	386.0	264.2	193.8	149.1	118.8	97.25	81.70	55.64
10	757.2	464.3	317.7	233.1	179.3	142.9	117.0	97.79	66.92
10½	902.6	553.5	378.7	277.8	213.8	170.3	139.4	116.6	79.77
11	1067.1	654.4	447.8	328.5	252.7	201.4	164.9	137.8	94.31
11½	1252.3	767.9	525.5	385.4	296.6	236.4	193.5	161.7	110.7
12	1459.6	895.1	612.5	449.3	345.7	275.5	225.5	188.5	129.0

Where the length is less than 30 diameters,

$$\text{Strength in tons of short columns} = \frac{SC}{10S + \frac{3}{4}C},$$

S being the strength given in the above table, and $C = 49$ times the sectional area of the metal in inches.

Hollow Columns.

The strength nearly equals the difference between that of two solid columns, the diameters of which are equal to the external and internal diameters of the hollow one.

More recent experiments carried out by the Building Department of New York City on full-size cast-iron columns, and other tests made at the Watertown Arsenal on cast-iron mill columns, show Gordon's formula, based on Hodgkinson's experiments, to give altogether too high results.

The following table, from results of the New York Building Department tests, as published in the *Engineering News*, January 13–20, 1898, show actual results on columns such as are constantly used in buildings. Applying Gordon's formula to the same columns gives the following as the breaking load per square inch. For 15-inch columns, 57,000 lbs.; for 8-inch and 6-inch columns, 40,000 lbs., all of which are much too high, as shown by the table.

Prof. Lanza gives the average of 11 columns in the Watertown tests as 29,600 pounds per square inch, and recommends that 5,000 pounds per square inch be used as the maximum safe load for crushing strength.

Tests of Cast-iron Columns.

Number.	Diam. Inches.	Thickness.			Breaking Load.	
		Max.	Min.	Average.	Pounds.	Pounds per sq. in.
1	15	1	1	1	1,356,000	30,830
2	15	$1\frac{5}{16}$	1	$1\frac{1}{8}$	1,330,000	27,700
3	15	$1\frac{1}{4}$	1	$1\frac{1}{8}$	1,198,000	24,900
4	$15\frac{1}{8}$	$1\frac{7}{32}$	1	$1\frac{1}{8}$	1,246,000	25,200
5	15	$1\frac{11}{16}$	1	$1\frac{11}{64}$	1,632,000	32,100
6	15	$1\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{3}{16}$	2,082,000+	40,400+
7	$7\frac{3}{4}$ to $8\frac{1}{4}$	$1\frac{1}{4}$	$\frac{5}{8}$	1	651,00	31,900
8	8	$1\frac{3}{32}$	1	$1\frac{3}{64}$	612,800	26,800
9	$6\frac{1}{16}$	$1\frac{5}{32}$	$1\frac{1}{8}$	$1\frac{9}{64}$	400,000	22,700
10	$6\frac{3}{32}$	$1\frac{1}{8}$	$1\frac{1}{16}$	$1\frac{1}{64}$	455,200	26,300

Ultimate Strength of Hollow, Cylindrical Wrought and Cast-iron Columns, when Fixed at the Ends.

(Pottsville Iron and Steel Co.)

Computed by Gordon's formula, $p = \dfrac{f}{1 + C\left(\dfrac{l}{d}\right)^2}$

$p =$ Ultimate strength in lbs. per square inch;

$\left.\begin{array}{l} l = \text{Length of column,} \\ h = \text{Diameter of column,} \end{array}\right\}$ both in same units;

$f = \left\{\begin{array}{l} \text{40,000 lbs. for wrought iron;} \\ \text{80,000 lbs. for cast iron;} \end{array}\right\}$

$C = 1/3000$ for wrought iron, and $1/800$ for cast iron.

For cast iron, $p = \dfrac{80{,}000}{1 + \dfrac{1}{800}\left(\dfrac{l}{h}\right)^2}$.

For wrought iron, $p = \dfrac{40{,}000}{1 + \dfrac{1}{3{,}000}\left(\dfrac{l}{h}\right)^2}$.

Hollow Cylindrical Columns.

Ratio of Length to Diameter. $\frac{l}{h}$	Maximum Load per sq. in.		Safe Load per Square Inch.	
	Cast Iron.	Wrought Iron.	Cast Iron, Factor of 6.	Wrought Iron, Factor of 4.
8	74075	39164	12346	9791
10	71110	38710	11851	9677
12	67796	38168	11299	9542
14	64256	37546	10709	9386
16	60606	36854	10101	9213
18	56938	36100	9489	9025
20	53332	35294	8889	8823
22	49845	34442	8307	8610
24	46510	33556	7751	8389
26	43360	32642	7226	8161
28	40404	31712	6734	7928
30	37646	30768	6274	7692

Hollow Cylindrical Columns.—*Continued.*

Ratio of Length to Diameter. $\frac{l}{h}$	Maximum Load per Sq. In.		Safe Load per Square Inch.	
	Cast Iron.	Wrought Iron.	Cast Iron, Factor of 6.	Wrought Iron, Factor of 4.
32	35088	29820	5848	7455
34	32718	28874	5453	7218
36	30584	27932	5097	6983
38	28520	27002	4753	6750
40	26666	26086	4444	6522
42	24962	25188	4160	6297
44	23396	24310	3899	6077
46	21946	23454	3658	5863
48	20618	22620	3436	5655
50	19392	21818	3262	5454
52	18282	21036	3047	5259
54	17222	20284	2870	5071
56	16260	19556	2710	4889
58	15368	18856	2561	4714
60	14544	18180	2424	4545

Ultimate Strength of Wrought-iron Columns.

$p =$ ultimate strength per square inch;
$l =$ length of column in inches;
$r =$ least radius of gyration in inches.

For square end-bearings,
$$p = \frac{40000}{1 + \frac{1}{40000}\left(\frac{l}{r}\right)^2}.$$

For one pin and one square bearing,
$$p = \frac{40000}{1 + \frac{1}{30000}\left(\frac{l}{r}\right)^2}$$

For two pin bearings,
$$p = \frac{40000}{1 + \frac{1}{20000}\left(\frac{l}{r}\right)^2}.$$

For safe working-load on these columns use a factor of 4 when used in buildings, or when subjected to dead load only; but when used in bridges the factor should be 5.

Wrought-Iron Columns.

$\frac{l}{r}$	Ultimate Strength in Lbs. per Square Inch.			$\frac{l}{r}$	Safe Strength in Lbs. per Square Inch—Factor of 5.		
	Square Ends.	Pin and Sq. End.	Pin Ends.		Square Ends.	Pin and Sq. End.	Pin Ends.
10	39944	39866	39800	10	7989	7973	7960
15	39776	39702	39554	15	7955	7940	7911
20	39604	39472	39214	20	7921	7894	7843
25	39384	39182	38788	25	7877	7836	7758
30	39118	38834	38278	30	7821	7767	7656
35	38810	38430	37690	35	7762	7686	7538
40	38460	37974	37036	40	7692	7595	7407
45	38072	37470	36322	45	7614	7494	7264
50	37646	36928	35525	50	7529	7386	7105
55	37186	36336	34744	55	7437	7267	6949
60	36697	35714	33898	60	7339	7143	6780
65	36182	34478	33024	65	7236	6896	6605
70	35634	34384	32128	70	7127	6877	6426
75	35076	33682	31218	75	7015	6736	6244
80	34482	32966	30288	80	6896	6593	6058
85	33883	32236	29384	85	6777	6447	5877
90	33264	31496	28470	90	6653	6299	5694
95	32636	30750	27562	95	6527	6150	5512
100	32000	30000	26666	100	6400	6000	5333
105	31357	29250	25786	105	6271	5850	5157

TRANSVERSE STRENGTH.

Transverse strength of bars of rectangular section is found to vary directly as the breadth of the specimen tested, as the square of its depth, and inversely as its length. The deflection under load varies as the cube of the length, and inversely as the breadth and as the cube of the depth. Algebraically, if $S =$ the strength and D the deflection, l the length, b the breadth, and d the depth,

$$S \text{ varies as } \frac{bd^2}{l} \text{ and } D \text{ varies as } \frac{l^3}{bd^3}.$$

To reduce the strength of pieces of various sizes to a common standard, the term *modulus of rupture* (R) is used. Its value is obtained by experiment on a bar of rectangular section supported at the ends and loaded in the middle, and substituting numerical values in the following formula:

$$R = \frac{3}{2} \frac{Pl}{bd^2},$$

in which $P =$ the breaking load in pounds, $l =$ the length in inches, b the breadth, and d the depth.

Fundamental Formulæ for Flexure of Beams.

(Merriman.)

Resisting shear = vertical shear;
Resisting moment = bending moment;
Sum of tensile stresses = sum of compressive stresses;
Resisting shear = algebraic sum of all the vertical components of the internal stresses at any section of the beam.

If A be the area of the section and S_s the shearing unit stress, then resisting shear $= AS_s$; and if the vertical shear $= V$, then $V = AS_s$.

The vertical shear is the algebraic sum of all the external vertical forces on one side of the section considered. It is equal to the reaction of one support, considered as a force acting upward, minus the sum of all the vertical downward forces acting between the support and the section.

The resisting moment = algebraic sum of all the moments of the internal horizontal stresses at any section with reference to a point in that section, $= \frac{SI}{c}$, in which $S =$ the horizontal unit stress, tensile or compressive as the case may be, upon the fiber most remote from the neutral axis, $c =$ the shortest distance from that fiber to said axis, and $I =$ the moment of inertia of the cross-section with reference to that axis.

The bending moment M is the algebraic sum of the moment of the external forces on one side of the section with reference to a point in that section = moment of the reaction of one support minus sum of moments of loads between the support and the section considered.

$$M = \frac{SI}{c}.$$

The bending moment is a compound quantity = product of a force by the distance of its point of application from the section considered, the distance being measured on a line drawn from the section perpendicular to the direction of the action of the force.

Concerning the above formula, Prof. Merriman, *Eng. News*, July 21, 1894, says: The formula just quoted is true when the unit-stress S on the part of the beam farthest from the neutral axis is within the elastic limit of the material. It is not true when this limit is exceeded, because then the neutral axis does not pass through the center of gravity of the cross-section, and because also the different longitudinal stresses are not proportional to their distances from that axis, these two requirements being involved in the deduction of the formula. But in all cases of design the permissible unit-stresses should not exceed the elastic limit, and hence the formula applies rationally, without regarding the ultimate strength of the material or any of the circumstances regarding rupture. Indeed, so great reliance is placed upon this formula that the practice of testing beams by rupture has been almost entirely abandoned, and the allowable unit-stresses are mainly derived from tensile and compressive tests.

General Formulæ for Transverse Strength of Beams of Uniform Cross-Section.

Beam.	Rectangular Beam.		Beam of any Section.		
	Breaking Load.	Deflection for Load P or W.	Maximum Moment of Stress.	Moment of Rupture.	Deflection Δ
Fixed at one end, load at the other	$P=\frac{1}{6}\frac{Rbd^2}{l}$	$\frac{4Pl^3}{Ebd^3}$	$Pl =$	$\frac{RI}{c}$	$\frac{1}{3}\frac{Pl^3}{EI}$
Same with load distributed uniformly	$W=\frac{1}{3}\frac{Rbd^2}{l}$	$\frac{3}{2}\frac{Wl^3}{Ebd^3}$	$\frac{1}{2}Wl =$	$\frac{RI}{c}$	$\frac{1}{8}\frac{Wl^3}{EI}$
Supported at ends, loaded in middle	$P=\frac{2}{3}\frac{Rbd^2}{l}$	$\frac{Pl^3}{4Ebd^3}$	$\frac{1}{4}Pl =$	$\frac{RI}{c}$	$\frac{1}{48}\frac{Pl^3}{EI}$
Same loaded uniformly	$W=\frac{4}{3}\frac{Rbd^2}{l}$	$\frac{5}{32}\frac{Wl^3}{Ebd^3}$	$\frac{1}{8}Wl =$	$\frac{RI}{c}$	$\frac{5}{384}\frac{Wl^3}{EI}$
Same, loaded at middle, and also with uniform load	$2P+W=\frac{4}{3}\frac{Rbd^2}{l}$	$\frac{1}{4}\left(P+\frac{1}{8}W\right)\frac{l^3}{Ebd^3}$	$\left(\frac{1}{4}P+\frac{1}{8}W\right)l =$	$\frac{RI}{c}$	$\frac{1}{48}\left(P+\frac{5}{8}W\right)\frac{l^3}{EI}$
Fixed at both ends, loaded in middle . . . . . . :	$P=\frac{4}{3}\frac{Rbd^2}{l}$	$\frac{1}{16}\frac{Pl^3}{Ebd^3}$	$\frac{1}{8}Pl =$	$\frac{RI}{c}$	$\frac{P}{192}\frac{l^3}{EI}$
Same, Barlow's Experiments	$P=\frac{Rbd^2}{l}$		$\frac{1}{6}Pl =$	$\frac{RI}{c}$	
Same, uniformly loaded	$W=\frac{2Rbd^2}{l}$	$\frac{1}{32}\frac{Wl^3}{Ebd^3}$	$\frac{1}{12}Wl =$	$\frac{RI}{c}$	$\frac{W}{384}\frac{l^3}{EI}$
Fixed at one end, supported at the other, loaded at .634l from fixed end		$\frac{.1148Pl^3}{Ebd^3}$	$\frac{3}{8}\left(2\sqrt{3}-3\right)Pl =$	$\frac{RI}{c}$	$\frac{P}{105}\frac{l^3}{EI}$ (nearly).
Same, uniformly loaded	$W=\frac{4}{3}\frac{Rbd^2}{l}$	$\frac{.0648Wl^3}{Ebd^3}$	$\frac{1}{8}Wl =$	$\frac{RI}{c}$	$\frac{W}{185}\frac{l^3}{EI}$ (nearly).

Formulæ for Transverse Strength of Beams.

(Referring to table on preceding page.)

$P =$ load at middle;
$W =$ total load, distributed uniformly;
$l =$ length; $b =$ breadth; $d =$ depth, in inches;
$E =$ modulus of elasticity;
$R =$ modulus of rupture, or stress per square inch of extreme fiber;
$I =$ moment of inertia;
$c =$ distance between neutral axis and extreme fiber.

For breaking-load of circular section, replace bd^2 by $0.59d^3$.

For good wrought iron the value of R is about 80,000, for steel about 120,000, the percentage of carbon apparently having no influence. (Thurston, "Iron and Steel," p. 491.)

For cast iron the value of R varies greatly according to quality. Thurston found 45,740 and 67,980 in No. 2 and No. 4 cast iron, respectively.

For beams fixed at both ends and loaded in the middle, Barlow, by experiment, found the maximum moment of stress $= \frac{1}{6}Pl$ instead of $\frac{1}{8}Pl$, the result given by theory. Prof. Wood ("Resistance Materials," p. 155) says of this case, "The phenomena are of too complex a character to admit of a thorough and exact analysis, and it is probably safer to accept the results of Mr. Barlow in practice than to depend upon theoretical results."

APPROXIMATE GREATEST SAFE LOAD IN LBS. ON STEEL BEAMS.

(Pencoyd Iron Works.)

Based on fiber strains of 16,800 lbs. for steel. (For iron the loads should be one-sixth less, corresponding to a fiber strain of 14,000 lbs. per square inch.)

$L =$ length in feet between supports;
$A =$ sectional area of beam in square inches;
$D =$ depth of beam in inches;
$a =$ interior area in square inches;
$d =$ interior depth in inches;
$w =$ working-load in net tons.

Shape of Section.	Greatest Safe Load in Lbs.		Deflection in Inches.	
	Load in Middle.	Load Distributed.	Load in Middle.	Load Distributed.
Solid Rectangle.	$\frac{940AD}{L}$	$\frac{1880AD}{L}$	$\frac{wL^3}{32AD^2}$	$\frac{wL^3}{52AD^2}$
Hollow Rectangle.	$\frac{940(AD-ad)}{L}$	$\frac{1880(AD-ad)}{L}$	$\frac{wL^3}{32(AD^2-ad^2)}$	$\frac{wL^3}{52(AD^2-ad^2)}$
Solid Cylinder.	$\frac{700AD}{L}$	$\frac{1400AD}{L}$	$\frac{wL^3}{24AD^2}$	$\frac{wL^3}{38AD^2}$
Hollow Cylinder.	$\frac{700(AD-ad)}{L}$	$\frac{1400(AD-ad)}{L}$	$\frac{wL^3}{24(AD^2-ad^2)}$	$\frac{wL^3}{38(AD^2-ad^2)}$

Shape of Section.	Greatest Safe Load in Lbs.		Deflection in Inches.	
	Load in Middle.	Load Distributed.	Load in Middle.	Load Distributed.
Even-legged Angle or Tee.	$\frac{930AD}{L}$	$\frac{1860AD}{L}$	$\frac{wL^3}{32AD^2}$	$\frac{wL^3}{52AD^2}$
Channel or Z Bar.	$\frac{1600AD}{L}$	$\frac{3200AD}{L}$	$\frac{wL^3}{53AD^2}$	$\frac{wL^3}{85AD^2}$
Deck Beam.	$\frac{1450AD}{L}$	$\frac{2900AD}{L}$	$\frac{wL^3}{50AD^2}$	$\frac{wL^3}{80AD^2}$
I-Beam.	$\frac{1780AD}{L}$	$\frac{3560AD}{L}$	$\frac{wL^3}{58AD^2}$	$\frac{wL^3}{93AD^2}$
I	II	III	IV	V

The rules for rectangular and circular sections are correct, while those for the flanged sections are approximate, and limited in their application to the standard shapes as given in the Pencoyd tables.

The calculated safe loads will be approximately one-half of loads that would injure the elasticity of the materials.

The rules for deflection apply to any load below the elastic limit, or less than double the greatest safe load by the rules.

If the beams are long, without lateral support, reduce the loads for the ratios of width to span as follows :

Length of Beam.	Proportion of Calculated Load forming Greatest Safe Load.
20 times flange width.	Whole calculated load.
30 " " "	9–10 " "
40 " " "	8–10 " "
50 " " "	7–10 " "
60 " " "	6–10 " "
70 " " "	5–10 " "

These rules apply to beams supported at each end. For beams supported otherwise, alter the coefficients of the table as described below, referring to the respective columns indicated by number.

Changes of Coefficients for Special Forms of Beams.

Kind of Beam.	Coefficient for Safe Load.	Coefficient for Deflection.
Fixed at one end, loaded at the other.	One-fourth of the coefficient of col. II.	One-sixteenth of the coefficient of col. IV.

Changes of Coefficients — *Continued.*

Kind of Beam.	Coefficient for Safe Load.	Coefficient of Deflection.
Fixed at one end, load evenly distributed.	One-fourth of the coefficient of col. III.	Five forty-eighths of the coefficient of col. V.
Both ends rigidly fixed, or a continuous beam, with a load in middle.	Twice the coefficient of col. II.	Four times the coefficient of col. IV.
Both ends rigidly fixed, or a continuous beam, with load evenly distributed.	One and a half times the coefficient of col. III.	Five times the coefficient of col. V.

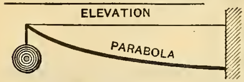
Modulus of Elasticity and Elastic Resistance.

Let $P =$ tensile stress in pounds per square inch at the elastic limit;
$e =$ elongation per unit of length at the elastic unit;
$E =$ modulus of elasticity $= P \div e$; $e = P \div E$.
Then elasticity resilience per cubic inch $= \frac{1}{2}Pe = \frac{1}{2}\frac{P^2}{E}$.

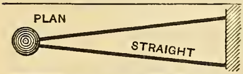
BEAMS OF UNIFORM STRENGTH THROUGHOUT THEIR LENGTH.

The section is supposed in all cases to be rectangular throughout. The beams shown in plan are of uniform depth throughout. Those shown in elevation are of uniform breadth throughout.

$B =$ breadth of beam. $D =$ depth of beam.

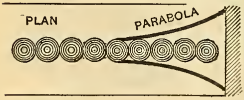


Fixed at one end, loaded at the other; curve parabola, vertex at loaded end; BD^2 proportional to distance from loaded end. The beam may be reversed so that the upper edge is parabolic, or both edges may be parabolic.

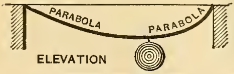


Fixed at one end, loaded at the other; triangle, apex at loaded end; BD^2 proportional to the distance from the loaded end.

Fixed at one end; load distributed; triangle, apex at unsupported end; BD^2 proportional to square of distance from unsupported end.



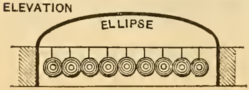
Fixed at one end; load distributed; curves two parabolas, vertices touching each other, at unsupported end; BD^2 proportional to distance from unsupported end.



Supported at both ends; load at any one point; two parabolas, vertices at the points of support, bases at point loaded; BD^2 proportional to distance from nearest point of support. The upper edge or both edges may also be parabolic.

Supported at both ends; load at any one point; two triangles, apices at points of support, bases at point loaded; BD^2 proportional to distance from the nearest point of support.

Supported at both ends; load distributed; curves two parabolas, vertices at the middle of the beam; bases center line of beam; BD^2 proportional to product of distances from points of support.



Supported at both ends; load distributed; curve semi-ellipse; BD^2 proportional to the product of the distances from the points of support.

TRENTON BEAMS AND CHANNELS.

(Trenton Iron Works.)

To find which beam, supported at both ends, will be required to support with safety a given *uniformly distributed* load:

Multiply the load in pounds by the span in feet, and take the beam whose "Coefficient for Strength" is nearest to and exceeds the number so found. The weight of the beam itself should be included in the load.

The deflection in inches for such distributed load will be found by dividing the square of the span taken in feet, by seventy (70) times the depth of the beam taken in inches for iron beams, and by 52.5 times the depth for steel.

EXAMPLE. — Which beam will be required to support a uniformly distributed load of 12 tons (= 24,000 lbs.) on a span of 15 feet?

24,000 × 15 = 360,000, which is less than the coefficient of the $12\frac{1}{4}$-inch 125-lb. iron beam. The weight of the beam itself would be 625 lbs., which, added to the load and multiplied by the span, would still give a product less than the coefficient; thus,

$$24,625 \times 15 = 369,375.$$

The deflection will be:

$$\frac{15 \times 15}{70 \times 12\frac{1}{4}} = 0.26 \text{ inch.}$$

The safe distributed load for each beam can be found by dividing the coefficient by the span in feet, and subtracting the weight of the beam.

When the load is concentrated entirely at the center of the span, one-half of this amount must be taken.

The beams must be secured against yielding sideways, or the safe loads will be much less.

TRENTON ROLLED STEEL BEAMS.

Designation of Beam.	Weight per Yard in Lbs. Min.	Weight per Yard in Lbs. Max.	Width of Flanges in Inches.	Thickness of Stem.	Coefficient for Strength in Lbs., Minimum Weight.
15 inch	150	190	5.75	.45	753,000
15 "	123	160	5.5	.40	603,000
12 "	120	150	5.5	.39	500,000
12 "	96	125	5.25	.32	407,000
10 "	135	160	5.25	.45	461,000
10 "	99	125	5.0	.37	344,000
10 "	76	100	4.75	.32	264,000
9 "	81	105	4.75	.31	262,000
9 "	63	85	4.5	.27	200,000
8 "	66	85	4.5	.27	192,000
8 "	54	75	4.25	.25	154,000
7 "	60	80	4.25	.27	151,000
7 "	46.5	65	4.0	.23	118,000
6 "	50	65	3.5	.30	104,000
6 "	40	55	3.0	.25	83,300
5 "	39	52	3.13	.26	67,000
5 "	30	42	3.0	.22	52,900
4 "	30	40	2.75	.24	41,200
4 "	22.5	32	2.62	.20	31,400
2 "	$4\frac{1}{2}$		.75	$\frac{1}{8}$	2,660
$1\frac{1}{4}$ "	$5\frac{1}{4}$		1.50	$\frac{1}{8}$	2,300

TRENTON IRON BEAMS AND CHANNELS.

Height in In.	Least Weight per Yd. in Lbs.	Width of Flange in Inches.	Thickness of Web in Inches.	Coefficient in Lbs. for Transverse Strength.
I-Beams.				
20	272	6¾	$\frac{11}{16}$	1,320,000
20	200	6	½	990,000
15⅛	200	5¾	.6	748,000
15$\frac{3}{16}$	150	5	½	551,000
15⅛	125	5	.42	460,000
12$\frac{5}{16}$	170	5½	.6	511,000
12¼	125	4.8	.47	377,000
12	120	5½	.39	375,000
12	96	5¼	.32	306,000
10½	135	5	.47	360,000
10½	105	4½	⅜	286,000
10½	90	4½	$\frac{5}{16}$	250,000
9	125	4½	.57	268,000
9	85	4½	⅜	199,000
9	70	4	.3	167,000
8	80	4½	⅜	168,000
8	65	4	.3	135,000
7	55	3¾	.3	101,000
6	120	5¼	⅝	172,000
6	90	5	½	132,000
6	50	3½	.3	76,800
6	40	3	¼	62,600
5	40	3	$\frac{5}{16}$	49,100
5	30	2¾	¼	38,700
4	37	3	$\frac{5}{16}$	36,800
4	30	2¾	¼	30,100
4	18	2	$\frac{3}{16}$	18,000

Height in In.	Least Weight per Yard in Lbs.	Width of Flange in Inches.	Thickness of Web in Inches.	Coefficient in Lbs. for Transverse Strength.
Channels.				
15	190	4¾	¾	625,000
15	120	4	½	401,000
12¼	140	4	$\frac{11}{16}$	381,000
12¼	70	3	.33	200,100
10½	60	2¾	⅜	134,750
10	48	2½	$\frac{5}{16}$	102,000
9	70	3⅛	$\frac{7}{16}$	146,000
9	50	2½	.33	104,000
8	45	2½	.26	88,950
8	33	2.2	.20	65,800
7	36	2½	¼	62,000
7	25½	2	.20	39,500
6	45	2½	.40	58,300
6	33	2¼	.28	45,700
6	22½	1⅞	.18	33,680
5	19	1⅝	.20	22,800
4	16½	1½	.20	15,700
3	15	1½	.20	10,500
Deck Beams.				
8	65	4½	⅜	91,800
7	55	4½	$\frac{5}{16}$	63,500
Strut Bars.				
5	22	1$\frac{7}{16}$	$\frac{5}{16}$	11,900
5	16	1$\frac{5}{16}$	¼	9,100

TABLE GIVING THE SIZE OF BEAMS AND THEIR DISTANCE APART, SUITABLE FOR FLOORS HAVING LOADS PER SQUARE FOOT FROM 100 LBS. TO 300 LBS.

Clear Span in Feet.	Load per Square Foot. 100 Lbs.			Load per Square Foot. 150 Lbs.			Load per Square Foot. 200 Lbs.			Load per Square Foot. 250 Lbs.			Load per Square Foot. 300 Lbs.		
	Size and Weight per Yard.		Distance from Center to Center.	Size and Weight per Yard.		Distance from Center to Center.	Size and Weight per Yard.		Distance from Center to Center.	Size and Weight per Yard.		Distance from Center to Center.	Size and Weight per Yard.		Distance from Center to Center.
	IN.	LB.	FEET.	IN.	LB.	FEET.	IN.	LB.	FEET.	IN.	LB.	FEET.	IN.	LB	FEET.
8	4	30	4.6	4	30	3.1	5	30	3.0	6	40	3.9	6	40	3.2
	5	30	5.9	5	30	4.0	6	40	4.8	6	50	4.7	5	50	3.9
10	5	30	3.8	6	40	4.1	6	40	3.0	6	50	3.0	7	55	3.3
	5	40	4.8	6	50	5.0	6	50	3.7	7	55	4.0	8	65	4.4
12	6	40	4.2	6	50	3.4	7	55	3.4	8	65	3.6	8	65	3.0
	6	50	5.2	7	55	4.6	8	65	4.5	9	70	4.5	9	70	3.8
14	7	55	5.0	7	55	3.3	8	65	3.3	9	70	3.3	9	85	3.3
	8	65	6.7	8	65	4.5	9	70	4.1	10½	90	5.0	10½	90	4.2
16	8	65	5.0	8	65	3.3	9	85	3.7	10½	90	3.8	10½	105	3.6
	9	70	6.3	9	70	4.2	10½	90	4.7	10½	105	4.3	12¼	125	4.8
18	9	70	4.9	9	85	3.9	10½	105	4.2	10½	105	3.4	10½	135	3.6
	9	85	5.9	10½	90	4.9	12	96	4.6	12¼	125	4.5	12¼	125	3.7
20	10½	90	6.0	10½	105	4.5	10½	105	3.4	12¼	125	3.6	12¼	125	3.0
	...	...	...	12¼	125	6.0	12¼	125	4.5	12¼	170	4.9	15	150	4.4
22	10½	90	4.9	12	96	4.0	12¼	125	3.7	12¼	125	3.0	12¼	170	3.3
	10½	105	5.6	12¼	125	4.9	15	125	4.5	15	125	3.6	15	150	3.6
24	12	96	5.0	12¼	125	4.1	12¼	125	3.0	12¼	170	3.3	15	150	3.0
	12¼	125	6.1	15	125	5.0	15	150	4.5	15	150	3.6	15	200	4.1
26	12¼	125	5.1	15	125	4.3	15	150	3.8	15	150	3.0	15	200	3.5
	...	...	...	15	150	5.1	15	200	5.2	15	200	4.2	20	200	4.7
28	15	125	5.5	15	150	4.3	15	200	4.4	15	200	3.5	20	200	3.9
	...	...	...	15	200	5.9	20	200	6.0	20	200	4.8	20	272	5.3
30	15	150	5.6	15	150	3.7	15	200	3.8	20	200	4.1	20	200	3.4
	...	...	...	15	200	5.1	20	200	5.2	20	272	5.5	20	272	4.6

WOOD.

Properties of Timber.

Description.	Weight per cubic foot in lbs.	Weight per ft. B. M. in lbs. average	Tensile strength per sq. in., in lbs.	Crushing strength per sq. in., in lbs.	Relative strength for cross breaking White Pine=100.	Shearing strength with the grain, lbs. per sq. in.	Pressure in lbs. per sq. in. to indent $\frac{1}{20}''$.
Ash	43 to 55.8	4.1	11000 to 17207	4400 to 9363	130 to 180	458 to 700	1800 to 1850
Beech	43 to 53.4	3.9	11500 to 18000	5800 to 9363	100 to 144	. . . .	. . . . .
Cedar	50 to 56.8	4.5	10300 to 11400	5600 to 6000	55 to 63	. . . .	. . . . .
Cherry	. . . . .	. . . . .	. . . . . .	. . . . . .	130	. . . .	. . . . .
Chestnut	33	2.75	10500	5350 to 5600	96 to 123	. . . .	. . . . .
Elm	34 to 36.7	2.9	13400 to 13489	6831 to 10331	96	. . . .	. . . . .
Hemlock	. . . . .	. . . . .	8700	5700	88 to 95	. . . .	. . . . .
Hickory	. . . . .	. . . . .	12800 to 18000	8925	150 to 210	. . . .	. . . . .
Locust	44	3.7	20500 to 24800	9113 to 11700	132 to 227	. . . .	. . . . .
Maple	49	4.1	10500 to 10584	8150	122 to 220	367 to 647	1700 to 1900
Oak, White	45 to 54.5	4.1	10253 to 19500	4684 to 9509	130 to 177	752 to 966	2300 to 3550
Oak, Live	70	5.8	. . . . . .	6850	155 to 189	. . . .	. . . . .
Pine, White	30	2.5	10000 to 12000	5000 to 6650	100	225 to 423	875 to 1160
Pine, Yellow	28.8 to 33	2.6	12600 to 19200	5400 to 9500	98 to 170	286 to 415	1900
Spruce	. . . . .	. . . . .	10000 to 19500	5050 to 7850	86 to 110	253 to 374	875 to 1025
Walnut, Black . . .	42	3.5	9286 to 16000	7500	. . . .	. . . .	2200 to 2600

Tests of American Woods.

In all cases a large number of tests were made of each wood. Minimum and maximum results only are given. All of the test specimens had a sectional area of 1.575 × 1.575 inches. The transverse test specimens were 39.37 inches between supports, and the compressive test specimens were 12.60 inches long. Modulus of rupture calculated from formula $R = \frac{3}{2} \frac{Pl}{bd^2}$; $P =$ load in pounds at the middle, $l =$ length in inches, $b =$ breadth, $d =$ depth:

Name of Wood.	Transverse Tests, Modulus of Rupture.		Compression Parallel to Grain, pounds per sq. in.	
	Min.	Max.	Min.	Max.
Cucumber tree	7440	12050	4560	7410
Yellow poplar, white wood	6560	11756	4150	5790
White wood, Basswood	6720	11530	3810	6480
Sugar maple, Rock maple	9680	20130	7460	9940
Red maple	8610	13450	6010	7500
Locust	12200	21730	8330	11940
Wild cherry	8310	16800	5830	9120
Sweet gum	7470	11130	5630	7620
Dogwood	10190	14560	6250	9400
Sour gum, pepperidge	9830	14300	6240	7480
Persimmon	18500	10290	6650	8080
White ash	5950	15800	4520	8830
Sassafras	5180	10150	4050	5970
Slippery elm	10220	13952	6980	8790
White elm	8250	15070	4960	8040
Sycamore, Buttonwood	6720	11360	4960	7340
Butternut, white walnut	4700	11740	5480	6810
Black walnut	8400	16320	6940	8850
Shellbark hickory	14870	20710	7650	10280
Pignut	11560	19430	7460	8470
White oak	7010	18360	5810	9070
Red oak	9760	18370	4960	8970
Black oak	7900	18420	4540	8550
Chestnut	5950	12870	3680	6650
Beech	13850	18840	5770	7840
Canoe birch, paper birch	11710	17610	5770	8590
Cottonwood	8390	13430	3790	6510
White cedar	6310	9530	2660	5810
Red cedar	5640	15100	4400	7040
Cypress	9530	10030	5060	7140
White pine	5610	11530	3750	5600
Spruce pine	3780	10980	2580	4680
Long-leaved pine, Southern pine	9220	21060	4010	10600
White spruce	9900	11650	4150	5300
Hemlock	7590	14680	4500	7420
Red fir, yellow fir	8220	17920	4880	9800
Tamarack	10080	16770	6810	10700

Wooden Beams.

Safe Uniformly Distributed Load in Tons of 2000 Pounds for Rectangular Spruce or White Pine Beams one Inch in Thickness.

Span in feet.	Depth in Inches.														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.069	0.278	0.625	1.111	1.736	2.500	3.403	4.444	5.625	6.944	8.403	10.000	11.737	13.611	15.625
2	0.035	0.139	0.312	0.556	0.868	1.250	1.701	2.222	2.812	3.472	4.201	5.000	5.868	6.806	7.812
3	0.023	0.093	0.208	0.370	0.579	0.833	1.134	1.481	1.875	2.315	2.801	3.333	3.912	4.537	5.208
4	0.017	0.069	0.156	0.278	0.434	0.625	0.851	1.111	1.406	1.738	2.101	2.500	2.934	3.403	3.906
5	0.014	0.056	0.125	0.222	0.347	0.500	0.681	0.888	1.125	1.389	1.681	2.000	2.347	2.722	3.125
6	0.012	0.046	0.104	0.185	0.289	0.417	0.567	0.741	0.938	1.157	1.400	1.667	1.956	2.269	2.604
7	0.010	0.040	0.089	0.159	0.248	0.357	0.486	0.635	0.804	0.992	1.200	1.429	1.677	1.944	2.232
8	0.009	0.035	0.078	0.139	0.217	0.312	0.425	0.555	0.703	0.868	1.050	1.250	1.467	1.701	1.953
9	0.008	0.031	0.069	0.123	0.193	0.278	0.378	0.494	0.625	0.772	0.934	1.111	1.304	1.512	1.736
10	0.007	0.028	0.062	0.111	0.174	0.250	0.340	0.444	0.562	0.694	0.840	1.000	1.174	1.361	1.562
11	0.006	0.025	0.057	0.101	0.158	0.227	0.309	0.404	0.511	0.631	0.764	0.909	1.067	1.237	1.420
12	0.006	0.023	0.052	0.093	0.145	0.208	0.284	0.370	0.469	0.579	0.700	0.833	0.978	1.134	1.302
13	0.005	0.021	0.048	0.085	0.134	0.192	0.261	0.342	0.433	0.534	0.646	0.769	0.903	1.047	1.202
14	0.005	0.020	0.045	0.079	0.124	0.179	0.243	0.317	0.402	0.496	0.600	0.714	0.838	0.972	1.116
15	0.005	0.019	0.042	0.074	0.116	0.167	0.227	0.296	0.375	0.463	0.560	0.667	0.782	0.907	1.042
16	0.004	0.017	0.039	0.069	0.109	0.156	0.213	0.278	0.352	0.434	0.525	0.625	0.734	0.851	0.977
17	0.004	0.016	0.037	0.065	0.102	0.147	0.200	0.261	0.331	0.408	0.494	0.588	0.690	0.801	0.919
18	0.004	0.015	0.035	0.062	0.096	0.139	0.189	0.247	0.312	0.386	0.467	0.556	0.652	0.756	0.868
19	0.004	0.015	0.033	0.058	0.091	0.132	0.179	0.234	0.296	0.365	0.442	0.526	0.617	0.716	0.822
20	0.003	0.014	0.031	0.056	0.087	0.125	0.170	0.222	0.281	0.347	0.420	0.500	0.587	0.681	0.781
21	...	0.013	0.030	0.053	0.083	0.119	0.162	0.212	0.268	0.331	0.400	0.476	0.559	0.648	0.744
22	...	0.013	0.028	0.051	0.079	0.114	0.155	0.202	0.256	0.311	0.382	0.455	0.533	0.619	0.710
23	...	...	0.027	0.048	0.075	0.109	0.148	0.193	0.245	0.302	0.365	0.435	0.510	0.592	0.679
24	...	...	...	0.046	0.072	0.104	0.142	0.185	0.234	0.289	0.350	0.417	0.489	0.567	0.651
25	...	...	...	...	0.069	0.100	0.136	0.178	0.225	0.278	0.336	0.400	0.469	0.544	0.625
26	...	...	...	...	...	0.096	0.131	0.171	0.216	0.267	0.323	0.385	0.451	0.524	0.601
27	...	...	...	...	...	...	0.126	0.165	0.208	0.257	0.311	0.370	0.435	0.504	0.579
28	...	...	...	...	...	...	...	0.159	0.201	0.248	0.300	0.357	0.419	0.486	0.558
29	...	...	...	...	...	...	...	...	0.196	0.239	0.290	0.345	0.405	0.469	0.539
30	...	...	...	...	...	...	...	...	...	0.231	0.280	0.333	0.391	0.454	0.521

These loads are about one-eighth the breaking-load.

RULE. — *To find the safe uniformly distributed load* in tons for white pine or spruce beams, multiply the number given in the above table by the thickness of the beam in inches. For beams of other wood, multiply also by the following numbers :

White Oak.	Hemlock.	White Cedar.	Yellow Pine.	Chestnut.
1.45	.99	.60	1.50	1.08

Formulæ for White Pine Beams.

Subject to vibration from *live* loads.

$w =$ safe load in pounds, less weight of beam.
$l =$ length of beam in inches.
$d =$ depth of beam in inches.
$b =$ breadth of beam in inches.

For a beam fixed at one end and loaded at the other:

$$w = \frac{1000\,bd^2}{6l}.$$

For a beam fixed at one end and uniformly loaded:

$$w = \frac{1000\,bd^2}{3l}.$$

For a beam supported at both ends and loaded at the middle:

$$w = \frac{2000\,bd^2}{3l}.$$

For a beam supported at both ends and uniformly loaded:

$$w = \frac{4000\,bd^2}{3l}$$

NOTE.—In placing very heavy loads upon short, but deep and strong beams, care should be taken that the beams rest for a sufficient distance on their supports to prevent all danger from *crushing* or *shearing* at the ends. Ordinary timbers crush under 6,000 lbs. per square inch. To assure a safety of beam against crushing at the end, divide half of the load by 1000; the quotient will be the least number of square inches of base that should be allowed for each end to rest on.

Table of Safe Load for Moderately Seasoned White Pine Struts or Pillars.

The following table, exhibiting the approximate strength of white pine struts or pillars, with flat ends, is outlined and interpolated from the rule of Rondolet, that the safe load upon a cube of the material being regarded as unity, the safe load upon a post whose height is,

12 times the side will be	$\frac{5}{6}$
24 " " "	$\frac{1}{2}$
36 " " "	$\frac{1}{3}$
48 " " "	$\frac{1}{6}$
60 " " "	$\frac{1}{12}$
72 " " "	$\frac{1}{24}$

700 pounds per square inch is assumed as the safe load upon a cube of white pine.

The strength of each strut is considered with reference to the first-named dimension of its cross-section, so that if the second dimension is less than the first, the strut must be supported in that direction, to fulfill the conditions of the computation.

The strength of pillars, as well as of beams of timber, depends much on their *degree of seasoning*. Hodgkinson found that perfectly seasoned blocks 2 diameters long, required in many cases twice as great a load to crush them as when only moderately dry. This should be borne in mind when building with green timber.

I. Safe Distributed Loads upon Southern Pine Beams One Inch in Width.

(C. J. H. Woodbury.)

(If the load is concentrated at the center of the span, the beams will sustain half the amount as given in the table.)

Span, Feet.	Depth of Beam in Inches.														
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Load in Pounds per Foot of Span.														
5	38	86	154	240	346	470	614	778	960						
6	27	60	107	167	240	327	427	540	667	807					
7	20	44	78	122	176	240	314	397	490	593	705	828			
8	15	34	60	94	135	184	240	304	375	454	540	634	735		
9	. .	27	47	74	107	145	190	240	296	359	427	501	581	667	759
10	. .	22	38	60	86	118	154	194	240	290	346	406	470	540	614
11	. .	. .	32	50	71	97	127	161	198	240	286	335	389	446	508
12	. .	. .	27	42	60	82	107	135	167	202	240	282	327	375	474
13	. .	. .	. .	36	51	70	90	115	142	172	205	240	278	320	364
14	. .	. .	. .	31	44	60	78	99	123	148	176	207	240	276	314
15	. .	. .	. .	27	38	52	68	86	107	129	154	180	209	240	273
16	. .	. .	. .	. .	34	46	60	76	94	113	135	158	184	211	240
17	. .	. .	. .	. .	30	41	53	67	83	101	120	140	163	187	217
18	. .	. .	. .	. .	. .	36	47	60	74	90	107	125	145	167	190
19	. .	. .	. .	. .	. .	. .	43	54	66	80	96	112	130	150	170
20	. .	. .	. .	. .	. .	. .	38	49	60	73	86	101	118	135	154
21	. .	. .	. .	. .	. .	. .	. .	44	54	66	78	92	107	122	139
22	. .	. .	. .	. .	. .	. .	. .	. .	50	60	71	84	97	112	127
23	. .	. .	. .	. .	. .	. .	. .	. .	45	55	65	77	89	102	116
24	. .	. .	. .	. .	. .	. .	. .	. .	. .	50	60	70	82	94	107
25	. .	. .	. .	. .	. .	. .	. .	. .	. .	46	55	65	75	86	98

II. Distributed Loads upon Southern Pine Beams Sufficient to Produce Standard Limit of Deflection.

(C. J. H. Woodbury.)

Span, Feet.	Depth of Beam in Inches.															Deflection, Inches.
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
	Load in Pounds per Foot of Span.															
5	3	10	23	44	77	122	182	259								.0300
6	2	7	16	31	53	85	126	180	247							.0432
7	. .	5	12	23	39	62	93	132	181	241						.0588
8	. .	4	9	17	30	48	71	101	139	185	240	305				.0768
9	. .	. .	7	14	24	38	56	80	110	146	190	241	301			.0972
10	. .	. .	6	11	19	30	46	65	89	118	154	195	244	300		.1200
11	. .	. .	. .	9	16	25	38	54	73	98	127	161	202	248	301	.1452
12	. .	. .	. .	. .	13	21	32	45	62	82	107	136	169	208	253	.1728
13	. .	. .	. .	. .	11	18	27	38	53	70	91	116	144	178	215	.2028
14	. .	. .	. .	. .	. .	16	23	33	45	60	78	100	124	153	186	.2352
15	. .	. .	. .	. .	. .	14	20	29	40	53	68	87	108	133	162	.2700
16	. .	. .	. .	. .	. .	. .	18	25	35	46	60	76	95	117	147	.3072
17	. .	. .	. .	. .	. .	. .	16	22	31	41	53	68	84	104	126	.3468
18	. .	. .	. .	. .	. .	. .	. .	20	27	37	47	60	75	93	112	.3888
19	. .	. .	. .	. .	. .	. .	. .	18	25	33	43	54	68	83	101	.4332
20	. .	. .	. .	. .	. .	. .	. .	. .	22	30	38	49	61	75	91	.4800
21	. .	. .	. .	. .	. .	. .	. .	. .	20	27	35	44	55	68	83	.5292
22	. .	. .	. .	. .	. .	. .	. .	. .	. .	24	32	40	50	62	75	.5808
23	. .	. .	. .	. .	. .	. .	. .	. .	. .	22	29	37	46	57	69	.6348
24	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	27	34	42	52	63	.6912
25	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	25	31	39	48	58	.7500

MASONRY.

Brick-Work.

Brick work is generally measured by 1000 bricks laid in the wall. In consequence of variations in size of bricks, no rule for volume of laid brick can be exact. The following scale is, however, a fair average.

7	common bricks to a super. ft.	4-inch wall.
14	“ “ “ “	9-inch “
21	“ “ “ “	13-inch “
28	“ “ “ “	18-inch “
35	“ “ “ “	22-inch “

Corners are not measured twice, as in stone-work. Openings over 2 feet square are deducted. Arches are counted from the spring. Fancy work counted $1\frac{1}{2}$ bricks for 1. Pillars are measured on their face only.

One thousand bricks, closely stacked, occupy about 56 cubic feet.

One thousand old bricks, cleaned and loosely stacked, occupy about 72 cubic feet.

One cubic foot of foundation, with one-fourth inch joints, contains 21 bricks. In some localities 24 bricks are counted as equal to a cubic foot.

One superficial foot of gauged arches requires 10 bricks.

Stock bricks commonly measure $8\frac{3}{4}$ inches by $4\frac{1}{4}$ inches by $2\frac{3}{4}$ inches, and weigh from 5 to 6 lbs. each.

Paving bricks should measure 9 inches by $4\frac{1}{2}$ inches by $1\frac{3}{4}$ inches, and weigh about $4\frac{1}{2}$ lbs. each.

One yard of paving requires 36 stock bricks, of above dimensions, laid flat, or 52 on edge; and 35 paving bricks, laid flat, or 82 on edge.

The following table gives the usual dimensions of the bricks of some of the principal makers.

Description.	Inches.	Description.	Inches.
Baltimore front .	$8\frac{1}{4} \times 4\frac{1}{8} \times 2\frac{3}{8}$	Maine	$7\frac{1}{2} \times 3\frac{3}{8} \times 2\frac{3}{8}$
Philadelphia front		Milwaukee . .	$8\frac{1}{2} \times 4\frac{1}{8} \times 2\frac{3}{8}$
Wilmington front		North River .	$8 \times 3\frac{1}{2} \times 2\frac{1}{4}$
Trenton front .		Trenton . . .	$8 \times 4 \times 2\frac{1}{4}$
Croton	$8\frac{1}{2} \times 4 \times 2\frac{1}{4}$	Ordinary . . .	$7\frac{3}{4} \times 3\frac{5}{8} \times 2\frac{1}{4}$
Colabaugh . . .	$8\frac{1}{4} \times 3\frac{5}{8} \times 2\frac{3}{8}$		$8 \times 4\frac{1}{8} \times 2\frac{1}{2}$

Fire Brick —	Valentine's (Woodbridge, N. J.) . .	$8\frac{7}{8} \times 4\frac{3}{8} \times 2\frac{1}{2}$ inches
	Downing's (Allentown, Pa.)	$9 \times 4\frac{1}{2} \times 2\frac{1}{2}$ inches

To compute the number of bricks in a square foot of wall.—To the face dimensions of the bricks used, add the thickness of one joint of mortar, and multiply these together to obtain the area. Divide 144 square inches by this area, and multiply by the number of times which the dimension of the brick, at right angles to its face, is contained in the thickness of the wall.

EXAMPLE.—How many Trenton bricks in a square foot of 12-inch wall, the joints being $\frac{1}{4}$ inch thick?

$\overline{8+\frac{1}{4}} \times \overline{2\frac{1}{4}+\frac{1}{4}} = 20.62$; $144 \div 20.62 = 7$; $7 \times 3 = 21$ bricks per square ft.

Weight and Bulk of Bricks.

Gross Tons.	Pounds.	Cu. ft.	Number of Bricks, by itself.		Number of Bricks, in wall with cement.	
			C. Brick.	F. Brick.	C. Brick.	F. Brick.
1	2240	22.4	448	416.6	381	347
0.04464	100	**1**	20	18.6	17	15½
2.23	5000	50.00	**1000**	930	850	772
2.4	5376	53.76	1075	**1000**	914	834
2.62	5872	58.72	1130	1100	**1000**	913
2.88	6451	64.51	1240	1200	1100	**1000**

One perch of stone is 24.75 cubic feet.

In New York City laws a cubic foot of brick-work is deemed to weigh 115 lbs.

Building-stone is deemed to weigh 160 lbs. per cubic foot.

The safe load for brick-work according to the New York City Laws is as follows: —

In tons per superficial foot,

For good lime mortar	8 tons.
For good lime and cement mortar mixed	11½ tons.
For good cement mortar	15 tons.

Average Ultimate Crushing-Load in Pounds per Square Inch for Bricks, Stones, Mortars, and Cements.

	Lbs. per Sq. In.
Brick, common (Eastern)	10000
Brick, best pressed	12000
Brick (Trautwine)	770 to 4660
Brick, paving, average of 10 varieties (Western)	7150
Brick-work, ordinary	300 to 500
Brick-work, in good cement	450 to 1000
Brick-work, first-class, in cement	930
Concrete (1 part lime, 3 parts gravel, 3 weeks old)	620
Lime mortar, common	770
Portland cement, best English,	
Pure, three months old	3760
Pure, nine months old	5960
1 part sand, 1 part cement,	
Three months old	2480
Nine months old	4520
Granites, 7750 to 22,750	12000
Blue granite, Fox Island, Me.	14875
Blue granite, Staten Island, N. Y.	22250
Gray granite, Stony Creek, Conn.	15750
North River (N. Y.) flagging	13425
Limestones, 11,000 to 25,000	12000
Limestone from Glen's Falls, N. Y.	11475
Lake limestone, Lake Champlain, N. Y.	25000
White limestone, Marblehead, O.	11225
White limestone from Joliet, Ill.	12775
Marbles,	
From East Chester, N. Y.	12950
Common Italian	11250
Vermont (Southerland Falls Co.)	10750
Vermont, Dorset, Vt.	7612
Drab, North Bay Quarry, Wis.	20025

Average Ultimate Crushing-Load — *Continued.*

	Lbs. per Sq. In.
Sandstones	6000
Brown, Little Falls, N. Y.	9850
Brown, Middletown, Conn.	6950
Red, Haverstraw, N. Y.	4350
Red-brown, Seneca freestone, Ohio	9687
Freestone, Dorchester, N. B.	9150
Longmeadow sandstone, Springfield, Mass.	8000 to 14000

MISCELLANEOUS MATERIALS.

Weight of Round Bolt Copper Per Foot.

Inches.	Pounds.	Inches.	Pounds.	Inches.	Pounds.
$\frac{3}{8}$	.425	1	3.02	$1\frac{5}{8}$	7.99
$\frac{1}{2}$	.756	$1\frac{1}{8}$	3.83	$1\frac{3}{4}$	9.27
$\frac{5}{8}$	1.18	$1\frac{1}{4}$	4.72	$1\frac{7}{8}$	10.64
$\frac{3}{4}$	1.70	$1\frac{3}{8}$	5.72	2	12.10
$\frac{7}{8}$	2.31	$1\frac{1}{2}$	6.81		

Weight of Sheet and Bar Brass.

Thickness. Inches.	Sheets per sq. ft.	Square Bars 1 ft. long.	Round Bars 1 ft. long.	Thickness. Inches.	Sheets per sq. ft.	Square Bars 1 ft. long.	Round Bars 1 ft. long.
	lbs.	lbs.	lbs.		lbs.	lbs.	lbs.
$\frac{1}{16}$	2.7	.015	.011	$1\frac{1}{16}$	45.95	4.08	3.20
$\frac{1}{8}$	5.41	.055	.045	$1\frac{1}{8}$	48.69	4.55	3.57
$\frac{3}{16}$	8.12	.125	.1	$1\frac{3}{16}$	51.4	5.08	3.97
$\frac{1}{4}$	10.76	.225	.175	$1\frac{1}{4}$	54.18	5.65	4.41
$\frac{5}{16}$	13.48	.350	.275	$1\frac{5}{16}$	56.85	6.22	4.86
$\frac{3}{8}$	16.25	.51	.395	$1\frac{3}{8}$	59.55	6.81	5.35
$\frac{7}{16}$	19.	.69	.54	$1\frac{7}{16}$	62.25	7.45	5.85
$\frac{1}{2}$	21.65	.905	.71	$1\frac{1}{2}$	65.	8.13	6.37
$\frac{9}{16}$	24.3	1.15	.9	$1\frac{9}{16}$	67.75	8.83	6.92
$\frac{5}{8}$	27.12	1.4	1.1	$1\frac{5}{8}$	70.35	9.55	7.48
$\frac{11}{16}$	29.77	1.72	1.35	$1\frac{11}{16}$	73.	10.27	8.05
$\frac{3}{4}$	32.46	2.05	1.66	$1\frac{3}{4}$	75.86	11.	8.65
$\frac{13}{16}$	35.18	2.4	1.85	$1\frac{13}{16}$	78.55	11.82	9.29
$\frac{7}{8}$	37.85	2.75	2.15	$1\frac{7}{8}$	81.25	12.68	9.95
$\frac{15}{16}$	40.55	3.15	2.48	$1\frac{15}{16}$	84.	13.5	10.58
1	43.29	3.65	2.85	2	86.75	14.35	11.25

Composition of Various Grades of Rolled Brass.

Trade Name.	Copper.	Zinc.	Tin.	Lead.	Nickel.
Common high brass	61.5	38.5	...	...	...
Yellow metal	60	40	...	...	...
Cartridge brass	$66\frac{2}{3}$	$33\frac{1}{3}$	...	...	...
Low brass	80	20	...	...	...
Clock brass	60	40	...	$1\frac{1}{2}$	...
Drill rod	60	40	...	$1\frac{1}{2}$ to 2	...
Spring brass	$66\frac{2}{3}$	$33\frac{1}{3}$	$1\frac{1}{2}$	...	...
18 per cent German silver	$61\frac{1}{2}$	$20\frac{1}{2}$	...	...	18

Weight of Copper and Brass Wire and Plates.

B. & S. Gauge No.	Size of Each No.	Weight of Wire per 1000 Lineal Feet.		Weight of Plates per Square Foot.	
		Copper.	Brass.	Copper.	Brass.
	Inch.	Lbs.	Lbs.	Lbs.	Lbs.
0000	.46000	640.5	605.28	20.84	19.69
000	.40964	508.0	479.91	18.55	17.53
00	.36480	402.0	380.77	16.52	15.61
0	.32476	319.5	301.82	14.72	13.90
1	.28930	253.3	239.45	13.10	12.38
2	.25763	200.9	189.82	11.67	11.03
3	.22942	159.3	150.52	10.39	9.82
4	.20431	126.4	119.48	9.25	8.74
5	.18194	100.2	94.67	8.24	7.79
6	.16202	79.46	75.08	7.34	6.93
7	.14428	63.01	59.55	6.54	6.18
8	.12849	49.98	47.22	5.82	5.50
9	.11443	39.64	37.44	5.18	4.90
10	.10189	31.43	29.69	4.62	4.36
11	.090742	24.92	23.55	4.11	3.88
12	.080808	19.77	18.68	3.66	3.46
13	.071961	15.65	14.81	3.26	3.08
14	.064084	12.44	11.75	2.90	2.74
15	.057068	9.86	9.32	2.59	2.44
16	.050820	7.82	7.59	2.30	2.18
17	.045257	6.20	5.86	2.05	1.94
18	.040303	4.92	4.65	1.83	1.72
19	.035890	3.90	3.68	1.63	1.54
20	.031961	3.09	2.92	1.45	1.37
21	.028462	2.45	2.317	1.29	1.22
22	.025347	1.94	1.838	1.15	1.08
23	.022571	1.54	1.457	1.02	.966
24	.020100	1.22	1.155	.911	.860
25	.017900	.699	.916	.811	.766
26	.01494	.769	.727	.722	.682
27	.014195	.610	.576	.643	.608
28	.012641	.484	.457	.573	.541
29	.011257	.383	.362	.510	.482
30	.010025	.304	.287	.454	.429
31	.008928	.241	.228	.404	.382
32	.007950	.191	.181	.360	.340
33	.007080	.152	.143	.321	.303
34	.006304	.120	.114	.286	.270
35	.005614	.096	.0915	.254	.240
36	.005000	.0757	.0715	.226	.214
37	.004453	.0600	.0567	.202	.191
38	.003965	.0476	.0450	.180	.170
39	.003531	.0375	.0357	.160	.151
40	.003144	.0299	.0283	.142	.135

Galvanized Iron Wire Rope.

For Ships' Rigging and Guys for Derricks.

CHARCOAL ROPE.

Circumference in Inches.	Weight per Fathom in Pounds.	Cir. of New Manila Rope of Equal Strength.	Breaking Strain in Tons of 2000 Lbs.	Circumference in Inches.	Weight per Fathom in Pounds.	Cir. of New Manila Rope of Equal Strength.	Breaking Strain in tons of 2000 Lbs.
5½	26½	11	43	2½	5½	5	9
5¼	24½	10½	40	2¼	4½	4¾	8
5	22	10	35	2	3½	4½	7
4¾	21	9½	33	1¾	2½	3¾	5
4½	19	9	30	1½	2	3	3½
4¼	16½	8½	26	1¼	1¾	2½	2½
4	14¼	8	23	1⅛	1¼	2½	2¼
3¾	12¾	7½	20	1	⅞	2¼	2
3½	10¾	6½	16	⅞	¾	1¾	1
3¼	9½	6	14	¾	½	1½	¾
3	8	5¾	12	⅝	⅜	1¼	⅝
2¾	6¾	5¼	10	½	¼	1⅛	⅜

Transmission and Standing Rope.

With 6 Strands of 7 Wires Each.

IRON.

Trade Number.	Diameter.	Circumference.	Weight per Foot in Lbs. of Rope with Hemp Center.	Breaking Strain in Tons of 2000 Lbs.	Proper Working Load in Tons of 2000 Lbs.	Circumference of new Manila Rope of Equal Strength.	Min. Size of Drum or Sheave in Feet.
11	1½	4⅝	3.37	36	9	10	13
12	1⅜	4¼	2.77	30	7½	9	12
13	1¼	3¾	2.28	25	6¼	8½	10¾
14	1⅛	3⅜	1.82	20	5	7½	9½
15	1	3	1.50	16	4	6½	8½
16	⅞	2⅝	1.12	12.3	3	5¾	7½
17	¾	2⅜	0.88	8.8	2¼	4¾	6¾
18	11/16	2⅛	0.70	7.6	2	4½	6
19	⅝	1⅞	0.57	5.8	1½	4	5¼
20	9/16	1⅝	0.41	4.1	1	3¼	4½
21	½	1⅜	0.31	2.83	¾	2¾	4
22	7/16	1¼	0.23	2.13	½	2½	3¼
23	⅜	1⅛	0.19	1.65	. . .	2¼	2¾
24	5/16	1	0.16	1.38	. . .	2	2½
25	9/32	⅞	0.125	1.03	. . .	1¾	2¼

CAST STEEL.

Trade Number.	Diameter.	Circumference.	Weight per Foot in Lbs. of Rope with Hemp Center.	Breaking Strain in Tons of 2000 Lbs.	Proper Working Load in Tons of 2000 Lbs.	Circumference of new Manila Rope of Equal Strength.	Min. Size of Drum or Sheave in Feet.
11	1½	4⅝	3.37	62	13	13	8½
12	1⅜	4¼	2.77	52	10	12	8
13	1¼	3¾	2.28	44	9	11	7¼
14	1⅛	3⅜	1.82	36	7½	10	6¼
15	1	3	1.50	30	6	9	5¾
16	⅞	2⅝	1.12	22	4½	8	5

Transmission and Standing Rope. — *Continued.*

CAST STEEL.

Trade Number.	Diameter.	Circumference.	Weight per Foot in Lbs. of Rope with Hemp Center.	Breaking Strain in Tons of 2000 Lbs.	Proper Working Load in Tons of 2000 Lbs.	Circumference of new Manila Rope of Equal Strength.	Min. Size of Drum or Sheave in Feet.
17	$\frac{3}{4}$	$2\frac{3}{8}$	0.88	17	$3\frac{1}{2}$	7	$4\frac{1}{2}$
18	$\frac{11}{16}$	$2\frac{1}{8}$	0.70	14	3	6	4
19	$\frac{5}{8}$	$1\frac{7}{8}$	0.57	11	$2\frac{1}{4}$	$5\frac{1}{2}$	$3\frac{1}{2}$
20	$\frac{9}{16}$	$1\frac{5}{8}$	0.41	8	$1\frac{3}{4}$	$4\frac{3}{4}$	3
21	$\frac{1}{2}$	$1\frac{3}{8}$	0.31	6	$1\frac{1}{2}$	4	$2\frac{1}{2}$
22	$\frac{7}{16}$	$1\frac{1}{4}$	0.23	$4\frac{1}{2}$	$1\frac{1}{4}$	$3\frac{1}{2}$	$2\frac{1}{4}$
23	$\frac{3}{8}$	$1\frac{1}{8}$	0.19	4	1	$3\frac{1}{4}$	2
24	$\frac{5}{16}$	1	0.16	3	$\frac{3}{4}$	$2\frac{3}{4}$	$1\frac{3}{4}$
25	$\frac{9}{32}$	$\frac{7}{8}$	0.12	2	$\frac{1}{2}$	$2\frac{1}{4}$	$1\frac{1}{2}$

Pliable Hoisting Rope.

With 6 strands of 19 Wires Each. (Trenton Iron Works.)

IRON.

Trade Number.	Diameter.	Circumference in Inches.	Weight per Ft. in Lbs. Rope with Hemp Center.	Breaking Strain, Tons of 2000 Lbs.	Proper Working Load in Tons of 2000 Lbs.	Circumference of new Manila Rope of Equal Strength.	Minimum Size of Drum or Sheave in Feet.
1	$2\frac{1}{4}$	$6\frac{3}{4}$	8.00	74	15	14	13
2	2	6	6.30	65	13	13	12
3	$1\frac{3}{4}$	$5\frac{1}{2}$	5.25	54	11	12	10
4	$1\frac{5}{8}$	5	4.10	44	9	11	$8\frac{1}{2}$
5	$1\frac{1}{2}$	$4\frac{3}{4}$	3.65	39	8	10	$7\frac{1}{2}$
$5\frac{1}{2}$	$1\frac{3}{8}$	$4\frac{3}{8}$	3.00	33	$6\frac{1}{2}$	$9\frac{1}{2}$	7
6	$1\frac{1}{4}$	4	2.50	27	$5\frac{1}{2}$	$8\frac{1}{2}$	$6\frac{1}{2}$
7	$1\frac{1}{8}$	$3\frac{1}{2}$	2.00	20	4	$7\frac{1}{2}$	6
8	1	$3\frac{1}{8}$	1.58	16	3	$6\frac{1}{2}$	$5\frac{1}{4}$
9	$\frac{7}{8}$	$2\frac{3}{4}$	1.20	11.50	$2\frac{1}{2}$	$5\frac{1}{2}$	$4\frac{1}{2}$
10	$\frac{3}{4}$	$2\frac{1}{4}$	0.88	8.64	$1\frac{3}{4}$	$4\frac{3}{4}$	4
$10\frac{1}{4}$	$\frac{5}{8}$	2	0.60	5.13	$1\frac{1}{4}$	$3\frac{3}{4}$	$3\frac{1}{2}$
$10\frac{1}{2}$	$\frac{9}{16}$	$1\frac{5}{8}$	0.44	4.27	$\frac{3}{4}$	$3\frac{1}{2}$	$2\frac{3}{4}$
$10\frac{3}{4}$	$\frac{1}{2}$	$1\frac{1}{2}$	0.35	3.48	$\frac{1}{2}$	3	$2\frac{1}{4}$
10*a*	$\frac{7}{16}$	$1\frac{3}{8}$	0.29	3.00	$\frac{3}{8}$	$2\frac{3}{4}$	2
$10\frac{7}{8}$	$\frac{3}{8}$	$1\frac{1}{4}$	0.26	2.50	$\frac{1}{4}$	$2\frac{1}{2}$	$1\frac{1}{2}$

CAST STEEL.

1	$2\frac{1}{4}$	$6\frac{3}{4}$	8.00	155	31	. . .	$8\frac{1}{2}$
2	2	6	6.30	125	25	. . .	8
3	$1\frac{3}{4}$	$5\frac{1}{2}$	5.25	106	21	. . .	$7\frac{1}{4}$
4	$1\frac{5}{8}$	5	4.10	86	17	15	$6\frac{1}{4}$
5	$1\frac{1}{2}$	$4\frac{3}{4}$	3.65	77	15	14	$5\frac{3}{4}$
$5\frac{1}{2}$	$1\frac{3}{8}$	$4\frac{3}{8}$	3.00	63	12	13	$5\frac{1}{2}$
6	$1\frac{1}{4}$	4	2.50	52	10	12	5
7	$1\frac{1}{8}$	$3\frac{1}{2}$	2.00	42	8	11	$4\frac{1}{2}$
8	1	$3\frac{1}{8}$	1.58	33	6	$9\frac{1}{2}$	4
9	$\frac{7}{8}$	$2\frac{3}{4}$	1.20	25	5	$8\frac{1}{2}$	$3\frac{1}{2}$
10	$\frac{3}{4}$	$2\frac{1}{4}$	0.88	18	$3\frac{1}{2}$	7	3
$10\frac{1}{4}$	$\frac{5}{8}$	2	0.60	12	$2\frac{1}{2}$	$5\frac{3}{4}$	$2\frac{1}{4}$
$10\frac{1}{2}$	$\frac{9}{16}$	$1\frac{5}{8}$	0.44	9	$1\frac{1}{2}$	5	$1\frac{3}{4}$
$10\frac{3}{4}$	$\frac{1}{2}$	$1\frac{1}{2}$	0.35	7	1	$4\frac{1}{2}$	$1\frac{1}{2}$
10*a*	$\frac{7}{16}$	$1\frac{3}{8}$	0.29	$5\frac{1}{2}$	$\frac{3}{4}$	$3\frac{3}{4}$	$1\frac{1}{4}$
$10\frac{7}{8}$	$\frac{3}{8}$	$1\frac{1}{4}$	0.26	$4\frac{1}{2}$	$\frac{1}{2}$	$3\frac{1}{2}$	1

STEAM.

STEAM BOILERS.

Points to Remember in Selecting a Boiler.

(*a*) Suitability of furnace and boiler to kind of fuel.
(*b*) Efficiency as to evaporative results.
(*c*) Rapidity of steaming including
 (I.) Water capacity for given power.
 (II.) Water surface for given power.
(*d*) Steam keeping qualities.
(*e*) Safety from explosion.
(*f*) Floor space required.
(*g*) Portability, and ease with which boiler can be removed when old, for replacement by a new boiler.
(*h*) Amount of, ease of, and rapidity of repairs.
(*i*) Simplicity and fewness of parts.
(*j*) Ability to stand forcing in case of necessity.
(*k*) Price, including cost of freight and setting.
(*l*) Durability and reliability.
(*m*) Ease of cleaning and inspection both inside and outside.
(*n*) Freedom from excessive strains due to unequal expansion and ability to withstand same.
(*o*) Efficient natural circulation of water.
(*p*) Absence of joints or seams where flames may impinge.

For central stations it is necessary to arrange for a number of boilers rather than one or two large ones. The size of unit adopted will depend to some extent on the character of the expected load diagram. With a number of boilers the cost of the reserve plant is reduced, though beyond, say six, there is less object in increasing the number on this account.

Types.

Horizontal Return Tubular. — More generally used in United States than any other. Fire first passes under the shell, returns to front through tubes, thence up the chimney, except in some cases gases are again returned over top of the shell. Limited as to size and pressures carried by reason of external firing.

Water-tube. — Very largely used where high steam pressures or safety from explosion are desirable. Fire passes about the exterior of tubes and in most cases under about one-half the circumference of the steam drums. Can be built for any size or pressure. Tubes are generally placed in a slanting position, from one set of headers to another, as in the Babcock & Wilcox, Heine & Co.; or vertically, as in the Sterling and Cahall.

Vertical Fire Tube. — Used considerably in New England. Special design by Captain Manning; tubes 15 feet long $2\frac{1}{2}$ inches diameter, arranged in vertical shell with large combustion chamber surrounded by a water leg. Gases mingle in combustion chamber, and in passing through the long narrow tubes give up nearly all the heat, practicably leaving flue gases 450° to 500° F. By controlling height of water, steam can be superheated. Can be built for high pressures and of large size.

Scotch or Marine Boilers. — Not much used for electrical purposes. Shell of thick material, short in length and large in diameter. Furnaces internal, with return tubes from combustion chamber to uptake.

Old types are the *cylinder boiler*, of small diameter and considerable length (20 to 35 feet). Fired externally, and gases pass under full length to chimney. *Flue boiler*, has two or three large tubes running full length of shell, which is long and of small diameter. Fired externally under the shell, gases return through the flues to uptake. Neither of these types is now used for electrical purposes.

The Horse-Power of Steam Boiler.

The committee of the A. S. M. E. on "Trials of Steam Boilers in 1884" (Trans., vol. vi. p. 265), discussed the question of the horse-power of boilers:

The Committee) A.S.M.E. see Trans. vol. xxi.) approves the conclusions of the 1885 Code to the effect that the standard "unit of evaporation" should be one pound of water at 212° F. evaporated into dry steam of the same temperature. This unit is equivalent to 965.7 British thermal units.

The committee recommends that, as far as possible, the capacity of a boiler be expressed in terms of the "number of pounds of water evaporated per hour from and at 212°." It does not seem expedient, however, to abandon the widely recognized measure of capacity of stationary or land boilers expressed in terms of "boiler horse-power."

The unit of commercial boiler horse-power adopted by the Committee of 1885 was the same as that used in the reports of the boiler tests made at the Centennial Exhibition in 1876. The Committee of 1885 reported in favor of this standard in language of which the following is an extract:

"Your Committee, after due consideration, has determined to accept the Centennial standard, and to recommend that in all standard trials the commercial horse-power be taken as an evaporation of 30 pounds of water per hour from a feed-water temperature of 100° F. into steam at 70 pounds gauge pressure, which shall be considered to be equal to 34½ units of evaporation; that is, to 34½ pounds of water evaporated from a feed-water temperature of 212° F. into steam at the same temperature. This standard is equal to 33,305 thermal units per hour."

The present Committee accepts the same standard, but reverses the order of two clauses in the statement, and slightly modifies them to read as follows:

The unit of commercial horse-power developed by a boiler shall be taken as 34½ units of evaporation per hour; that is, 34½ pounds of water evaporated per hour from a feed-water temperature of 212° F. into dry steam of the same temperature. This standard is equal to 33,317 British thermal units per hour. It is also practically equivalent to an evaporation of 30 pounds of water from a feed-water temperature of 100° F. into steam at 70 pounds gauge pressure.*

The Committee also indorses the statement of the Committee of 1885 concerning the commercial rating of boilers, changing somewhat its wording, so as to read as follows:

A boiler rated at any stated capacity should develop that capacity when using the best coal ordinarily sold in the market where the boiler is located, when fired by an ordinary fireman, without forcing the fires, while exhibiting good economy; and, further, the boiler should delelop at least one-third more than the stated capacity when using the same fuel and operated by the same fireman, the full draft being employed and the fires being crowded; the available draft at the damper, unless otherwise understood, being not less than ½ inch water column.

Heating Surface of Boilers.

Although authorities disagree on what is to be considered the heating surface of boilers, it is generally taken as all surfaces that transmit heat from the flame or gases to the water. The outside surface of all tubes is used in calculations.

Kent gives the following rule for finding the heating surface of

Vertical Tubular Boilers. — Multiply the circumference of the firebox (in inches) by its height above the grate. Multiply the combined circumference of all the tubes by their length, and to these two products add the area of the lower tube sheet; from this sum subtract the area of all the tubes, and divide by 144: the quotient is the area of heating surface in square feet.

Horizontal Return Tubular Boilers. — (Christie). Multiply the length of that part of circumference of the shell (in inches) exposed to the fire by its length; multiply the circumferences of the tubes by their number, by their length in inches; to the sum of these products add two-thirds of the area of both tube sheets less twice the area of tubes, and divide the remainder by 144. The result is the herting surface in square feet.

Heating Surface of Tubes. — Multiply the number of tubes by the diameter of a tube in inches, by its length in feet, and by .2618. The diameter used should be that of the fire side of the tube.

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* *According to the tables in Porter's Treatise on the Richards Steam Engine Indicator, an evaporation of 30 pounds of water from 100° F. into steam at 70 pounds pressure is equal to an evaporation of 34.488 pounds from and at 212°; and an evaporation of 34½ pounds from and at 212° F. is equal to 30.010 pounds from 100° F. into steam at 70 pounds pressure.*

The "unit of evaporation" being equivalent to 965.7 thermal units, the commercial horse-power $= 34.5 \times 965.7 = 33{,}317$ *thermal units.*

Heating Surface per Horse-power.—There is little uniformity of practice among builders as to the amount of heating surface per horse-power, but 12 square feet may be taken as a fair average. Babcock & Wilcox ordinarily allow 10 square feet, but usually specify the number of square feet of heating surface. The Heine Boiler Company allow $7\frac{1}{2}$ square feet, and the water-tube type in general will develop a horse-power for that amount of surface.

Specifications for boilers should always clearly state the amount of heating surface required.

Grate Surface.—The amount of grate surface per horse-power varies with the character of fuel used and the draught that is available. With good quality of coal about equal results can be obtained with strong draught and small grate surface, and with large grate surface and light draught. Pittsburg coal gives best results with strong draught and a small grate surface. The following table shows the usual requirements, but in general grate surface should be liberal in size, and a rate of combustion of about 10 lbs. per hour will be found good practice.

Grate Surface per Horse-Power. (Kent.)

	Lbs. Water from and at 212° per lb. Coal.	Lbs. Coal per H.P. per hour.	Pounds of Coal burned per square foot of Grate per hour.								
			8	10	12	15	20	25	30	35	40
			Square Feet Grate per H.P.								
Good coal and boiler . . .	10	3.45	.43	.35	.28	.23	.17	.14	.11	.10	.09
	9	3.83	.48	.38	.32	.25	.19	.15	.13	.11	.10
Fair coal or boiler . . .	8.61	4.	.50	.40	.33	.26	.20	.16	.13	.12	.10
	8	4.31	.54	.43	.36	.29	.22	.17	.14	.13	.11
	7	4.93	.62	.49	.41	.33	.24	.20	.17	.14	.12
Poor coal or boiler . . .	6.9	5.	.63	.50	.42	.34	.25	.20	.17	.15	.13
	6	5.75	.72	.58	.48	.38	.29	.23	.19	.17	.14
	5	6.9	.86	.69	.58	.46	.35	.28	.23	.22	.17
Lignite and poor boiler .	3.45	10.	1.25	1.00	.83	.67	.50	.40	.33	.29	.25

Area of Gas-Passages and Flues.

This is commonly stated in a ratio to the grate area. Mr. Barrus says the highest efficiency for anthracite coal, when burning 10 to 12 lbs. per square foot of grate per hour, is with tube area $\frac{1}{9}$ to $\frac{1}{10}$ of grate surface; and for soft coal the tube area should be $\frac{1}{6}$ to $\frac{1}{7}$ of the grate surface.

Other rules in common use are to make the area over bridge walls (for horizontal return tubular boilers) $\frac{1}{7}$ the grate surface; tube area $\frac{1}{8}$ and chimney area $\frac{1}{9}$.

Air-space in Grates.—Usual practice is 30% to 50% area of grate for air space. If fuel clinkers easily, use the largest air space available. With coal free from clinker smaller air space may be used.

Distance between Under Side of Boiler and Top of Grate.

(For Horizontal Tubular Boiler.)

For anthracite coal this should be 24 inches for the larger sizes, and can be 20 inches for the smaller sizes, such as pea, buckwheat, and rice. For bituminous coals non-caking, the grate should be about 30 inches below the boiler, and for fatty or gaseous coals from 36 to 48 inches. For average bituminous coals the distance can be 36 inches. Anthracite and bituminous coals cannot be economically burned in the same furnace.

Steam Boiler Efficiency.

The ratio of the heat units utilized in making steam in a boiler, to the total heat units in the coal used is called the efficiency of the boiler, and is rated in *per cent.* For example, the heating value of good anthracite coal is about 14.500 B. T. U., and will evaporate from and at 212° 15 lbs. water (14,500 ÷ 966). If a boiler under test evaporates 12 lbs. water per pound of combustible, the efficiency will be $\frac{12 \times 100}{15} = 80\%$, a figure not often obtained, but possible under special conditions. The heating value of bituminous coals varies so much that it is necessary to determine it by a coal calorimeter before it is possible to determine the boiler efficiency.

Strength of Riveted Shell.

(Abridged from Barr on "Boilers and Furnaces.")

Wrought-iron boiler-plates should average 45,000 lbs., and mild steel 55,000 lbs., tensile strength per square inch of section; but the gross strength of plate is lessened by the amount which has been taken out of it for the insertion of rivets.

The following tables give the calculated working pressure for double-riveted and triple-riveted lap joints, and for butt-joints triple riveted, the factor of safety being 5. The rule for calculating the safe working pressure is: Multiply together the tensile strength of the plate, the thickness of the plate in parts of an inch, and the efficiency of the joint (see Riveting); divide the product by one-half the diameter of the boiler multiplied by the factor of safety.

Working Pressure for Cylindrical Shells of Steam Boilers.

Factor of Safety, 5. (Barr.)

Diameter Inches.	Thickness in 16ths of an Inch.	Lap-Joints, Double-Riveted.			Lap-Joints, Triple-Riveted.		
		Iron Shell, Iron Rivets.	Steel Shell, Iron Rivets.	Steel Shell, Steel Rivets.	Iron Shell, Iron Rivets.	Steel Shell, Iron Rivets.	Steel Shell, Steel Rivets.
36	4	91	111	111	100	121	123
	5	112	128	137	124	139	151
40	4	82	100	100	90	109	110
	5	101	115	123	112	125	136
44	4	74	91	91	83	99	100
	5	91	105	112	101	114	124
48	5	84	96	102	93	104	114
	6	99	107	121	110	118	135
52	5	77	89	95	86	96	105
	6	92	99	112	102	109	124
54	5	75	85	91	83	93	101
	6	88	96	108	98	105	120
56	5	72	82	88	80	89	97
	6	85	92	104	95	101	116
60	5	67	77	82	74	83	91
	6	79	85	97	88	95	108
62	6	77	83	94	85	92	104
	7	88	92	108	98	103	120
64	6	74	81	91	83	89	101
	7	86	89	105	95	100	117
66	6	72	78	88	80	86	98
	7	83	87	102	93	97	113
68	6	70	76	86	78	84	95
	7	81	80	99	90	94	110
70	6	68	74	83	76	81	92
	7	78	82	96	87	91	107
72	7	76	79	93	85	89	104
	8	85	89	104	97	98	117

Working Pressure for Cylindrical Shells of Steam Boilers. (Barr.)

Butt Joints, Triple Riveted. *Factor of Safety*, 5.

Diameter Inches.	Thickness in 16ths of an inch.	Iron Shell, Iron Rivets.	Steel Shell, Iron or Steel Rivets.	Diameter, Inches.	Thickness in 16ths of an inch.	Iron Shell. Iron Rivets.	Steel Shell, Iron or Steel Rivets.
36	4	108	134	70	6	83	102
	5	135	165		7	97	118
	6	161	197		8	110	134
38	4	102	127		9	123	151
	5	128	156	72	6	80	99
	6	152	187		7	94	115
40	4	97	120		8	107	131
	5	121	148		9	120	147
	6	145	178	75	7	90	110
42	4	93	115		8	102	125
	5	116	141		9	115	141
	6	138	169		10	128	157
44	4	89	109	78	7	87	106
	5	110	135		8	99	121
	6	132	161		9	111	135
46	4	85	105		10	123	151
	5	106	129	84	8	92	112
	6	126	154		9	103	126
48	5	101	124		10	115	140
	6	121	148		11	126	158
	7	141	172		12	137	167
50	5	97	119	90	8	86	105
	6	116	142		9	96	117
	7	135	165		10	107	131
52	5	93	114		11	117	143
	6	111	137		12	128	156
	7	130	159	96	8	80	98
54	5	90	110		9	90	110
	6	107	132		10	100	123
	7	125	153		11	110	134
56	5	87	106		12	120	146
	6	103	127	102	8	75	92
	7	121	148		9	85	104
58	5	84	102		10	94	115
	6	100	123		11	104	127
	7	117	142		12	113	138
60	6	97	118	108	8	71	87
	7	111	138		9	80	98
	8	128	157		10	89	109
62	6	93	115		11	98	120
	7	109	133		12	107	130
	8	124	152	114	8	68	83
64	6	90	111		9	76	93
	7	106	129		10	84	103
	8	120	147		11	93	113
	9	135	165		12	101	123
66	6	88	108	120	8	64	78
	7	102	125		9	71	88
	8	117	143		10	80	98
	9	131	160		11	88	108
68	6	85	105		12	96	117
	7	99	121				
	8	113	138				
	9	127	155				

Safe Working Pressure for Shell Plate.

U. S. Statutes.—

$d =$ diameter of boiler in inches.
$P =$ safe working pressure, lbs. per square inch.
$t =$ thickness of metal in inches.
$w =$ tensile strength of metal.
$k =$ factor of safety $= 6$ for U. S. and 4.5 for Great Britain.

$$P = \frac{t \times 2 \times w}{d \times 6} \text{ for single-riveted. For double-riveted, add } 20\%.$$

Board of Trade.—

$$P = \frac{w \times B \times t \times 2}{d \times k \times 100}$$

where the notation is the same as in U. S. rule, and $B =$ percentage of strength of joint as compared with solid plate.

Rules Governing Inspection of Boilers in Philadelphia.

In estimating the strength of the longitudinal seams in the cylindrical shells of boilers, the inspector shall apply two formulæ, A and B:

$$\text{A, }\left\{\frac{\text{Pitch of rivets} - \text{diameter of holes punched to receive the rivets}}{\text{pitch of rivets}}\right. =$$

percentage of strength of the sheet at the seam.

$$\text{B, }\left\{\frac{\text{Area of hole filled by rivet} \times \text{No. of rows of rivets in seam} \times \text{shearing strength of rivet}}{\text{pitch of rivets} \times \text{thickness of sheet} \times \text{tensile strength of sheet}}\right. =$$

percentage of strength of the rivets in the seam.

Take the lowest of the percentages as found by formulæ A and B, and apply that percentage as the "strength of the seam" in the following formula, C, which determines the strength of the longitudinal seams:

$$\text{C, }\left\{\frac{\text{Thickness of sheet in parts of inch} \times \text{strength of seam as obtained by formula A or B} \times \text{ultimate strength of iron stamped on plates}}{\text{internal radius of boiler in inches} \times 5 \text{ as a factor of safety}}\right. =$$

safe working pressure.

Safe Working Pressure for Flat Plates.

U. S. Statutes.—

$P =$ safe working pressure.
$S =$ surface supported, square inches.
$t =$ thickness of metal in sixteenths of an inch.
$k =$ constant for plates of different thickness, and for various conditions.
$p =$ greatest pitch in inches.

$$P = \frac{t \times k}{p^2}.$$

$K = 112$ for $\frac{7}{16}$-inch plates and less, fitted with screw stay bolts and nuts, or plain bolt fitted with single nut and socket, or riveted head and socket.
$K = 120$ for plates more than $\frac{7}{16}$ inch thick, under same conditions.
$K = 140$ for flat surfaces where the stays are fitted with nuts inside and out.
$K = 200$ for flat surfaces under same conditions, but with washer riveted to plate, washer to be one-half as thick as plate, and of a diameter $\frac{5}{8}$ pitch.

No brace or stay on marine boilers to have a greater pitch than $10\frac{1}{2}$ inches on fire boxes and back connections. Plates fitted with double-angle irons riveted to plate, and with leaf at least two-thirds thickness of plate, and depth at least one-fourth of pitch, allowed the same pressure as plate with washer riveted on.

Board of Trade. — Using same notation as in U. S. rules:

$$P = \frac{k\,(t+1)^2}{S-6}.$$

$K = 125$ for plates not exposed to heat or flame, the stays fitted with nuts and washers, the latter at least three times the diameter of the stay and $\frac{2}{3}$ the thickness of the plate;

$K = 187.5$ for the same condition, but the washers $\frac{2}{3}$ the pitch of stays in diameter, and thickness not less than plate;

$K = 200$ for the same condition, but doubling plates in place of washers, the width of which is $\frac{2}{3}$ the pitch, and thickness the same as the plate;

$K = 112.5$ for the same condition, but the stays with nuts only;

$K = 75$ when exposed to impact of heat or flame and steam in contact with the plates, and the stays fitted with nuts and washers three times the diameter of the stay, and $\frac{2}{3}$ the plate's thickness;

$K = 67.5$ for the same condition, but stays fitted with nuts only;

$K = 100$ when exposed to heat or flame, and water in contact with the plates, and stays screwed into the plates, and fitted with nuts;

$K = 66$ for the same condition, but stays with riveted heads.

Ductility of Boiler Plate. — U. S. Inspectors of Steam Vessels.

In test for tensile strength, sample shall show reduction of area of cross-section not less than the following percentages:

Iron.

45,000 lbs. tensile strength and under	15 per cent.
For each additional 1000 t. s. up to 55,000 t. s. add .	1 "
55,000 lbs. tensile strength, and above	25 "

Steel.

All steel plates $\frac{1}{2}$ inch thick and under	50 per cent.
" " " $\frac{1}{2}$ to $\frac{3}{4}$ inch	45 "
" " " $\frac{3}{4}$ inch and above	40 "

Boiler Head Stays.

The United States Regulations on braces are: "No braces or stays hereafter employed in the construction of boilers shall be allowed a greater strain than 6,000 lbs. per square inch of section. Braces must be put in sufficiently thick so that the area in inches which each has to support, multiplied by the pressure per square inch, will not exceed 6,000 when divided by the cross-sectional area of the brace or stay.

"Steel stay-bolts exceeding a diameter of $1\frac{1}{4}$ inches, and not exceeding a diameter of $2\frac{1}{2}$ inches at the bottom of the thread may be allowed a strain not exceeding 8,000 lbs. per square inch of cross-section; steel stay bolts exceeding a diameter of $2\frac{1}{2}$ inches at bottom of thread may be allowed a strain not exceeding 9,000 lbs. per square inch of cross-section; but no forged or welded steel stays will be allowed.

"The ends of such stay may be upset to a sufficient thickness to allow for truing up, and including the depth of the thread. And all such stays after being upset, shall be thoroughly annealed."

Direct Braces.—The following table is given by Mr. Wm. M. Barr in "Boilers and Furnaces," p. 122. The working strength assumes an ultimate strength of 6000 lbs. per square inch of section.

Diameter of Brace Inches.	Wrought Iron Stays.		Inches square each Brace will Support for Pressures per Square Inch.			
	Area sq. in.	Working Strength Pounds.	75 Pounds.	100 Pounds.	125 Pounds.	150 Pounds.
$\frac{7}{8}$	.60	3600	7.0	6.0	5.4	4.9
1	.78	4712	7.9	6.9	6.1	5.6
$1\frac{1}{8}$	.99	5964	8.9	7.7	6.9	6.4
$1\frac{1}{4}$	1.23	7362	9.9	8.6	7.7	7.0
$1\frac{3}{8}$	1.48	8880	10.7	9.5	8.5	7.7
$1\frac{1}{2}$	1.77	10620	11.9	10.4	9.2	8.5

Diagonal Braces.—("Boilers and Furnaces," p. 129.) These must be calculated separately.

Let

A = surface to be supported in square inches.
B = working pressure in lbs.
H = length of diagonal stay in inches.
L = length of line drawn at right angles from surface, to be supported to end of diagonal stay in inches.
S = working stress per square inch on stay in lbs.
a = area required for direct stay in square inches.
a_1 = area of diagonal stay in square inches.
T = diameter of diagonal stay in square inches.

Then

$$a_1 = a \times H \div L;$$
$$H = a_1 \times L \div a.$$

$$T = \sqrt{\frac{a_1}{.7854}} = \sqrt{\frac{A \times B \times H}{.7854\, S \times L}};$$

$$B = \frac{.7854 \times T^2 \times S \times L}{A \times H}.$$

Boiler Settings.

Water tube and special types of boilers require special settings largely controlled by local conditions, location of flues, etc., and cannot be tabulated here.

The setting of *horizontal return tubular* boilers has become so nearly standardized that the table following, taken in connection with the cuts, will give all the general dimensions of brick-work required.

For all special boiler settings, furnaces, etc., the reader is referred to the makers of each.

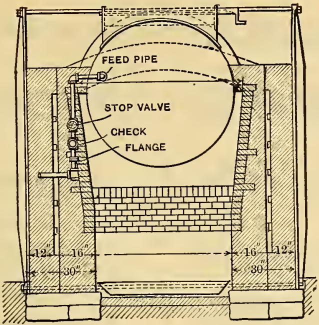

FIG. 1.

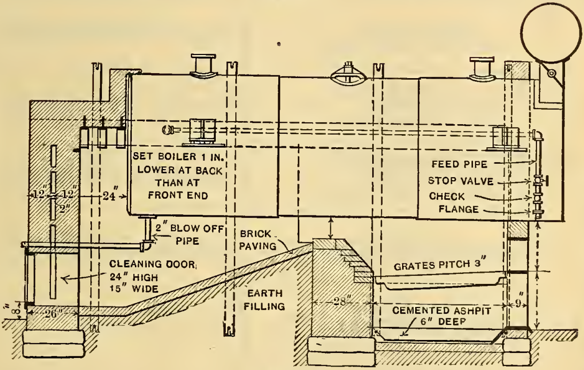

FIG. 2.

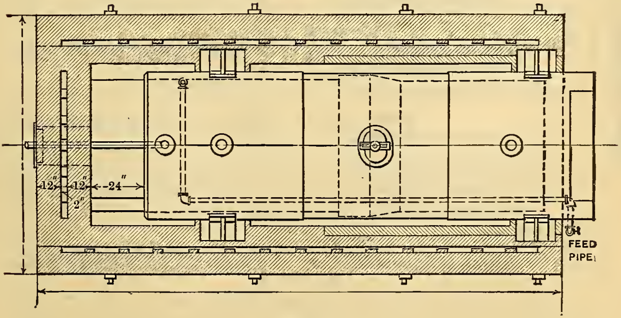

FIG. 3.

Measurements for Setting Return Tubular Boilers Arch Fronts.

	Boiler.			Dome.		Walls.									
	Diameter of Boiler.	Length of Boiler less Curtain Sheet.	Length of Curtain Sheet.	Top of Boiler to Top of Flange on Dome.	Center of Dome to Front of Boiler.	Thickness of Outside Side Walls.	Thickness of Inside Side Walls.	Thickness of 2 Side Walls, with 2-inch Air Space.	Thickness of 2 Rear Walls, with 2-inch Air Space.	Thickness of Front Wall at Bottom.	Length of Foundation for Side Walls.	Width of Walls over all.	Height of Walls from Top of Floor.	Thickness of Bridge Wall at Bottom.	Thickness of Bridge Wall at Top.
H. P.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	Inches.	Feet.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Ft. In.	Ft. In.	Ft. In.	Inches.	Inches.
15	36	8	11	22	39	8	12	22	18	13	11– 7	6– 8	7– 0	32	15
20	36	10	11	22	51	8	12	22	18	13	13– 7	6– 8	7– 0	32	15
25	42	10	12	26	49	8	12	22	18	13	13– 7	7– 2	7– 7	36	15
30	42	12	12	26	78	8	12	22	18	13	15– 7	7– 2	7– 7	36	15
35	44	12	12	28	78	8	12	22	18	13	15– 7	7– 4	7–10	36	15
40	48	12	14	30	79	8	12	22	18	$15\frac{1}{2}$	15– 7	7– 8	8– 0	36	15
45	50	13	14	32	85	8	12	22	18	$15\frac{1}{2}$	16– 7	7–10	8– 1	36	15
50	54	13	14	32	85	8	12	22	18	$15\frac{1}{2}$	15– 9	8– 2	8– 6	36	15
60	54	15	14	32	97	8	12	22	18	$15\frac{1}{2}$	18– 9	8– 2	8– 6	36	15
70	60	14	16	32	92	8	16	26	18	$15\frac{1}{2}$	17–11	9– 4	8–11	40	15
75	60	15	16	32	98	8	16	26	18	$15\frac{1}{2}$	18–11	9– 4	8–11	40	15
80	60	16	16	38	104	8	16	26	18	$15\frac{1}{2}$	19–11	9– 4	8–11	40	15
90	66	15	17	38	98	8	16	26	18	$15\frac{1}{2}$	19– 3	9–10	9– 8	40	15
100	66	16	17	38	104	8	16	26	18	$15\frac{1}{2}$	20– 3	9–10	9– 8	40	15
125	72	16	18	38	105	8	16	26	18	16	20– 5	10– 4	10– 1	40	15

	Furnace.					Setting.							
	Floor Line to Top of Grates at the Front.	Floor Line to Top of Grates at the Rear.	Top of Grates to Under Side of Boiler.	Length of Furnace.	Width of Furnace.	Top of Floor to Under Side of Boiler at Front.	Top of Floor to Under Side of Boiler at Rear.	Top of Floor to Top of Flange on Dome.	Top of Bridge Wall to Under Side of Boiler.	Space in Rear between Boiler and Wall.	Space between Boiler and Wall at the Side.	No. of Common Brick above Floor Line.	No. of Fire Brick.
H. P.	P	Q	R	S	T	U	V	W	X	Y	Z		
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Ft. In.					
15	25	23½	26	36	36	51	50½	9– 1	10	20	2	6250	650
20	25	23½	26	42	36	51	50½	9– 1	10	20	2	7100	700
25	27	25½	26	42	42	53	52½	10– 1	10	20	2	8200	725
30	27	25½	26	48	42	53	52½	10– 1	10	20	2	8750	780
35	27	25½	26	48	44	53	52½	10– 5	10	20	2	9250	800
40	30	28	26	48	48	56	55½	11– 2	10	20	2	10700	850
45	30	28	26	48	50	56	55½	11– 6	12	20	2	11700	910
50	30	28	28	54	54	58	57½	12–	12	22	2	14450	900
60	30	28	28	60	54	58	57½	12–	12	22	2	17680	1000
70	30	28	30	60	60	60	59½	12– 8	12	24	2	16600	1000
75	30	28	30	60	60	60	59½	12– 8	12	24	2	17900	1000
80	30	28	30	60	60	60	59½	13– 2	12	24	2	19000	1200
90	33	31	30	66	66	63	62½	13–11	14	28	2	19600	1200
100	33	31	30	66	66	63	62½	13–11	14	28	2	21550	1400
125	34	32	30	72	72	64	63½	14– 6	14	30	2	22500	1500

CHIMNEYS.

THE DRAUGHT POWER OF A CHIMNEY varies as the square root of the height.

The retarding friction of the chimney may be taken as equivalent to a diminution of its actual area by a layer of gas two inches thick all the way around the perimeter of its flue.

$A =$ actual area of flue in square feet.
$E =$ effective area of flue in square feet.
$H =$ height in feet.
$D =$ diameter of flue in feet.
$D_1 =$ side of a square chimney equivalent to A.

Then: $E = A - 0.6\sqrt{A}$. (1)

$D_1 = \sqrt{E} + 4$ inches. (2)

Horse-power $= 3.33\ E\sqrt{H}$. (3)

The above formulæ are by Kent, and are based on a consumption of 5 lbs. coal per h. p. per hour. W. W. Christie, in a paper read before the A.S.M.E., Trans., vol. xviii., p. 387, gives as his opinion that all chimneys should be compared and rated by using coal capacity as a basis, not horse-power. In the following table, coal capacity can be found by multiplying h.p. by 4.

Size of Chimneys for Steam-Boilers.

(W. W. Christie.)

Diam. Inches.	Height of Chimney.													
	50 ft.	60 ft.	70 ft.	80 ft.	90 ft.	100 ft.	110 ft.	125 ft.	150 ft.	175 ft.	200 ft.	225 ft.	250 ft.	300 ft.
	Boiler Horse-power $= 3.25\ A\sqrt{H}$; 4 lbs. of coal burned considered 1 H.P.													
18	42	46	49	52	. .	. .	. .	. .	. .	. . .	. . .	. . .	. . .	. . .
21	55	62	65	68	. .	. .	. .	. .	. .	. . .	. . .	. . .	. . .	. . .
24	72	78	85	91	98	. .	. .	. .	. .	. . .	. . .	. . .	. . .	. . .
27	91	101	107	114	124	. .	. .	. .	. .	. . .	. . .	. . .	. . .	. .
30	114	124	133	143	153	159	. .	. .	. .	. . .	. . .	. . .	. . .	. . .
33	. .	149	163	172	182	192	202	. .	. .	. . .	. . .	. . .	. . .	. . .
36	. .	179	192	205	218	228	241	257	. .	. . .	. . .	. . .	. . .	. . .
39	. .	. .	224	241	257	270	283	302	. .	. . .	. . .	. . .	. . .	. . .
42	. .	. .	263	282	296	312	332	351	390	. . .	. . .	. . .	. . .	. . .
48	. .	. .	. .	364	387	410	429	458	510	. . .	. . .	. . .	. . .	. . .
54	. .	. .	. .	. .	491	517	543	579	647	683	. . .	. . .	. . .	. . .
60	. .	. .	. .	. .	605	637	669	715	797	845	. . .	. . .	. . .	. . .
66	. .	. .	. .	. .	. .	774	809	865	965	1021	1092	. . .	. . .	. . .
72	. .	. .	. .	. .	.	920	962	1051	1147	1215	1300	1378	. . .	. . .
78	. .	. .	. .	. .	. .	. .	1131	1206	1349	1459	1524	1619	1706	. . .
84	. .	. .	. .	. .	. .	. .	1310	1401	1563	1654	1768	1875	1976	2165
90	. .	. .	. .	. .	. .	. .	. .	1609	1794	1898	2031	2155	2269	2486
96	. .	. .	. .	. .	. .	. .	. .	1830	2041	2161	2311	2451	2584	2831
102	. .	. .	. .	. .	. .	. .	. .	2067	2304	2434	2607	2766	2915	3195
108	. .	. .	. .	. .	. .	. .	. .	2314	2584	2734	2925	3101	3269	3578
114	. .	. .	. .	. .	. .	. .	. .	. .	2879	3045	3257	3455	3643	3991
120	. .	. .	. .	. .	. .	. .	. .	. .	3191	3374	3611	3829	4037	4420
132	. .	. .	. .	. .	. .	. .	. .	. .	3861	4082	4368	4631	4882	5350
144	. .	. .	. .	. .	. .	. .	. .	. .	4596	4859	5200	5515	5811	6367

The following table* will prove useful to those having to do with electric installations, and gives the horse-power of chimneys to be used in power plants having very efficient engines, such as compound or triple expansion engines, when 2 lbs. of coal burned under the boiler produce one horse-power at the engine.

Size of Chimney for Steam Boilers.

(W. W. Christie.)

Diam. Inches.	Height of Chimney.													
	50′	60′	70′	80′	90′	100′	110′	125′	150′	175′	200′	225′	250′	300′
	Horse-power $= 6.5\ A\sqrt{H}$. When 2 lbs. coal burned per hour = 1 H.P.													
18	84	92	98	104	..	..	..	..	..	...	...	...	...	...
21	110	124	130	136	..	..	..	..	..	...	...	...	...	...
24	144	156	170	182	196	..	..	..	..	...	...	...	...	...
27	182	202	214	228	248	..	..	..	..	...	...	...	...	...
30	228	248	266	286	306	318	..	..	..	...	...	...	...	...
33	..	298	326	344	364	384	404	..	..	...	...	...	...	...
36	..	358	384	410	436	456	482	514	..	...	...	...	...	...
39	..	..	448	482	514	540	566	604	..	...	...	...	...	...
42	..	..	526	564	592	624	662	702	780	...	...	...	...	...
48	..	..	..	728	774	820	858	916	1020	...	...	...	...	...
54	..	..	..	..	982	1034	1086	1158	1294	1366	...	...	...	...
60	..	..	..	..	1210	1274	1338	1430	1594	1690	...	...	...	...
66	..	..	..	..	..	1548	1618	1730	1930	2042	2184	...	...	...
72	..	..	..	..	..	1840	1924	2102	2294	2430	2600	2756	...	...
78	..	..	..	..	..	..	2262	2412	2698	2918	3048	3238	3412	...
84	..	..	..	..	..	..	2620	2802	3126	3308	3536	3750	3952	4330
90	..	..	..	..	..	..	..	3218	3588	3796	4062	4310	4538	4972
96	..	..	..	..	..	..	..	3660	4082	4322	4622	4902	5168	5662
102	..	..	..	..	..	..	..	4134	4608	4868	5214	5532	5830	6360
108	..	..	..	..	..	..	..	4628	5168	5468	5850	6202	6538	7156
114	..	..	..	..	..	..	..	..	5758	6090	6514	6910	7286	7982
120	..	..	..	..	..	..	..	..	6382	6748	7222	7658	8074	8840
132	..	..	..	..	..	..	..	..	7722	8164	8736	9262	9764	10700
144	..	..	..	..	..	..	..	..	9192	9718	10400	11030	11622	12734

Chimney Construction.

A brick chimney shaft is made up of a series of steps, each of which is of uniform thickness, but as we ascend each succeeding step is thinner than the one it rests upon. These bed joints at which the thickness changes are the joints of least stability. The joints and the one at the ground line are the only ones to which it is necessary to apply the formulas for determining the stability of the stack.

The height of the different steps of uniform thickness varies greatly, according to the judgment of the engineer, but 170 feet is, approximately, the extreme height that any one section should be made. This length is seldom approached even in the tallest chimneys, as the brick-work has to bear, in addition to its weight, that due to the pressure of the wind. The steps should not exceed about 90 feet, unless the chimney stack is inside a tower which protects it from the wind. In chimneys from 90 to 120 feet high the steps vary from 17 to 25 feet, the top step being one brick thick; in chim-

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* "*Chimney Design and Theory,*" *W. W. Christie, D. Van Nostrand Company.*

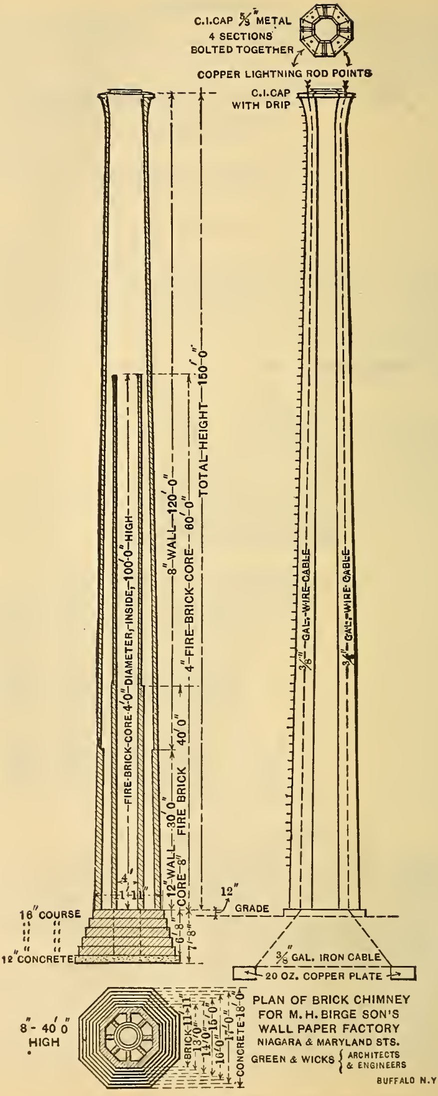
C.I.CAP ⅝" METAL
4 SECTIONS
BOLTED TOGETHER
COPPER LIGHTNING ROD POINTS
C.I.CAP
WITH DRIP
TOTAL-HEIGHT—150'-0"
8"-WALL—120'-0"
4"-FIRE-BRICK-CORE—60'-0"
FIRE-BRICK-CORE-4'-0"-DIAMETER,-INSIDE,-100'-0"-HIGH
40'0"
12"-WALL—30'0"
FIRE BRICK
CORE-8"
4'
1-11
1-11
12"
GRADE
16" COURSE
12" CONCRETE
6'-8"
7'-8"
⅜" GAL.-WIRE-CABLE
¾" GAL.-WIRE-CABLE
⅜" GAL. IRON CABLE
20 OZ. COPPER PLATE
8"-40'0"
HIGH
BRICK-11'-11"
13'0"
14'0"
15'-0"
16'-0"
17'-0"
CONCRETE-18'-0"
PLAN OF BRICK CHIMNEY
FOR M. H. BIRGE SON'S
WALL PAPER FACTORY
NIAGARA & MARYLAND STS.
GREEN & WICKS { ARCHITECTS & ENGINEERS
BUFFALO N.Y

FIG. 4.

neys from 130 to 150 feet the steps vary from 25 to 35 feet; in chimneys from 150 to 200 feet the steps vary from 35 to 50 feet; in chimneys from 200 to 300 feet and over, the steps vary from 50 to 90 feet, the top step being one and one-half bricks thick. The outside dimensions of a chimney at the base should generally not be less than one-tenth of the height of the stack for square chimneys; one-eleventh for octagonal, and one-twelfth for round. The batter may be 2½ inches for every 10 feet.

The foundation of a chimney is one of the most important points to be considered. When this is upon solid rock it is only necessary to excavate to a depth sufficient to prevent the heat of the gases from materially affecting the natural stone, and to secure the spread of the base. In cases where chimneys are to be built upon alluvial clays or made ground, it is necessary to excavate until a good stiff clay, hard sand, or rock bottom is reached. The excavation is filled with concrete in various ways, or filled according to the judgment of the engineer, so as to economize material without endangering the structure.

Babcock and Wilcox give the following formula for the ability of brick chimneys to withstand wind pressure.

w = weight of chimney in lbs. (brickwork = 100 to 130 lbs. per cubic foot.)
d = average diameter in feet, or width if square.
h = height in feet.
b = width of base.
k = constant, for square chimneys = 56.
for round chimneys = 28.
for octagonal chimneys = 35.

$$c = k\,\frac{d\,h^2}{w} \text{ and } w = k\,\frac{d\,h^2}{b}.$$

Thin Shell Brick Chimneys. — While the steel-plate lined stack is considerably cheaper than the ordinary heavy brick chimney, there is a design of brick chimney used by Messrs. Green & Wicks, architects, of Buffalo, N. Y., that has all the durability of the brick stack, and costs less than one of the same capacity in steel plate. The bricks must all be specially selected, hard burned, laid in rich Portland cement. By courtesy of the architects we are able to show drawings of such a chimney, that was erected by them for a wall-paper factory in Buffalo, and which has successfully withstood the most severe winds of the region (Figs. 4 and 5).

Note on Thin Shell Brick Chimneys. — The fire-brick core must be kept free from the outer shell, not being tied or bonded to it in any manner. The bricks are circular, with inside diameter laid up to 4 feet.

The galvanized iron-wire cables shown in the plans are for lightning protection. They are soldered and bolted to the iron cap, and after passing down through staples built into the walls for the purpose, are grounded on 20-oz. copper plates 3 feet by 1½ feet, set on edge ten feet away from the foot of the stack. The cables are to be soldered and riveted to the plates, and all the plates must be connected together by a ⅜-inch galvanized iron cable soldered to all the plates,

The chimney shown in the plans cost about $2,000, and can be built for less.

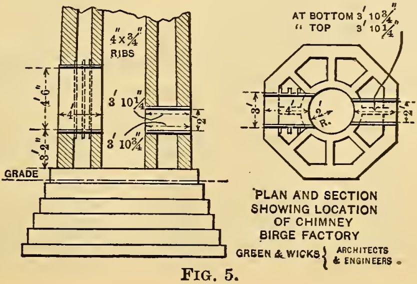

FIG. 5.

Draft Power for Combustion of Fuels.

(R. H. Thurston.)

Fuel.	Draft of Chimney in Inches of Water.	Fuel.	Draft in Ins. of Water.
Wood.	0.20 to 0.25	Coal-dust	0.80 to 1.25
Sawdust	0.35 “ 0.50	Semi Anthracite coal	0.90 “ 1.25
Sawdust mixed with small coal	0.60 “ 0.75	Mixture of breeze and slack	1.00 “ 1.33
Steam coal	0.40 “ 0.75	Anthracite	1.25 “ 1.50
Slack, ordinary . .	0.60 “ 0.90	Mixture of breeze and coal-dust	1.25 “ 1.75
Slack, very small . .	0.75 “ 1.25	Anthracite slack . .	1.30 “ 1.80

Height of Chimney for Burning Given Amounts of Coal.

Professor Wood (Trans. A. S. M. E., vol. xi.) derives a formula from which he calculates the height of chimney necessary to burn stated quantity of coal per square foot of grate per hour, for certain temperatures of the chimney gas.

Temp. Outside Air.	Absolute Temp. Chimney Gases.	Pounds of Coal per Square Foot Grate Area.		
		16	20	24
		Height of Chimney, Feet.		
520° Absolute, or 59° Fahr.	700	67.8	157.6	250.9
	800	55.7	115.8	172.4
	1000	48.7	100.0	149.1
	1100	48.2	98.9	148.8
	1200	49.1	100.9	152.0
	1400	51.2	105.6	159.9
	1600	53.5	110.9	168.8
	2000	63.0	132.2	206.5

Rate of Combustion Due to Height of Chimney.

Prof. Trowbridge (“Heat and Heat Engines,” p. 153) gives the following table, showing the heights of chimneys for producing certain rates of combustion per square foot of area of section of the chimney. The ratio of the grate to the chimney section being 8 to 1.

Height in Feet.	Lbs. Coal burned per Hour per sq. ft. of Section of Chimney.	Lbs. Coal burned per Hour per sq. ft. of Grate.	Height in Feet.	Lbs. Coal burned per Hour per sq. ft. Section of Chimney.	Lbs. Coal burned per Hour per sq. ft. Grate.
25	68	8.5	70	126	15.8
30	76	9.5	75	131	16.4
35	84	10.5	80	135	16.9
40	93	11.6	85	139	17.4
45	99	12.4	90	144	18.0
50	105	13.1	95	148	18.5
55	111	13.8	100	152	19.0
60	116	14.5	105	156	19.5
65	121	15.1	110	160	20.0

Dimensions and Cost of Brick Chimneys.

(Buckley.)

Approx. Horse-Power.	Height, Feet.	Diameter Flue Inside.	Outside Dimensions, Base, Square.	Outside Wall.		Cost Fire Brick Lining, ½ Height.	Cost Concrete Foundations.	Total Cost Chimney.
				No. Brick.	Cost @ $14 per M.			
85	80	25 in.	7 ft. 5 in.	32,000	$ 448.00	$ 60.00	$ 90.00	$ 598.00
135	90	30 in.	8 " 3 "	40,000	560.00	82.00	144.00	786.00
200	100	35 in.	9 " 10 "	65,000	910.00	118.00	198.00	1,226.00
300	110	43 in.	10 " 2 "	75,000	1,050.00	190.00	252.00	1,492.00
450	120	51 in.	11 " 2 "	87,000	1,218.00	261.00	306.00	1,785.00
750	130	61 in.	12 " 6 "	131,000	1,834.00	334.00	360.00	2,528.00
1000	140	74 in.	13 " 11 "	151,000	2,114.00	432.00	414.00	3,060.00
1650	150	88 in.	15 " 1 "	200,000	2,800.00	482.00	468.00	3,750.00
2500	160	110 in.	17 " 10 "	275,000	3,850.00	720.00	525.00	5,095.00

Steel Plate Chimneys have long been used in the iron and coal regions, but have only recently come into use in the East, except in the old style thin sheet iron guyed stack, which lasts but a short time.

Many of the manufacturers of steel structures are now erecting very substantial steel-plate stacks lined with fire bricks, that are of artistic outline, strong, and when kept well painted are durable and need no guys, as they are spread at the base, and bolted to a heavy foundation. They are usually designed to stand a wind pressure of 50 lbs. per square foot.

Sizes of Foundations for Steel Chimney.

(Selected from Circular of Philadelphia Engineering Works.)

HALF-LINED CHIMNEYS.

Diameter, clear, feet . . .	3	4	5	8	7	9	11
Height, feet.	100	100	150	150	150	150	150
Least diameter foundation .	15′9″	16′4″	20′4″	21′10′	22′7″	23′8′′	24′8″
Least depth foundation . .	6′	6′	9′	8′	9′	10′	10′
Height, feet	. . .	125	200	200	250	275	300
Least diameter foundation .	. . .	18′5″	23′8″	25′	29′8′′	33′6″	36′
Least depth foundation . .	. . .	7′	10′	10′	12′	12′′	14′

Brick Lining for Steel Stacks.

Allowing $1\frac{3}{4}$ inches air space between stack and lining:

Bricks $8\frac{1}{4} \times 4 \times 2$ inches, laid without mortar;
Lining $8\frac{1}{4}$ inches (one brick) thick;
Number of bricks per foot in diameter of stack, and per foot of height $= 47$.

Allowing 1 inch air space between stack and lining:

Bricks $8\frac{1}{4} \times 4 \times 2$ inches, laid without mortar;
Lining 4 inches (one brick) thick;
Number of bricks per foot in diameter of stack, and per foot of height $= 25$.

Dimensions and Cost of Iron Stacks. (Guyed.)

(Buckley.)

Horse-Power.	Height, Feet.	Diameter, Inches.	Number of Iron.	Price Stack Complete.	Price per Foot.
25	40	16	12 and 14	$ 61.00	$ 1.52
...	40	18	12 and 14	71.00	1.78
...	50	18	12 and 14	84.00	1.68
75	50	20	12 and 14	87.00	1.75
...	50	26	12 and 14	105.00	2.10
...	60	22	12 and 14	111.00	1.85
100	60	24	12 and 14	125.00	2.08
...	60	26	12 and 14	133.00	2.22
...	60	28	12 and 14	148.00	2.45
125	60	28	10 and 12	190.00	3.18
...	60	32	10 and 12	203.00	3.38
150	60	34	12 and 14	165.00	2.75
200	60	36	10 and 12	215.00	3.58
225	60	38	10 and 12	228.00	3.80
250	60	42	10 and 11	257.00	4.28
300	60	46	10 and 12	286.00	4.76
400	60	52	10 and 12	340.00	5.66

For general details of construction of the various types of chimneys used in the U. S. the reader is referred to "Chimney Design and Theory," by W. Wallace Christie, published by D. Van Nostrand Co.

FUEL.

Kinds and Ingredients of Fuels.

The substances which we call fuel are: wood, charcoal, coal, coke, peat, certain combustible gases, and liquid hydrocarbons.

Combustion or burning is a rapid chemical combination.

The imperfect combustion of carbon produces carbonic oxide (CO), and carbonic acid or dioxide (CO_2).

From certain experiments and comparisons Rankine concludes "that the total heat of combustion of any compound of hydrogen and carbon is nearly the sum of the quantities of heat which the hydrogen and carbon contained in it would produce separately by their combustion (CH_4 — marsh gas or fire-damp excepted)."

In computing the total heat of combustion of a compound, it is convenient to substitute for the hydrogen a quantity of carbon which would give the same quantity of heat; this is accomplished by multiplying the weight of hydrogen by $62032 \div 14500 = 4.28$.

From experiments by Dulong, Despretz, and others, "when hydrogen and oxygen exist in a compound in the proper proportion to form water (by weight nearly 1 part H to 8 parts O), these constituents have no effect on the total heat of combustion.

"If hydrogen exists in a greater proportion, take into the heat account only the surplus."

Dulong's formula for the total heat of combustion of carbon, hydrogen, oxygen, and sulphur, where C, H, O, and S refer to the fractions of one pound of the compound, the remainder being ash, etc. Let h = total heat of combustion in B.T.U. per pound of compound.

$$h = 14600\,C + 62000\left(H - \frac{O}{8}\right) + 4000\,S. \quad \text{(A.S.M.E. Trans. vol. xxi.)}$$

Rankine says: "The ingredients of every kind of fuel commonly used may be thus classed: (1) Fixed or free carbon, which is left in the form of charcoal or coke after the volatile ingredients of the fuel have been distilled away. These ingredients burn either wholly in the solid state, or part in the solid state and part in the gaseous state, the latter part being first dissolved by previously formed carbonic acid.

"(2) Hydrocarbons, such as olefiant gas, pitch, tar, naphtha, etc., all of which must pass into the gaseous state before being burned.

"If mixed on their first issuing from amongst the burning carbon with a large quantity of air, these inflammable gases are completely burned with a transparent blue flame, producing carbonic acid and steam. When raised to a red heat, or thereabouts, before being mixed with a sufficient quantity of air for perfect combustion, they disengage carbon in fine powder, and pass to the condition partly of marsh gas, and partly of free hydrogen ; and the higher the temperature, the greater is the proportion of carbon thus disengaged.

"If the disengaged carbon is cooled below the temperature of ignition before coming in contact with oxygen, it constitutes, while floating in the gas, smoke, and when deposited on solid bodies, soot.

"But if the disengaged carbon is maintained at the temperature of ignition, and supplied with oxygen sufficient for its combustion, it burns while floating in the inflammable gas, and forms red, yellow, or white flame. The flame from fuel is the larger the more slowly its combustion is effected.

"(3) Oxygen or hydrogen either actually forming water, or existing in combination with the other constituents in the proportions which form water. Such quantities of oxygen and hydrogen are to be left out of account in determining the heat generated by the combustion. If the quantity of water actually or virtually present in each pound of fuel is so great as to make its latent heat of evaporation worth considering, that heat is to be deducted from the total heat of combustion of the fuel. The presence of water or its constituents in fuel promotes the formation of smoke, or of the carbonaceous flame, which is ignited smoke, as the case may be, probably by mechanically sweeping along fine particles of carbon.

"(4) Nitrogen, either free or in combination with other constituents. This substance is simply inert.

"(5) Sulphuret of iron, which exists in coal and is detrimental, as tending to cause spontaneous combustion.

"(6) Other mineral compounds of various kinds, which are also inert, and form the ash left after complete combustion of the fuel, and also the clinker or glassy material produced by fusion of the ash, which tends to choke the grate."

Total Heat of Combustion of Fuels. (D. K. Clark.)

The following table gives the total heat evolved by combustibles and their equivalent evaporative power, with the weight of oxygen and volume of air chemically consumed.

Combustibles.	Weight of Oxygen Consumed per Pound of Combustible.	Quantity of Air Consumed per Pound of Combustible.		Total Heat of Combustion of 1 lb. of Combustible, B.T.U.	Equivalent evaporative Power of 1 lb. Combustible from and at 212° F.
	lbs.	lbs.	Cu. Ft. at 62°F.		
Hydrogen	8.0	34.8	457	62000	64.20
Carbon making CO	1.33	5.8	76	4452	4.61
Carbon making CO_2	2.66	11.6	152	14500	15.00
Carbonic oxide	0.57	2.48	33	4325	4.48
Light Carbureted Hydrogen	4.00	17.4	229	23513	24.34
Olefiant Gas	3.43	15.0	196	21343	22.09
Coal (adopted average desiccated)	2.45	10.7	140	14700	15.22
Coke (adopted average desiccated)	2.49	10.81	142	13548	14.02
Lignite, perfect	2.04	8.85	116	13108	13.57
Wood, desiccated	1.40	6.09	80	10974	11.36
Wood, 25 per cent moisture	1.05	4.57	60	7951	8.20
Petroleum	3.29	14.33	188	20411	21.13
Petroleum oils	4.12	17.93	235	27531	28.50
Sulphur	1.00	4.35	57	4000	4.17

Table of Combustibles.

("Steam," B. & W Co.)

Kind of Combustible.	Air Required.	Temperature of Combustion.				Theoretical Value.		Highest Attainable Value under Boiler.	
	In pounds Per Pound of Combustible.	With Theoretical Supply of Air.	With 1½ Times the Theoretical Supply of Air.	With Twice the Theoretical Supply of Air.	With Three Times the Theoretical Supply of Air.	In Pounds of Water raised 1° per Pound of Combustible.	In Pounds of Water evaporated from and at 212°, with 1 lb. Combustible.	With Chimney Draft.	With Blast, Theoretical Supply of Air at 60°, Gas 320°.
Hydrogen	36.00	5750	3860	2860	1940	62032	64.20		
Petroleum	15.43	5050	3515	2710	1850	21000	21.74	18.55	19.90
Carbon (Charcoal, Coke, Anthracite Coal)	12.13	4580	3215	2440	1650	14500	15.00	13.30	14.14
Coal, Cumberland	12.06	4900	3360	2550	1730	15370	15.90	14.28	15.06
Coking Bituminous	11.73	5140	3520	2680	1810	15837	16.00	14.45	15.19
Cannel	11.80	4850	3330	2540	1720	15080	15.60	14.01	14.76
Lignite	9.30	4600	3210	2490	1670	11745	12.15	10.78	11.46
Peat, Kiln-dried	7.68	4470	3140	2420	1660	9660	10.00	8.92	9.42
Air-dried, 25 per cent water	5.76	4000	2820	2240	1550	7000	7.25	6.41	6.78
Wood, Kiln-dried	6.00	4080	2910	2260	1530	7245	7.50	6.64	7.02
Air-dried, 20 per cent water	4.80	3700	2607	2100	1490	5600	5.80	4.08	4.39

Temperature of Fire.

By reference to the table of combustibles, it will be seen that the temperature of the fire is nearly the same for all kinds of combustibles, under similar conditions. If the temperature is known, the conditions of combustion may be inferred. The following table, from M. Pouillet, will enable the temperature to be judged by the appearance of the fire:

Appearance.	Temp. F.	Appearance.	Temp. F.
Red, just visible . .	977°	Orange, deep . . .	2010
" dull	1290	" clear . . .	2190
" cherry, dull . .	1470	White heat	2370
" " full . .	1650	" bright . . .	2550
" " clear .	1830	" dazzling . .	2730

To determine Temperature by Fusion of Metals, etc.

Substance.	Tem. F.	Metal.	Tem. F.	Metal.	Tem. F.
Tallow . . .	92°	Bismuth .	518°	Silver, pure . .	1830°
Spermaceti .	120	Lead . . .	630	Gold, coin . .	2156
Wax, white .	154	Zinc . . .	793	Iron, cast, med.	2010
Sulphur . .	239	Antimony .	810	Steel	2550
Tin	455	Brass . .	1650	Wrought iron .	2910

American Woods.

Kind of Wood.	Weight per Cord.	Value in Tons Coal.	
		Anthracite	Bituminous
Hickory — Shell bark.	4469	.608	.563
White oak	3821	.52	.481
Hickory — Red heart	3705	.504	.467
Southern pine	3375	.459	.425
Red oak	3254	.443	.41
Beech	3126	.425	.394
Hard maple	2878	.391	.363
Virginia pine	2680	.364	.338
Spruce.	2325	.316	.293
New Jersey pine	2137	.291	.269
Yellow pine	1904	.259	.24
White pine	1868	.254	.235

American Coals.

Coal.		Per Cent of Ash.	Theoretical Value.	
State.	Kind of Coal.		In Heat Units.	Pounds of Water Evap.
Pennsylvania.	Anthracite	3.49	14,199	14.70
“	“	6.13	13,535	14.01
“	“	2.90	14,221	14.72
“	Cannel	15.02	13,143	13.60
“	Connellsville	6.50	13,368	13.84
“	Semi-bituminous . .	10.70	13,155	13.62
“	Stone's Gas	5.00	14,021	14.51
“	Youghiogheny . . .	5.60	14,265	14.76
“	Brown	9.50	12,324	12.75
Kentucky.	Coking	2.75	14,391	14.89
“	Cannel	2.00	15,198	16.76
“	“	14.80	13,360	13.84
“	Lignite	7.00	9,326	9.65
Illinois.	Bureau Co.	5.20	13,025	13.48
“	Mercer Co..	5.60	13,123	13.58
“	Montauk	5.50	12,659	13.10
Indiana.	Block	2.50	13,588	14.38
“	Coking	5.66	14,146	14.64
“	Cannel	6.00	13,097	13.56
Maryland.	Cumberland	13.88	12,226	12.65
Arkansas.	Lignite	5.00	9,215	9.54
Colorado.	“	9.25	13,562	14.04
“	“	4.50	13,866	14.35
Texas.	“	4.50	12,962	13.41
Washington Ter.	“	3.40	11,551	11.96
Pennsylvania.	Petroleum	. . .	20,746	21.47

The weight of solid coal varies from 80 lbs. to 100 lbs. per cubic foot.

The Heating Value of Coals.

On page 851 are given the results (*Sibley, Journal of Engineering*) of some experiments made at Cornell University with a coal calorimeter devised by Prof. R. C. Carpenter. It consists of two cylindrical chambers, in the inner one of which the sample of coal is burned in oxygen. The heated gases pass through a coiled copper tube about 10 feet long contained in the outer chamber. The coil is surrounded by water which expands, the expansion being measured in a finely graduated glass tube, thus giving the heat units in the coal. The calorimeter is calibrated by burning in it pure carbon. Following are the tables:

Anthracite Coal.—Table of Average Results.

Mine.	Locality.	Moisture.	Volatile Matter.	Ash.	Fixed Carbon.	Specific Gravity.	Per Cent Slate.	B.T.U. In 1 lb. Combustible Matter.
L. V. Buckwheat	W.-Barre, Pa.	1.34	6.42	15.3	76.94	1.3	9.75	11801
Jermyn	Schuyl. Co., Pa.	1.7	5.78	10.84	71.68	1.425	9.80	12036
Woodward	Scranton, Pa.	3.33	3.73	13.71	79.23	1.42	2.51	12149
Cayuga	Scranton, Pa.	.97	5.37	9.2	84.46	1.49	6.2	12294
Mt. Pleasant	Scranton, Pa.	1.27	7.54	10.65	80.54	1.42	0.162	12307
L. V. Pea	L. V. Region	1.44	7.36	16.00	75.2	1.52	8.21	12423
Forty Foot	Scranton, Pa.	1.12	4.99	9.91	83.98	1.415	3.54	12903
Manville Shaft	Scranton, Pa.	1.04	5.95	7.31	85.7	1.42	0.589	12934
Continental	Scranton, Pa.	1.27	5.98	9.62	83.13	1.615	5.48	12943
Avondale	Avondale, Pa.	1.28	5.89	6.15	86.68	1.44	0.228	13051
Oxford	Scranton, Pa.	1.35	5.03	2.17	91.45	1.415	0.11	13254
Mammoth	Drifton, Pa.	2.97	2.3	6.77	87.96	1.55	0.00	13324
Buck Mountain	Cross Creek, Pa.	3.62	1.96	5.23	89.19	1.56	0.63	13723

Bituminous Coal.—Table of Average Results.

Mine.	Locality.	Moisture.	Volatile Matter.	Ash.	Fixed Carbon	Specific Gravity	Average B.T.U.	Pounds Combustible Matter in Smoke from 1 Ton Coal.	B.T.U. In 1 lb. Combustible Matter.
Gillespie	Gillespie, Ill.	3.77	34.94	11.74	49.55	1.23	10506	11.8	13700
B'mr'nt Co'l Wks	Monongahela River, Pa.	2.27	31.29	7.83	58.61	1.275	13126	20.94	12043
Antrim		1.23	18.51	10.9	69.3	1.42	13528	5.29	12724
Eureka	Clearfield Co., Pa.	1.03	23.55	5.73	69.69	1.32	13756	8.63	10899
Turtle Creek	Monongahela River, Pa.	2.11	34.22	4.22	59.45	1.28	14150	6.12	11827
Nova Scotia	No. 2 Slope, Nova Scotia	3.08	31.41	3.80	61.71	1.31	14864	5.33	11231
Reynold'sville	Reynold'sville, Pa.	1.09	21.4	5.3	69.21	1.34	14971	6.53	12217
Leisenring	Connellsville	1.93	28.71	6.1	63.26	1.34	15005	18.25	12855
Pocahontas	New River, Va.	1.25	17.62	3.65	77.48	1.255	15094	4.00	15255
Cooperstown	Nova Scotia	1.11	30.42	4.03	64.44	1.345	15266	9.88	11959

Proximate Analysis of Coal.

(Power.)

Designation of Coal.	Per Cent Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
ANTHRACITE.					
Beaver Meadow, Penn.	1.5	2.38	88.94	7.11	.01
Peach Mountain, Penn.	1.9	2.96	89.02	6.13	.01
Lackawanna, Penn.	2.12	3.91	87.74	6.35	.12
Lehigh, Penn.	3.01	3.28	88.15	5.56	.5
Welsh, Wales	1.2	6.25	88.	4.55	.92
SEMI-ANTHRACITE.					
Natural Coke, Virginia	1.12	12.44	75.08	11.38	.47
Cardiff, Wales	1.25	12.85	81.9	4.	.76
Lycoming Creek, Penn.	.67	13.84	71.53	13.96	.03
Arkansas, No. 16 Geol. Survey	1.35	14.93	74.06	9.66	....
SEMI-BITUMINOUS.					
Blossburg, Penn.	1.34	14.78	73.11	10.77	.85
Mexican	1.0	14.86	55.7	28.44	4.53
Fort Smith, Arkansas	1.07	17.2	73.05	8.68	....
Cliff, New South Wales, Australia	.85	17.7	71.8	9.65	1.26
Skagit River, State of Washington	1.19	18.8	71.66	8.35	....
Cumberland, Maryland	.97	19.87	72.26	6.12	.77
Cambria County, Penn.	2.46	20.52	69.37	9.15	1.5
Mount Kembla, New South Wales, Aus.	1.2	20.93	66.96	10.91	2.33
Fire Creek, West Virginia	.74	22.42	75.5	.8	.54
Arkansas, No. 12 Geol. Survey	.88	24.66	58.2	16.26	
BITUMINOUS.					
Wilkeson, Pierce County, Washington	1.33	25.88	66.75	6.04	Trace.
Cowlitz, Washington	1.16	26.12	61.9	10.69	0.13
New River, West Virginia	.67	26.64	70.66	1.53	.5
Pictou, Nova Scotia	2.57	27.83	56.98	13.39	.77
Big Muddy, Illinois	7.12	29.5	54.64	8.74	1.01
Bellingham Bay, Washington	3.98	29.54	59.9	6.	.58
Midlothian, Virginia	2.46	29.86	53.01	14.74	.06
Connellsville, Penn.	1.26	30.10	59.61	8.23	.78
Illinois, Average	8.93	30.14	45.93	15.	5.
Carbon Hill, Washington	2.16	31.73	55.8	10.31	2.33
Clover Hill, Virginia	1.34	32.21	56.83	10.13	.51
Wellington, Vancouver Island, B.C.	2.15	34.15	54.85	8.85	.27
Franklin, Washington.	3.5	34.27	54.23	8.	
Rocky Mountains	7.55	34.65	42.85	14.95	1.1
Newcastle, England	1.5	34.7	59.3	4.5	.23
Mokihinui, Westport, New Zealand	3.96	34.94	57.92	3.18	....
Brunner Mine, Greymouth, New Zealand	1.59	35.68	56.62	6.11	....
Pittsburg, Penn.	1.7	36.	55.	7.3	.16
Nanaimo, Vancouver Island, B.C.	2.25	36.05	51.95	9.75	2.39
Hocking Valley, Ohio	6.95	36.15	51.3	5.56	.67
Pleasant Valley, Utah	5.43	37.73	49.40	7.44	1.28
Kentucky	2.	37.89	56.01	4.1	....
Ellensburg, Washington	2.	39.1	54.4	3.4	1.1
Olympic Mountains, Washington	5.1	39.15	47.01	7.77	.97
Scotch, Scotland	3.01	39.19	48.81	9.34	.36
Roslyn, Washington	3.1	39.7	52.65	4.55	Trace.
Cook's Inlet, Alaska	1.25	39.87	49.89	7.82	1.2
Kootznahoo Inlet, Admiralty I., Alaska	3.74	37.02	45.15	14.09	.72
Liverpool, England	.89	39.96	54.9	4.62	.38
Calispel, Washington	2.39	41.18	42.92	13.21	.3
Carbonado, Washington	1.8	42.27	52.11	3.82	Trace.
Upper Yakima, Washington	1.2	42.47	52.21	4.12	Trace.
Methow, Washington	2.5	43.71	49.27	4.26	.26

Proximate Analysis of Coal—*Continued.*

Designation of Coal.	Per Cent Moisture	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
Newcastle, King County, Washington .	2.12	46.7	43.9	7.15	.13
Black Diamond, King County, Washington	3.11	47.19	45.11	4.58	.01
Black Diamond, Mt. Diablo, California .	14.69	33.89	46.84	4.58	
LIGNITES.					
Otago (Kaitangata Cr.), New Zealand .	19.61	37.25	39.41	3.73	. . .
Gilman, Washington	4.8	47.07	37.19	10.06	.88
Coos Bay (Newport Mine), Oregon . .	15.45	41.55	34.95	8.05	2.53
Alaska	14.6	44.85	31.2	9.35	1.15
Huron, Fresno County, California . .	11.7	51.73	19.63	16.94	2.73
Ione, Amador County, California . . .	42.58	34.88	17.42	5.12	Trace.

Space Required to Stow a Ton (2240 lbs.) of Various Kinds of Coal.

ANTHRACITE.		
Welsh, Wales	39	cubic feet.
Peach Mountain, Penn.	41.6	" "
Beaver Meadow, Penn.	40.2	" "
Lehigh, Penn.	40.5	" "
Lackawanna, Penn.	45.8	" "
SEMI-ANTHRACITE.		
Cardiff, Wales	38.3	cubic feet.
Natural Coke, Virginia	50.2	" "
SEMI-BITUMINOUS.		
Cumberland, Virginia	41.7	cubic feet.
Blossburgh, Penn.	42.2	" "
Mt. Kembla, Australia	37.7	" "
Mexican	36.7	" "
BITUMINOUS.		
New River, Virginia.	46	cubic feet.
Wellington, Vancouver Island, B.C.	41.8	" "
Midlothian, Virginia	41.4	" "
Newcastle, England	44	" "
Pictou, Nova Scotia	45	" "
Scotch Splint, Fordel	40.7	" "
Pleasant Valley, Utah	42.3	" "
Sydney, N. S. W., Australia	47.2	" "
Takasima, Japan	46.4	" "
Pittsburgh, Penn.	47.8	" "
Liverpool, England	46.7	" "
Scotch, Dalkeith	43.8	" "
Carbon Hill, Washington	36.9	" "
Clover Hill, Virginia	49.2	" "
Rocky Mountain	41.2	" "
LIGNITE.		
Alaska	41.8	cubic feet.
WOOD.		
Dry pine wood	107	cubic feet.

COKE. — Coke from ovens, preferred to gas coke as fuel, weighs with few exceptions about 40 lbs. per bushel. Light coke will weigh 33 to 38 lbs. Heavy coke, 42 to 50 lbs.

Analysis of Coke.

(From report of John R. Procter, Kentucky Geological Survey.)

Where Made.	Fixed Carbon	Ash.	Sulphur.
Connellsville, Pa. (Average of 3 samples) . . .	88.96	9.74	0.810
Chattanooga, Tenn. " " 4 " . . .	80.51	16.34	1.595
Birmingham, Ala. " " 4 " . . .	87.29	10.54	1.195
Pocahontas, Va. " " 3 " . . .	92.53	5.74	0.597
New River, W. Va. " " 8 " . . .	92.38	7.21	0.562
Big Stone Gap, Ky. " " 7 " . . .	93.23	5.69	0.749

Wood as Fuel.

Green wood contains from 30 to 50 per cent of moisture. After about a year in open air the moisture is 20 to 25 per cent.

The woods of various trees are nearly identical in chemical composition, which is practically as follows, showing the composition of perfectly dry wood, and of ordinary firewood holding hygroscopic moisture:

	Desiccated Wood.	Ordinary Firewood.
Carbon	50 per cent	37.5 per cent
Hydrogen	6 per cent	4.5 per cent
Oxygen	41 per cent	30.75 per cent
Nitrogen	1 per cent	0.75 per cent
Ash	2 per cent	1.5 per cent
	100 per cent	75.0 per cent
Hygrometric water		25.0 per cent
		100.0

Some of the pines and others of the coniferous family contain hydrocarbons (turpentine). Ash varies in American woods from .03 per cent to 1.20 per cent.

In steam boiler tests wood is assumed as 0.4 the value of the same weight of coal.

The fuel value of the same weights of wood of all kinds is practically the same; and it is important that the wood be dry.

Weight of Wood per Cord.

	Weighs per Cord, Lbs.	Equal in value to Coal, in Lbs.
Average pine	2000	800 to 925
Poplar, chestnut, elm	2350	940 to 1050
Beech, red and black oak	3250	1300 to 1450
White oak	3850	1540 to 1715
Hickory and hard maple	4500	1800 to 2000

A *cord* of wood $= 4 \times 4 \times 8 = 128$ cubic feet. About 56 per cent is solid wood, and 44 per cent spaces.

Liquid Fuels.

Petroleum is a hydrocarbon liquid which is found in abundance in America and Europe. According to the analysis of M. Sainte-Claire Deville, the composition of 15 petroleums from different sources was found to be practically the same. The average specific gravity was .870. The extreme and the average elementary compositions were as follows:

Chemical Composition of Petroleum.

Carbon	82.0 to 87.1 per cent.	Average, 84.7 per cent.
Hydrogen	11.2 to 14.8 per cent.	Average, 13.1 per cent.
Oxygen	0.5 to 5.7 per cent.	Average, 2.2 per cent.
		100.0

The total heating and evaporative powers of one pound of petroleum having this average composition are as follows:

$$\text{Total heating power} = 145\,[84.7 + (4.28 \times 13.1)] = 20411 \text{ units.}$$

Evaporative power: evaporating at 212°, water supplied at 62° = 18.29 lbs.
Evaporative power: evaporating at 212°, water supplied at 212° = 21.13 lbs.

Petroleum oils are obtained in great variety by distillation from petroleum. They are compounds of carbon and hydrogen, ranging from $C_{10}H_{24}$ to $C_{32}H_{64}$; or, in weight;

Chemical Composition of Petroleum Oils.

From	to	Mean.
71.42 Carbon	73.77 Carbon . . .	72.60
28.58 Hydrogen	26.23 Hydrogen . .	27.40
100.00	100.00	100.00

The specific gravity ranges from .628 to .792. The boiling point ranges from 86° to 495° F. The total heating power ranges from 28087 to 26975 units of heat; equivalent to the evaporation, at 212°, of from 25.17 to 24.17 lbs. of water supplied at 62°, or from 29.08 lbs. to 27.92 lbs. of water supplied at 212°.

Furnaces for the combustion of oil fuel need not be as large as when burning coal, as the latter, being solid matter, requires more time for decomposition, and the elimination of the products and supporters of combustion. Coal fuel requires a large fire chamber and the means for the introduction of air beneath the grate-bars to aid combustion. Compared with oil, the combustion of coal is tardy, and requires some aid by way of a strong draft. Oil having no ash or refuse, when properly burned, requires much less space for combustion, for the reason that, being a liquid, and the compound of gases that are highly inflammable when united in proper proportions, it gives off heat with the utmost rapidity, and at the point of ignition is all ready for consumption.

Gaseous Fuels. — Mr. Emerson McMillin (Am. Gas. Lt. Asso., 1887) made an exhaustive investigation of the subject of fuel gas; he states that the relative values of these gases, considering that of natural gas as of unit value, are:

	By Weight.	By Volume.
Natural gas	1000	1000
Coal gas	949	666
Water gas	292	292
Producer gas	76.5	130

The water gas rated in the above table is the gas obtained in the decomposition of steam by incandescent carbon, and does not attempt to fix the calorific value of illuminating water gas, which may be carbureted so as to exceed, when compared by volume, the value of coal gas.

Composition of Gases.	Volume.			
	Natural Gas.	Coal Gas.	Water Gas.	Producer Gas.
Hydrogen	2.18	46.00	45.00	6.00
Marsh gas	92.60	40.00	2.00	3.00
Carbonic oxide	0.50	6.00	45.00	23.50
Olefiant gas	0.31	4.00	0.00	0.00
Carbonic acid	0.26	0.50	4.00	1.50
Nitrogen	3.61	1.50	2.00	65.00
Oxygen	0.34	0.50	0.50	0.00
Water vapor	0.00	1.50	1.50	1.00
Sulphydric acid	0.20	. . .	. . .	. . .
	100.00	100.00	100.00	100.00

Mechanical Stoking.

In boiler installations that can be conveniently handled by one man it is doubtful if we can improve on the best hand firing; but where good firemen are scarce, or the installation is of considerable size, there can be no doubt that the use of some form of mechanical stoker will result in economy, and especially in the prevention of large quantities of smoke, as the combustion is gradual and more nearly perfect.

The types may perhaps be limited to three: the straight feed, as the Murphy, Roney, Wilkinson, and Brightman; the under-feed of which the "American" is a good representative; and the chain stoker, by Coxe and the B. & W. Co.

Mechanical draught is generally used with the two last-mentioned types, and sometimes with the first.

Mr. Eckley B. Coxe developed the chain stoker in the most scientific manner for the use of the cheap coals of the anthracite region.

The advantages and disadvantages of mechanical stokers are stated by Mr. J. M. Whitham (Trans. A.S.M.E., vol. xvii. p. 558) to be as follows: *Advantages.* 1. Adaptability to the burning of the cheapest grades of fuel. 2. A 40 per cent labor saving in plants of 500 or more h. p., when provided with coal-handling machinery. 3. Economy in combustion, even under forced firing, with proper management. 4. Constancy and uniformity of furnace conditions, the fires being clean at all times, and responding to sudden demands made for power. This should result in prolonged life of boilers. 5. Smokelessness. *Disadvantages.* 1. High first cost, varying from $25 to $40 per square foot of grate area. 2. High cost of repairs per year, which, with some stokers, is as much as $5 per square foot. 3. The dependence of the power-plant upon the stoker engine's working. 4. Steam cost of running the stoker engine, which is from $\frac{1}{5}$ to $\frac{2}{5}$ of 1 per cent of the steam generated. This is about $50 a year on a 10-hour basis for 1000 h. p., where fuel is $2 per ton. 5. Cost of steam used for a steam blast, or for driving a fan blast, whenever either is used. This, for a steam blast, is from 5 per cent to 11 per cent of the steam generated by the boilers, and from 3 per cent to 5 per cent for a fan blast. This amounts to about $1000 per year for a steam blast, and $500 a year in fuel for a fan blast, for a 1000 h. p. plant on a 10-hour basis, when fuel is $2 per ton. 6. Skill required to operate the stoker. Careless management causes either loss of fuel in the ash, or loss due to poor combustion when the coal is too soon burned out on the grate, thus permitting cold air to freely pass through the ash. 7. The stoker is a machine subject to a severe service, and, like any other machine, wears out and requires constant attention.

WATER.

Weight of Water per Cubic Foot, from 32° to 212° F., and heat-units per pound, reckoned above 32° F. (Wm. Kent, Trans. A. S. M. E., vi. 90.)

Temp., deg. F.	Weight, lbs. per cubic foot.	Heat-units.	Temperature, deg. F.	Weight, lbs. per cubic foot.	Heat-units.	Tempera. ture, deg. F.	Weight, lbs. per cubic foot.	Heat-units.	Temperature, deg. F.	Weight, lbs. per cubic foot.	Heat-units.
32	62.42	0.	41	62.42	9.	50	62.41	18.	59	62.38	27.01
33	62.42	1.	42	62 42	10.	51	62.41	19.	60	62.37	28.01
34	62.42	2.	43	62.42	11.	52	62.40	20.	61	62.37	29.01
35	62.42	3.	44	62.42	12.	53	62.40	21.01	62	62.36	30.01
36	62.42	4.	45	62.42	13.	54	62.40	22.01	63	62.36	31.01
37	62.42	5.	46	62.42	14.	55	62.39	23,01	64	62.35	32.01
38	62.42	6.	47	62.42	15.	56	62.39	24.01	65	62.34	33.01
39	62.42	7.	48	64.41	16.	57	62.39	25.01	66	62.34	34.02
40	62.42	8.	49	62.41	17.	58	62.38	26.01	67	62.33	35.02

Weight of Water — *Continued.*

Temp., deg. F.	Weight, lbs. per Cubic Foot.	Heat-units.	Tempera-ture, deg. F.	Weight, lbs. per Cubic Foot.	Heat-units.	Tempera-ture, deg. F.	Weight, lbs. per Cubic Foot.	Heat-units.	Tempera-ture, deg. F.	Weight, lbs. per Cubic Foot.	Heat-units.
68	62.33	36.02	105	61.96	73.10	141	61.36	109.25	177	60.62	145.52
69	62.32	37.02	106	61.95	74.10	142	61.34	110.26	178	60.59	146.52
70	62.31	38.02	107	61.93	75.10	143	61.32	111.26	179	60.57	147.53
71	62.31	39.02	108	61.92	76.10	144	61.30	112.27	180	60.55	148.54
72	62.30	40.02	109	61.91	77.11	145	61.28	113.28	181	60.53	149.55
73	62.29	41.02	110	61.89	78.11	146	61.26	114.28	182	60.50	150.56
74	62.28	42.03	111	61.88	79.11	147	61.24	115.29	183	60.48	151.57
75	62.28	43.03	112	61.86	80.12	148	61.22	116.29	184	60.46	152.58
76	62.27	44.03	113	61.85	81.12	149	61.20	117.30	185	60.44	153.59
77	62.26	45.03	114	61.83	82.13	150	61.18	118.31	186	60.41	154.60
78	62.25	46.03	115	61.82	83.13	151	61.16	119.31	187	60.39	155.61
79	62.24	47.03	116	61.80	84.13	152	61.14	120.32	188	60.37	156.62
80	62.23	48.04	117	61.78	85.14	153	61.12	121.33	189	60.34	157.63
81	62.22	49.04	118	61.77	86.14	154	61.10	122.33	190	60.32	158.64
82	62.21	50.04	119	61.75	87.15	155	61.08	123.34	191	60.29	159.65
83	62.20	51.04	120	61.74	88.15	156	61.06	124.35	192	60.27	160.67
84	62.19	52.04	121	61.72	89.15	157	61.04	125.35	193	60.25	161.68
85	62.18	53.05	122	61.70	90.16	158	61.02	126.36	194	60.22	162.69
86	62.17	54.05	123	61.68	91.16	159	61.00	127.37	195	60.20	163.70
87	62.16	55.05	124	61.67	92.17	160	60.98	128.37	196	60.17	164.71
88	62.15	56.05	125	61.65	93.17	161	60.96	129.38	197	60.15	165.72
89	62.14	57.05	126	61.63	94.17	162	60.94	130.39	198	60.12	166.73
90	62.13	58.06	127	61.61	95.18	163	60.92	131.40	199	60.10	167.74
91	62.12	59.06	128	61.60	96.18	164	60.90	132.41	200	60.07	168.75
92	62.11	60.06	129	61.58	97.19	165	60.87	133.41	201	60.05	169.77
93	62.10	61.06	130	61.56	98.19	166	60.85	134.42	202	60.02	170.78
94	62.09	62.06	131	61.54	99.20	167	60.83	135.43	203	60.00	171.79
95	62.08	63.07	132	61.52	100.20	168	60.81	136.44	204	59.97	172.80
96	62.07	64.07	133	61.51	101.21	169	60.79	137.45	205	59.95	173.81
97	62.06	65.07	134	61.49	102.21	170	60.77	138.45	206	59.92	174.83
98	62.05	66.07	135	61.47	103.22	171	60.75	139.46	207	59.89	175.84
99	62.03	67.08	136	61.45	104.22	172	60.73	140.47	208	59.87	176.85
100	62.02	68.08	137	61.43	105.23	173	60.70	141.48	209	59.84	177.86
101	62.01	69.08	188	61.41	106.23	174	60.68	142.49	210	59.82	178.87
102	62.00	70.09	139	61.39	107 24	175	60.66	143.50	211	59.79	179.89
103	61.99	71.09	140	61.37	108.25	176	60.64	144.51	212	59.76	180.90
104	61.97	72.09									

Weight of Water at Temperatures Above 212° F.

(Dr. R. H. Thurston, "Engine and Boiler Trials," p. 548.)

Tempera-ture, Deg. F.	Weight, pounds per Cubic Foot.	Tempera-ture, Deg. F.	Weight, pounds per Cubic Foot.	Tempera-ture, Deg. F.	Weight, pounds per Cubic Foot.	Tempera-ture, Deg. F.	Weight, pounds per Cubic Foot.	Tempera-ture, Deg. F.	Weight, pounds per Cubic Foot.
212	59.71	280	57.90	350	55.52	420	52.86	490	50.03
220	59.64	290	57.59	360	55.16	430	52.47	500	49.61
230	59.37	300	57.26	370	54.79	440	52.07	510	49.20
240	59.10	310	56.93	380	54.41	450	51.66	520	48.78
250	58.81	320	56.58	390	54.03	460	51.26	530	48.36
260	58.52	330	56.24	400	53.64	470	50.85	540	47.94
270	58.21	340	55.88	410	53.26	480	50.44	550	47.52

Expansion of Water.

(Kopp : corrected by Porter.)

Cent.	Fahr.	Volume.	Cent.	Fahr.	Volume.	Cent.	Fahr.	Volume.
4°	39.2°	1.00000	35°	95°	1.00586	70°	158°	1.02241
5	41	1.00001	40	104	1.00767	75	167	1.02548
10	50	1.00025	45	113	1.00967	80	176	1.02872
15	59	1.00083	50	122	1.01186	85	185	1.03213
20	68	1.00171	55	131	1.01423	90	194	1.03570
25	77	1.00286	60	140	1.01678	95	203	1.03943
30	86	1.00425	65	149	1.01951	100	212	1.04332

Water for Boiler Feed.

(Hunt and Clapp, A. I. M. E., 1888.)

Water containing more than 5 parts per 100,000 of free sulphuric or nitric acid is liable to cause serious corrosion, not only of the metal of the boiler itself, but of the pipes, cylinders, pistons, and valves with which the steam comes in contact.

The total residue in water used for making steam causes the interior linings of boilers to become coated, and often produces a dangerous hard scale, which prevents the cooling action of the water from protecting the metal against burning.

Lime and magnesia bicarbonates in water lose their excess of carbonic acid on boiling, and often, especially when the water contains sulphuric acid, produce, with the other solid residues constantly being formed by the evaporation, a very hard and insoluble scale. A larger amount than 100 parts per 100,000 of total solid residue will ordinarily cause troublesome scale, and should condemn the water for use in steam boilers, unless a better supply can be obtained.

The following is a tabulated form of the causes of trouble with water for steam purposes, and the proposed remedies, given by Prof. L. M. Norton.

CAUSES OF INCRUSTATION.

1. Deposition of suspended matter.
2. Deposition of deposed salts from concentration.
3. Deposition of carbonates of lime and magnesia by boiling off carbonic acid, which holds them in solution.
4. Deposition of sulphates of lime, because sulphate of lime is but slightly soluble in cold water, less soluble in hot water, insoluble above 270° F.
5 Deposition of magnesia, because magnesium salts decompose at high temperature.
6. Deposition of lime soap, iron soap, etc., formed by saponification of grease.

MEANS FOR PREVENTING INCRUSTATION.

1. Filtration.
2. Blowing off.
3. Use of internal collecting apparatus or devices for directing the circulation.
4. Heating feed-water,

5. Chemical or other treatment of water in boiler.
6. Introduction of zinc into boiler.
7. Chemical treatment of water outside of boiler.

TABULAR VIEW.

Troublesome Substance.	*Trouble.*	*Remedy or Palliation.*
Sediment, mud, clay, etc.	Incrustation.	Filtration, Blowing off.
Readily soluble salts.	"	Blowing off.
Bicarbonates of lime, magnesia, iron.	"	Heating feed. Addition of caustic soda, lime, or magnesia, etc.
Sulphate of lime.	"	Addition of carb. soda, barium chloride, etc.
Chloride and sulphate of magnesium.	Corrosion.	Addition of carbonate of soda, etc.
Carbonate of soda in large amounts.	Priming.	Addition of barium chloride, etc.
Acid (in mine waters).	Corrosion.	Alkali.
Dissolved carbonic acid and oxygen.	"	Heating feed. Addition of caustic soda, slacked lime, etc.
Grease (from condensed water).	"	Slacked lime and filtering, Carbonate of soda. Substitute mineral oil.
Organic matter (sewage).	Priming.	Precipitate with alum or ferric chloride and filter.
Organic matter.	Corrosion.	Ditto.

Solubilities of Scale-making Materials.

(" Boiler Incrustation," F. J. Rowan.)

The salts of lime and magnesia are the most common of the impurities found in water. Carbonate of lime is held in solution in fresh water by an excess of carbonic acid. By heating the water the excess of carbonic acid is driven off and the greater part of the carbonate precipitated. At ordinary temperatures carbonate of lime is soluble in from 16,000 to 24,000 times its volume of water; at 212° F. it is but slightly soluble, and at 290° F. (43 lbs. pressure) it is insoluble.

The solubility of sulphate of lime is also affected by the temperature; according to Regnault, its greatest solubility is at 95° F., where it dissolves in 393 times its weight of water; at 212° F. it is only soluble in 460 times its weight of water, and according to M. Couté, it is insoluble at 290° F.

Carbonate of magnesia usually exists in much smaller quantity than the salts of lime. The effect of temperature on its solubility is similar to that of carbonate of lime.

Prof. R. H. Thurston, in his "Manual of Steam Boilers," p. 261, states that:

The temperatures at which calcareous matters are precipitated are:
Carbonate of lime between 176° and 248° F.
Sulphate of lime between 284° and 424° F.
Chloride of magnesium between 212° and 257° F.
Chloride of sodium between 324° and 364° F.

"INCRUSTATION AND SEDIMENT," Prof. Thurston says, "are deposited in boilers, the one by the precipitation of mineral or other salts previously held in solution in the feed-water, the other by the deposition of mineral insoluble matters, usually earths, carried into it in suspension or mechanical admixture. Occasionally also vegetable matter of a glutinous nature is held in solution in the feed-water, and, precipitated by heat or concentration, covers the heating-surfaces with a coating almost impermeable to heat, and hence liable to cause an over-heating that may be very dangerous to the structure. A powdery mineral deposit sometimes met with is equally dangerous, and for the same reason. The animal and vegetable oils and greases carried over from the condenser or feed-water heater are also very likely to cause trouble. Only mineral oils should be permitted to be thus introduced, and that in minimum quantity. Both the efficiency and the safety of the boiler are endangered by any of these deposits.

"The only positive and certain remedy for incrustation and sediment once deposited is periodical removal by mechanical means, at sufficiently frequent intervals to insure against injury by too great accumulation. Between times, some good may be done by special expedients suited to the individual case. No one process and no one antidote will suffice for all cases.

"Where carbonate of lime exists, sal-ammoniac may be used as a preventive of incrustation, a double decomposition occurring, resulting in the production of ammonium carbonate and calcium chloride — both of which are soluble, and the first of which is volatile. The bicarbonate may be in part precipitated before use by heating to the boiling-point, and thus breaking up the salt and precipitating the insoluble carbonate. Solutions of caustic lime and metallic zinc act in the same manner. Waters containing tannic acid and the acid juices of oak, sumach, logwood, hemlock, and other woods, are sometimes employed, but are apt to injure the iron of the boiler, as may acetic or other acid contained in the various saccharine matters often introduced into the boiler to prevent scale, and which also make the lime-sulphate scale more troublesome than when clean. Organic matters should never be used.

"The sulphate scale is sometimes attacked by the carbonate of soda, the products being a soluble sodium sulphate and a pulverulent insoluble calcium carbonate, which settles to the bottom like other sediments and is easily washed off the heating-surfaces. Barium chloride acts similarly, producing barium sulphate and calcium chloride. All the alkalies are used at times to reduce incrustations of calcium sulphate, as is pure crude petroleum, the tannate of soda, and other chemicals.

"The effect of incrustation and of deposits of various kinds is to enormously reduce the conducting power of heating-surfaces; so much so, that the power, as well as the economic efficiency of a boiler, may become very greatly reduced below that for which it is rated, and the supply of steam furnished by it may become wholly inadequate to the requirements of the case.

"It is estimated that a sixteenth of an inch thickness of hard 'scale' on the heating-surface of a boiler will cause a waste of nearly one-eighth its efficiency, and the waste increases as the square of its thickness. The boilers of steam vessels are peculiarly liable to injury from this cause where using salt water, and the introduction of the surface-condenser has been thus brought about as a remedy. Land boilers are subject to incrustation by the carbonate and other salts of lime, and by the deposit of sand or mud mechanically suspended in the feed-water."

Kerosene oil ("Boiler Incrustation," Rowan) has been used to advantage in removing and preventing incrustation. From extended experiments made on a 100 h. p. water tube boiler, fed with water containing 6.5 grains of solid matter per gallon, it was found that one quart kerosene oil per day was sufficient to keep the boiler entirely free from scale. Prior to the introduction of the kerosene oil, the water had a corrosive action upon some of the fittings attached to the boiler; but after the oil had been used for a few months it was found that the corrosive action had ceased.

It should be stated, however, that objection has been made to the introduction of kerosene oil into a boiler for the purpose of preventing incrustation, on account of the possibility of some of the oil passing with the steam into the cylinder of the engine, and neutralizing the effect of the lubricant in the cylinder.

When oil is used to remove scale from steam-boilers, too much care cannot be exercised to make sure that it is free from grease or animal oil. Nothing but pure mineral oil should be used. Crude petroleum is one thing; black oil, which may mean almost anything, is very likely to be something quite different.

The action of grease in a boiler is peculiar. It does not dissolve in the water, nor does it decompose, neither does it remain on top of the water; but it seems to form itself into "slugs," which at first seem to be slightly lighter than the water, so that the circulation of the water carries them about at will. After a short season of boiling, these "slugs," or suspended drops, acquire a certain degree of "stickiness," so that when they come in contact with shell and flues of the boiler, they begin to adhere thereto. Then under the action of heat they begin the process of "varnishing" the interior of the boiler. The thinnest possible coating of this varnish is sufficient to bring about over-heating of the plates.

The time when damage is most likely to occur is after the fires are banked, for then, the formation of steam being checked, the circulation of water stops, and the grease thus has an opportunity to settle on the bottom of the boiler and prevent contact of the water with the fire-sheets. Under these circumstances, a very low degree of heat in the furnace is sufficient to overheat the plates to such an extent that bulging is sure to occur.

Zinc as a Scale Preventive. — Dr. Corbigny gives the following hypothesis: he says that "the two metals, iron and zinc, surrounded by water at a high temperature, form a voltaic pile with a single liquid, which slowly decomposes the water. The liberated oxygen combines with the most oxydizable metal, the zinc, and its hydrogen equivalent is disengaged at the surface of the iron. There is thus generated over the whole extent of the iron influenced a very feeble but continuous current of hydrogen, and the bubbles of this gas isolate at each instant the metallic surface from the scale-forming substance. If there is but little of the latter, it is penetrated by these bubbles and reduced to mud; if there is more, coherent scale is produced, which, being kept off by the intervening stratum of hydrogen, takes the form of the iron surface without adhering to it."

Zinc, in the shape of blocks, slabs, or as shavings inclosed in a perforated vessel, should be suspended throughout the water space of a boiler, care being used in getting perfect metallic contact between the zinc and the boiler. It should not be suspended directly over the furnace, as the oxide might fall upon the surface and be the cause of the plate being over-heated. The quantity placed in a boiler should vary with the hardness of the water, and the amount used, and should be measured by the surface presented. Generally one square inch of surface for every 50 lbs. water in the boiler is sufficient. The British Admiralty recommends the renewing of the blocks whenever the decay of the zinc has penetrated the slab to a depth of ¼ inch below the surface.

Purification of Feed-Water by Boiling.

Sulphates can be largely removed from feed-water by heating it to the temperature due to boiler pressure in a feed-water heater, or "live steam purifier" before introduction to boiler. This precipitates those salts in the heater and the water can then if necessary be pumped through a filter into the boiler. The feed-water is first heated as hot as possible in the ordinary exhaust feed-water heater in which the carbonates are precipitated, and then run through the purifier, which is most generally a receptacle containing a number of shallow pans, that can be removed for cleaning, over which the feed-water is allowed to flow from one to the other in a thin sheet. Live steam at boiler-pressure is introduced into the purifier, heating the water to a temperature high enough to precipitate the salts which form scale on the pans. This method of treating feed-water is said to largely increase the efficiency of a boiler plant by the almost complete avoidance of scale. Purification of feed-water by filtration before introduction to the system is often practised with good results.

Table of Water Analyses.

Grains per U. S. Gallon of 231 Cubic Inches.

Where From.	Lime and Magnesia Carbonates.	Lime and Magnesia Sulphates.	Sodium Chloride. (Salt.)	Iron Oxide, Carb. Sulph., etc.	Volatile and Organic Matter.	Total Solids in Grains.
Buffalo, N. Y., Lake Erie	5.66	3.32	0.58	. . .	0.18	9.74
Pittsburgh, Allegheny River	0.37	3.78	0.58	0.37	1.50	6.60
Pittsburgh, Monongahela River	1.06	5.12	0.64	0.78	3.20	10.80
Pittsburgh, Pa., artesian well	23.45	5.71	18.41	1.04	0.82	49.43
Milwaukee, Wisconsin River	6.23	4.67	1.76	20.14	6.50	39.30
Galveston, Texas, 1	13.68	13.52	326.64	Trace	Trace	353.84
Galveston, Texas, 2	21.79	29.15	398.99	. . .	4.00	453.93
Columbus, Ohio	20.76	11.74	7.02	0.58	6.50	46.60
Washington, D. C., city supply	2.87	3.27	Trace	0.36	2.10	8.60
Baltimore, Md., city supply	2.77	0.65	Trace	0.10	3.80	7.30
Sioux City, Ia., city supply	19.76	1.24	1.17	1.03	4.40	27.60
Los Angeles, Cal., 1	10.12	5.84	3.51	2.63	4.10	26.20
Los Angeles, Cal., 2	3.72	12.59	. . .	0.76	6.00	23.07
Bay City, Michigan, Bay	8.47	10.36	20.48	1.15	8.74	49.20
Bay City, Michigan, River	4.84	33.66	126.78	3.00	10.92	179.20
Cincinnati, Ohio River	3.88	0.78	1.79	. . .	Trace	6.73
Watertown, Conn.	1.47	4.51	1.76	Trace	1.78	9.52
Fort Wayne, Ind.	8.78	6.22	3.51	1.59	10.98	31.08
Wilmington, Del.	10.04	6.02	4.29	8.48	6.17	35.00
Wichita, Kansas	14.14	25.91	24.34	. . .	2.00	66.39
Springfield, Ill., 1	12.99	7.40	1.97	2.19	8.62	33.17
Springfield, Ill., 2	5.47	4.31	1.56	4.28	5.83	21.45
Hillsboro, Ill.	14.56	2.97	2.39	1.63	Trace	21.55
Pueblo, Colo.	4.32	16.15	1.20	1.97	5.12	28.76
Long Island City, L. I.	4.0	28.0	16.0	. . .	1.0	39.0
Mississippi River, above Missouri River	8.24	1.02	0.50	. . .	5.25	15.01
Mississippi River, below mouth of Missouri River	10.64	7.41	1.36	1.22	15.86	36.49
Mississippi River at St. Louis, W. W.	9.64	6.94	1.54	1.57	9.85	29.54
Hudson River, above Poughkeepsie, N. Y.	1.06	. . .	.11	10.76	.77	12.70
Croton River, above Croton Dam, N. Y.	4.57	.16	.40	1.92	.67	7.72
Croton River water from service pipes in New York City	2.36	. . .	. . .	1.36	. . .	3.72
Schuylkill River, above Philadelphia, Pa.	2.16	.29	.49	1.30	. . .	4.24

PUMPS.

Feed-Pumps.

These should be at least double the capacity found by calculation from the amount of water required for the engines, to allow for blowing off, leakage, slip in the pumps themselves, etc., and to enable the pump to keep down steam in case of sudden stoppage of the engines when the fires happen to be brisk, and in fact should be large enough to supply the boilers when run at their full capacity. In addition, for all important plants, there should be either a duplicate feed-pump or an injector to act as stand-by in case of accident. The speed of the plunger or piston may be 50 feet per minute and should never exceed 100 feet per minute, else undue wear and tear of the valves results, and the efficiency is reduced. If the pump be required to stand idle without continually working, the plunger or piston and rod should be of brass.

If

$D =$ diameter of barrel in inches,
$S =$ stroke in inches,
$n =$ number of useful strokes per minute,
$w =$ cubic feet of water pumped per hour,
$W =$ lbs. of water pumped per hour;

$$w = 1.7\ D^2 S\ n.$$

$$W = \frac{D^2\ S\ n}{36.6}.$$

If

$$S\ n = 50,$$

$$W = 1.36\ D^2,$$

and

$$D = \sqrt{\frac{W}{1.36}}.$$

Rubber valves may be used for cold water, but brass, rubber composition, or other suitable material is required for hot water or oil.

If a new pump will not start, it may be due to its imperfect connections or temporary stiffness of pump.

Unless the suction lift and length of supply pipe be moderate, a foot-valve, a charging connection, and a vacuum chamber are desirable. The suction-pipe must be entirely free from air leakage. If the pump refuses to start lifting water with full pressure on, on account of the air in the pump-chamber not being dislodged, but only compressed each stroke, arrange for running without pressure until the air is expelled and water flows. This is done with a check-valve in the delivery-pipe, and a waste delivery which may be closed when water flows.

Pumping Hot Water.— With a free suction-pipe, any good pump fitted with metal valves and with hot-water packing will pump water having a temperature of 212°, or higher, if so placed that the water will flow into it.

Robert D. Kinney, in "Power," gives the following formula for determining to what height water of temperatures below the boiling point can be lifted by suction.

$D =$ lift in feet,
$A =$ absolute pressure on surface of water; if open to air $= 14.7$ lbs.
B and $W =$ constants. See table.

$$D = \frac{144\ (A - B)}{W} \times .08 = 11.52\ \frac{A - B}{W}.$$

Water Temp. Degrees F.	B.	W.	Water Temp. Degrees F.	B.	W.
40	0.122	62.42	130	2.215	61.56
50	0.178	62.41	140	2.879	61.39
60	0.254	62.37	150	3.708	61.20
70	0.360	62.31	160	4.731	61.01
80	0.503	62.22	170	5.985	60.80
90	0.693	62.12	180	7.511	60.59
100	0.942	62.00	190	9.335	60.37
110	1.267	61.87	200	11.526	60.13
120	1.685	61.72	210	14.127	59.89

Speed of Water through Pump-Passages and Valves.

The speed of water flowing through pipes and passages in pumps varies from 100 to 200 feet per minute. The loss from friction will be considerable if the higher speed is exceeded.

The area of valves should be sufficient to permit the water to pass at a speed not exceeding 250 feet per minute.

The amount of steam which an average engine will require per indicated horse-power is usually taken at 30 pounds. It varies widely, however, from about 12 pounds in the best class of triple expansion condensing engines up to considerably over 90 pounds in many direct-acting pumps. Where an engine is overloaded or underloaded more water per horse-power will be required than when operated at rated capacity. Horizontal tubular boilers will evaporate on an average from 2 to 3 pounds of water per square foot heating-surface per hour, but may be forced up to 6 pounds if the grate surface is too large or the draught too great for economical working.

Sizes of Direct-acting Pumps.

The two following tables are selected as representing the two common types of direct-acting pump, viz., the single-cylinder and the duplex.

Efficiency of Small Direct-acting Pumps.

In "Reports of Judges of Philadelphia Exhibition," 1876, Group xx., Chas. E. Emery says: "Experiments made with steam-pumps at the American Institute Exhibition of 1867 showed that average size steam-pumps do not, on the average, utilize more than 50 per cent of the indicated power in the steam cylinders, the remainder being absorbed in the friction of the engine, but more particularly in the passage of the water through the pump. Again, all ordinary steam-pumps for miscellaneous use, require that the steam-cylinder shall have three to four times the area of the water-cylinder to give sufficient power when the steam is accidentally low; hence, as such pumps usually work against the atmospheric pressure, the net or effective pressure forms a small percentage of the total pressure, which, with the large extent of radiating surface exposed and the total absence of expansion, makes the expenditure of steam very large. One pump tested required 120 pounds weight of steam per indicated horse-power per hour, and it is believed that the cost will rarely fall below 60 pounds; and as only 50 per cent of the indicated power is utilized, it may be safely stated that ordinary steam pumps rarely require less than 120 pounds of steam per hour for each horse-power utilized in raising water, equivalent to a duty of only 15,000,000 foot pounds per 100 pounds of coal. With larger steam-pumps, particularly when they are proportioned for the work to be done, the duty will be materially increased.

Single-Cylinder Direct-acting Pump.

(Standard Sizes for ordinary service.)

Diameter of Steam-Cylinder in Inches.	Diameter of Water-Cylinder in Inches.	Length of Stroke in Inches.	Gallons per Stroke.	Maximum Number of Strokes per Minute.	Capacity per Minute at Given Speed.		Extreme Length in Inches.	Extreme Width in Inches.	Diameter of			
					Strokes.	Gallons.			Steam-Pipe.	Exhaust-Pipe.	Suction-Pipe.	Discharge-Pipe.
4	3½	5	.14	300	130	18	33	9½	½	¾	2	1½
4	4	5	.27	300	130	35	33	9½	½	¾	2	1½
5	4	7	.39	300	125	49	45½	15	¾	1	3	2½
5½	5	7	.51	275	125	64	45½	15	¾	1	3	2½
5½	5½	7	.72	275	125	90	45½	15	¾	1	3	2½
7	7	10	1.64	250	110	180	58	17	1	1½	5	4
7½	7½	10	1.91	250	110	210	58	17	1	1½	5	4
7½	8	10	2.17	250	110	239	58	17	1	1½	5	4
8	6	12	1.47	250	100	147	67	20½	1	1½	4	4
8	7	12	2.00	250	100	200	67	20½	1	1½	5	4
8	8	12	2.61	250	100	261	68	30	1	1½	5	5
8	10	12	4.08	250	100	408	68	20½	1	1½	8	8
10	8	12	2.61	250	100	261	68½	30	1½	2	5	5
10	10	12	4.08	250	100	408	68½	30	1½	2	8	8
10	12	12	5.87	250	100	587	68½	30	1½	2	8	8
12	10	12	4.08	250	100	408	64	24	2	2½	8	8
12	10	18	6.12	200	70	428	68½	30	2	2½	8	8
12	12	12	5.87	250	100	587	64	28½	2	2½	8	8
12	12	18	8.80	175	70	616	88	28½	2	2½	8	8
12	14	18	12.00	175	70	840	88	28½	2	2½	8	8
14	10	12	4.08	250	100	408	69	30	2	2½	8	8
14	10	18	6.12	175	70	428	93	25	2	2½	8	8
14	10	24	8.16	150	50	408	112	26	2	2½	8	8
14	12	12	5.87	250	100	587	69	30	2	2½	8	8
14	12	18	8.80	175	70	616	88	28½	2	2½	8	8
14	12	24	11.75	150	50	587	112	26	2	2½	10	8
14	14	24	15.99	150	50	800	112	34	2	2½	12	10
14	16	16	13.92	175	80	1114	84	34	2	2½	12	10
14	16	24	20.88	150	50	1044	112	38	2	2½	12	10
16	14	18	12.00	175	70	840	89	27	2	2½	8	8
16	14	24	15.99	150	50	800	109	34	2	2½	12	10
16	16	16	13.92	175	80	1114	85	34	2	2½	12	10
16	16	24	20.88	150	50	1044	115	34	2	2½	12	10
16	18	24	26.43	125	50	1322	115	40	2	2½	14	12
18	16	24	20.88	125	50	1044	118	38	3	3½	12	10
18	18	24	26.43	125	50	1322	118	40	3	3½	14	12
18	20	24	32.64	125	50	1632	118	40	3	3½	16	14
20	18	24	26.43	125	50	1322	118	40	3	3½	14	12
20	20	24	32.64	125	50	1632	118	40	3	3½	16	14
20	22	24	39.50	125	50	1975	120	40	3	3½	18	14

Duplex-Cylinder Direct-acting Pump.

(Standard sizes for ordinary service.)

Diameter of Steam-Cylinders, Inches.	Diameter of Water-Plungers, Inches.	Length of Stroke, Inches.	Displacement in Gallons per Stroke of one Plunger.	Proper Strokes per Minute of One Plunger, varying with kind of Work and Pressure.	Gallons Delivered per Minute by Both Plungers at Stated Number of Strokes.	Diameter of Plunger required in any Single-Cylinder Pump to do the same Work at same Speed.	Sizes of Pipes for Short Lengths. To be Increased as Length Increases.			
							Steam-Pipe.	Exhaust-Pipe.	Suction-Pipe.	Discharge-Pipe.
3	2	3	.04	100 to 250	8 to 20	$2\frac{7}{8}$	$\frac{3}{8}$	$\frac{1}{2}$	$1\frac{1}{4}$	1
$4\frac{1}{2}$	$2\frac{3}{4}$	4	.10	100 “ 200	20 “ 40	4	$\frac{1}{2}$	$\frac{3}{4}$	2	$1\frac{1}{2}$
$5\frac{1}{4}$	$3\frac{1}{2}$	5	.20	100 “ 200	40 “ 80	5	$\frac{3}{4}$	$1\frac{1}{4}$	$2\frac{1}{2}$	$1\frac{1}{2}$
6	4	6	.33	100 “ 150	70 “ 100	$5\frac{5}{8}$	1	$1\frac{1}{2}$	3	2
$7\frac{1}{2}$	$4\frac{1}{2}$	6	.42	100 “ 150	85 “ 125	$6\frac{3}{8}$	$1\frac{1}{2}$	2	4	3
$7\frac{1}{2}$	5	6	.51	100 “ 150	100 “ 150	7	$1\frac{1}{2}$	2	4	3
$7\frac{1}{2}$	$4\frac{1}{2}$	10	.69	75 “ 125	100 “ 170	$6\frac{3}{8}$	$1\frac{1}{2}$	2	4	3
9	$5\frac{1}{4}$	10	.93	75 “ 125	135 “ 230	$7\frac{1}{2}$	2	$2\frac{1}{2}$	4	3
10	6	10	1.22	75 “ 125	180 “ 300	$8\frac{1}{2}$	2	$2\frac{1}{2}$	5	4
10	7	10	1.66	75 “ 125	245 “ 410	$9\frac{7}{8}$	2	$2\frac{1}{2}$	6	5
12	7	10	1.66	75 “ 125	245 “ 410	$9\frac{7}{8}$	$2\frac{1}{2}$	3	6	5
14	7	10	1.66	75 “ 125	245 “ 410	$9\frac{7}{8}$	$2\frac{1}{2}$	3	6	5
12	$8\frac{1}{2}$	10	2.45	75 “ 125	365 “ 610	12	$2\frac{1}{2}$	3	6	5
14	$8\frac{1}{2}$	10	2.45	75 “ 125	365 “ 610	12	$2\frac{1}{2}$	3	6	5
16	$8\frac{1}{2}$	10	2.45	75 “ 125	365 “ 610	12	$2\frac{1}{2}$	3	6	5
$18\frac{1}{2}$	$8\frac{1}{2}$	10	2.45	75 “ 125	365 “ 610	12	3	$3\frac{1}{2}$	6	5
20	$8\frac{1}{2}$	10	2.45	75 “ 125	365 “ 610	12	4	5	6	5
12	$10\frac{1}{4}$	10	3.57	75 “ 125	530 “ 890	$14\frac{1}{4}$	$2\frac{1}{2}$	3	8	7
14	$10\frac{1}{4}$	10	3.57	75 “ 125	530 “ 890	$14\frac{1}{4}$	$2\frac{1}{2}$	3	8	7
16	$10\frac{1}{4}$	10	3.57	75 “ 125	530 “ 890	$14\frac{1}{4}$	$2\frac{1}{2}$	3	8	7
$18\frac{1}{2}$	$10\frac{1}{4}$	10	3.57	75 “ 125	530 “ 890	$14\frac{1}{4}$	3	$3\frac{1}{2}$	8	7
20	$10\frac{1}{4}$	10	3.57	75 “ 125	530 “ 890	$14\frac{1}{4}$	4	5	8	7
14	12	10	4.89	75 “ 125	730 “ 1220	17	$2\frac{1}{2}$	3	10	8
16	12	10	4.89	75 “ 125	730 “ 1220	17	$2\frac{1}{2}$	3	10	8
$18\frac{1}{2}$	12	10	4.89	75 “ 125	730 “ 1220	17	3	$3\frac{1}{2}$	10	8
20	12	10	4.89	75 “ 125	730 “ 1220	17	4	5	10	8
$18\frac{1}{2}$	14	10	6.66	75 “ 125	990 “ 1660	$19\frac{3}{4}$	3	$3\frac{1}{2}$	12	10
20	14	10	6.66	75 “ 122	990 “ 1660	$19\frac{3}{4}$	4	5	12	10
17	10	15	5.10	50 “ 100	510 “ 1020	14	3	$3\frac{1}{2}$	10	8
20	12	15	7.34	50 “ 100	730 “ 1460	17	4	5	12	10
20	15	15	11.47	50 “ 100	1145 “ 2290	21	. . .	. . .	. . .	. . .
25	15	15	11.47	50 “ 100	1145 “ 2290	21	. . .	. . .	. . .	. . .

INJECTORS.

Live Steam Injectors.

Let

$W =$ water injected in pounds her hour.
$P =$ steam pressure in pounds per square inch.
$D =$ diameter of throat in inches.
$T =$ diameter of throat in millimeters.

Then $$W = 1280\ D^2 \sqrt{P}$$
$$= 1.98\ d^2 \sqrt{P}$$

The rule given by Rankine, "Steam Engine," p. 477, for finding the proper sectional area in square inches for the narrowest part of the nozzle is as follows:

$$\text{area} = \frac{\text{cubic feet per hour gross feed-water}}{800 \sqrt{\text{pressure in atmospheres}}}$$

The expenditure of steam is about one-fourteenth the volume of water injected.

The following table gives the water delivered for different sizes of injectors at different pressures; but when the injector has to lift its water a deduction must be made varying from 10 to 30 per cent according to the lift.

Deliveries for Live Steam Injectors.

Size of Injector in Millimeters.	Pressure of Steam.						Size of Pipes and Fittings.
	30 lbs.	60 lbs.	80 lbs.	100 lbs.	120 lbs.	140 lbs.	
	Delivery in Gallons per Hour.						In.
2	43	61	71	80	87	93	½
3	97	138	160	178	196	211	½
4	173	246	285	317	348	376	1
5	272	385	445	496	545	587	1
6	392	555	640	715	783	846	1¼
7	533	755	871	973	1067	1152	1¼
8	696	985	1137	1272	1393	1505	1½
9	882	1247	1440	1610	1763	1905	1½
10	1088	1540	1777	1987	2177	2352	2
11	1317	1863	2150	2405	2633	2846	2
12	1567	2217	2560	2861	3136	3387	2¼
13	1840	2602	3005	3358	3680	3975	2¼
14	2133	3018	3485	3895	4267	4610	2½
15	2450	3465	4000	4471	4900	5292	2½
16	2787	3942	4551	5087	5575	6022	2¾
17	3146	4450	5138	5743	6291	6798	2¾
18	3527	4990	5760	6438	7055	7633	2¾
19	3930	5560	6418	7175	7861	8492	2¾
20	4355	6160	7110	7950	8710	9410	3

1 millimeter = $\frac{1}{25}$ inch, nearly.

As the vertical distance the injector lifts is increased, a greater steam pressure is required to start the injector, and the highest steam pressure at which it will work is gradually decreased.

If the feed-water is heated a greater steam pressure is required to start the injector, and it will not work with as high steam pressure.

The capacity of an injector is decreased as the lift is increased or the feed-water heated.

Performance of Injectors. — W. Sellers & Co. state that one of their injectors delivered 25.5 lbs. water to a boiler per pound of steam; steam pressure 65 lbs.; temperature of feed, 64° F.

Schaeffer & Budenberg state that their injectors will deliver 1 gallon water to a boiler for from 0.4 to 0.8 lbs. steam. They also state that the temperatures of feed-water taken by their injector, if non-lifting or at a low lift, can be as follows:

Pressure, lbs. .	35 to 45,	50 to 85,	90,	105,	120,	135,	150.
Temperature, °F.,	144 to 136,	133 to 130,	129,	122,	118 to 113,	109 to 105,	104 to 100.

The Hayden & Derby Mfg. Co. state that the results given below are from actual tests of Metropolitan Double-Tube Injectors.

With Cold Feed-Water.

On a 2-foot lift :	Starts with 14 lbs. steam pressure. Works up to 250 lbs. steam pressure.
On an 8-foot lift :	Starts with 23 lbs. steam pressure. Works up to 220 lbs. steam pressure.
On a 14-foot lift :	Starts with 27 lbs. steam pressure. Works up to 175 lbs. steam pressure.
On a 20-foot lift :	Starts with 42 lbs. steam pressure. Works up to 135 lbs. steam pressure.
When not lifting :	Starts with 14 lbs. steam pressure. Works up to 250 lbs. steam pressure.

With Feed-Water at 100° F.

On a 2-foot lift :	Starts with 15 lbs. steam pressure. Works up to 210 lbs. steam pressure.
On an 8-foot lift :	Starts with 26 lbs. steam pressure. Works up to 160 lbs. steam pressure.
On a 14-foot lift :	Starts with 37 lbs. steam pressure. Works up to 120 lbs. steam pressure.
On a 20-foot lift :	Starts with 46 lbs. steam pressure. Works up to 70 lbs. steam pressure.
When not lifting :	Starts with 15 lbs. steam pressure. Works up to 210 lbs. steam pressure.

With Feed-Water at 120° F.

On a 2-foot lift :	Starts with 20 lbs. steam pressure. Works up to 185 lbs. steam pressure.
On an 8-foot lift :	Starts with 30 lbs. steam pressure. Works up to 120 lbs. steam pressure.
On a 14-foot lift :	Starts with 42 lbs. steam pressure. Works up to 75 lbs. steam pressure.
When not lifting :	Starts with 20 lbs. steam pressure. Works up to 185 lbs. steam pressure.

With Feed-Water at 140° F.

On a short lift, or when not lifting, this injector will work with steam pressures from 20 lbs. to 120 lbs., and on an 8-foot lift with steam pressures from 35 lbs. to 70 lbs.

Exhaust Injectors working with exhaust steam from an engine, at about atmospheric pressure will deliver water against boiler pressure not exceeding 80 lbs. per square inch. The temperature of the water may be as high as 190° F., while 12 per cent of the water delivered will be condensed steam. For pressures over 80 lbs. it is necessary to supplement the exhaust steam with a jet of live steam.

Injector vs. Pump for Feeding Boilers.

The relative value of injectors, direct-acting steam pumps, and pumps driven from the engine, is a question of importance to all steam-users. The following table ("Stevens Indicator," 1888) has been calculated by D. S. Jacobs, M. E., from data obtained by experiment. It will be noticed that when feeding cold water direct to boilers, the injector has a slight economy, but when feeding through a heater a pump is much the most economical.

Method of Supplying Feed-Water to Boiler. Temperature of Feed-Water as delivered to the Pump or to the Injector, 60° F. Rate of Evaporation of Boiler, 10 lbs. of Water per pound of Coal from and at 212° F.	Relative Amount of Coal Required per Unit of Time, the Amount for a Direct-Acting Pump, Feeding Water at 60°, without a Heater, being taken as Unity.	Saving of Fuel over the Amount Required when the Boiler is Fed by a Direct-Acting Pump without Heater.
Direct-acting pump feeding water at 60°, without a heater	1.000	.0
Injector feeding water at 150°, without a heater	.985	1.5 per cent.
Injector feeding through a heater in which the water is heated from 150° to 200°	.938	6.2 "
Direct-acting pump feeding water through a heater, in which it is heated from 60° to 200°	.879	12.1 "
Geared pump, run from the engine, feeding water through a heater, in which it is heated from 60° to 200°	.868	13.2 "

Sizes for Feed-Water Pipes.

Three and six-tenths gallons of feed-water are required for each h. p. per hour. This makes 6 gallons per minute for a 100 h. p. boiler. In proportioning pipes, however, it is well to remember that boiler-work is seldom perfectly steady, and that as the engine cuts off just as much steam as the work demands at each stroke, *all the discrepancies of demand and supply have to be equalized in the boiler.* Therefore we may often have to evaporate during one-half hour 50 to 75 per cent more than the normal requirements. For this reason it is sound policy to arrange the feed-pipes so that 10 gallons per minute may flow through them, without undue speed or friction, for each 100 h. p. of boiler capacity. The following tables will facilitate this work.

Table Giving Rate of Flow of Water, in Feet per Minute, Through Pipes of Various Sizes, for Varying Quantities of Flow.

Gallons per Min.	¾ in.	1 in.	1¼ in.	1½ in.	2 in.	2½ in.	3 in.	4 in.
5	218	122½	78½	54½	30½	19½	13½	7⅔
10	436	245	157	109	61	38	27	15⅓
15	653	367½	235½	163½	91½	58½	40½	23
20	872	490	314	218	122	78	54	30⅔
25	1090	612½	392½	272½	152½	97½	67½	38⅓
30	. . .	735	451	327	183	117	81	46
35	. . .	857½	549½	381½	213½	136½	94½	53⅔
40	. . .	980	628	436	244	156	108	61⅓
45	. . .	1102½	706½	490½	274½	175½	121½	69
50	. . .	. . .	785	545	305	195	135	76⅔
75	. . .	. . .	1177½	817½	457½	292½	202½	115
100	. . .	. . .	. . .	1090	610	380	270	153⅓
125	. . .	. . .	. . .	. . .	762½	487½	337½	191⅔
150	. . .	. . .	. . .	. . .	915	585	405	230
175	. . .	. . .	. . .	. . .	1067½	682½	472½	268⅓
200	. . .	. . .	. . .	. . .	1220	780	540	306⅔

Table Giving Loss in Pressure due to Friction, in Pounds per Square Inch, for Pipe 100 Feet Long.

(By G. A. Ellis, C. E.)

Gallons Discharged per Min.	¾ in.	1 in.	1¼ in.	1½ in.	2 in.	2½ in.	3 in.	4 in.
5	3.3	0.84	0.31	0.12	. . .	. . .	. . .	. . .
10	13.0	3.16	1.05	0.47	0.12	. . .	. . .	. . .
15	28.7	6.98	2.38	0.97	. . .	. . .	. . .	. . .
20	50.4	12.3	4.07	1.66	0.42	. . .	. . .	. . .
25	78.0	19.0	6.40	2.62	. . .	0.21	0.10	. . .
30	. . .	27.5	9.15	3.75	0.91	. . .	. . .	. . .
35	. . .	37.0	12.4	5.05	. . .	. . .	. . .	. . .
40	. . .	48.0	16.1	6.52	1.60	. . .	. . .	. . .
45	. . .	. . .	20.2	8.15	. . .	. . .	. . .	. . .
50	. . .	. . .	24.9	10.0	2.44	0.81	0.35	0.09
75	. . .	. . .	56.1	22.4	5.32	1.80	0.74	. . .
100	. . .	. . .	. . .	39.0	9.46	3.20	1.31	0.33
125	. . .	. . .	. . .	. . .	14.9	4.89	1.99	. . .
150	. . .	. . .	. . .	. . .	21.2	7.0	2.85	0.69
175	. . .	. . .	. . .	. . .	28.1	9.46	3.85	. . .
200	. . .	. . .	. . .	. . .	37.5	12.47	5.02	1.22

Loss of Head due to Bends.

Bends produce a loss of head in the flow of water in pipes. Weisbach gives the following formula for this loss:

$H = f\,\dfrac{v^2}{2g}$ where $H =$ loss of head in feet, $f =$ coefficient of friction, $v =$ velocity of flow in feet per second, $g = 32.2$.

As the loss of head or pressure is in most cases more conveniently stated in pounds per square inch, we may change this formula by multiplying by 0.433, which is the equivalent in pounds per square inch for one foot head.

If $P =$ loss in pressure in pounds per square inch, $F =$ coefficient of friction.

$P = F\,\dfrac{v^2}{64.4}$, v being the same as before.

From this formula has been calculated the following table of values for F, corresponding to various exterior angles, A.

$A =$	20°	40°	45°	60°	80°	90°	100°	110°	120°	130°
$F =$	0.020	0.060	0.079	0.158	0.320	0.426	0.546	0.674	0,806	0.934

This applies to such short bends as are found in ordinary fittings, such as 90° and 45° Ells, Tees, etc.

A globe valve will produce a loss about equal to two 90° bends, a straightway valve about equal to one 45° bend. To use the above formula *find the speed p. second, being one-sixtieth of that found in Table p. 869; square this speed, and divide the result by 64.4; multiply the quotient by the tabular value of F corresponding to the angle of the turn, A.*

For instance, a 400 h.p. battery of boilers is to be fed through a 2-inch pipe. Allowing for fluctuations we figure 40 gallons per minute, making 244 feet per minute speed, equal to a velocity of 4.6 per second. Suppose our pipe is in all 75 feet long; we have from Table No. 36, for 40 gallons per minute, 1.60 pounds loss; for 75 feet we have only 75 per cent of this $= 1.20$ pounds. Suppose we have 6 right-angled ells, each giving $F = 0.426$. We have then $4.06 \times 4.06 = 16.48$; divide this by $64.4 = 0{,}256$. Multiply this by $F = 0.426$

pounds, and as there are 6 ells, multiply again by 6, and we have $6 \times 0.426 \times 0.256 = 0.654$. The total friction in the pipe is therefore $1.20 + 0.654 = 1.854$ pounds per square inch. If the boiler pressure is 100 pounds and the water level in the boiler is 8 feet higher than the pump suction level, we have first $8 \times 0.433 = 3.464$ pounds. The total pressure on the pump plunger then is $100 + 3.464 + 1.854 = 105.32$ pounds per square inch. If in place of 6 right-angled ells we had used three 45° ells, they would have cost us only $3 \times 0.079 = 0.237$ pounds; $0.237 \times 0.256 = 0.061$.

The total friction head would have been $1.20 + 0.061 = 1.261$, and the total pressure on the plunger $100 + 3.464 + 1.261 = 104.73$ pounds per square inch, a saving over the other plan of nearly 0.6 pounds.

To be accurate, we ought to add a certain head in either case, "to produce the velocity." But this is very small, being for velocities of:

2;	3;	4;	5;	6;	8;	10;	12 and 18 feet per sec.
0.027;	0.061;	0.108;	0.168;	0.244;	0.433;	0.672;	0.970 and 2.18 lbs. per sq. in.

Our results should therefore have been increased by about 0.11 pounds.

It is usual, however, to use larger pipes, and thus to materially reduce the frictional losses.

Feed-Water Heaters are of the "open" or "closed" type.

The open heater is usually made of cast iron, as this material will withstand the corrosive action of acids found in feed-waters better than any other metal. In this type of heater the exhaust steam from engines and pumps, and the feed-water broken up into drops by suitable means, are brought into immediate contact, and the steam not condensed in heating the water passes off to the atmosphere. The quantity of water that can be heated is only limited by the amount of steam and water that can be brought together. The steam condensed in heating the water is saved and utilized for boiler feed. An open heater should be provided with an efficient oil-separator, a large settling-chamber or hot well in which, if desired, a filtering bed of suitable material can be placed to insure the removal from the water, of all the impurities held in suspension, a device for skimming the surface of the water to remove the impurities floating on the water, and a large blow-off opening placed at the lowest point in the heater.

The closed heater is made with a wrought-iron or steel cylindrical shell and cast- or wrought-iron heads, having iron or brass tubes inside, set in tube plates so as to make steam- and water-tight joints, provision being made for the expansion and contraction of the tubes. According to the particular design of the heater, the exhaust steam passes through or around the tubes, the water being on the opposite of the walls of the tubes. The steam and water are separated by metal through which the heat of the exhaust steam is transmitted to the water. As an oil-separator is very seldom attached to a closed heater, the steam condensed in heating the water is wasted. The quantity of water that can be heated is limited by the amount of heat that can be transmitted through the tubes. The efficiency of heat transmission is decreased by the coating of oil that covers the steam side, and the crust of scale that coats the water side of the tubes. No provision can be made for purifying the water in a closed heater, as the constant circulation of the water prevents the impurities from settling. The impurities that are in the water pass on into the boiler. Purification must be done by means of an auxiliary apparatus.

Saving by Heating Feed-Water.

(W. W. Christie.)

In converting water at 32° F. into steam at atmospheric pressure, it must be raised to 212° F., the boiling point.

The specific heat of water varies somewhat with its temperature, so that to raise a pound of water from 32° to 212° F. or 180° F., requires 180.8 heat units.

To convert it into steam, after it has reached 212° F., requires 965.8 heat units, or in all $180.8 + 965.8 = 1146.6$ units of heat, thermal units.

The saving to be obtained by the use of waste heat, as exhaust steam, heating the water by transfer of some of its heat through metal walls, is calculated by this formula :

$$\text{Gain in per cent} = \frac{100\,(h_2 - h_1)}{H - h_1} = \frac{100\,(t_2 - t_1)}{H - t_1 + 32} \text{ very nearly,}$$

in which $H =$ total heat in steam at boiler pressure (above that in water at 32° F.) in B. T. U.

$h_2 =$ heat in feed-water (above 32° F.) after heating.

$h_1 =$ heat in feed-water (above 32° F.) before heating.

$t_2 =$ temperature of feed-water after heating °F.

$t_1 =$ temperature of feed-water before heating °F.

given $H = 1146.6$, $t_2 = 212$, $t_1 = 112$, or a difference of 100°; and we obtain by use of the above formula, gain in per cent = 9.37, or for 10° approximately .937 per cent, for 11° 1.02 per cent, so we may say that for every 11° F. added to the feed-water temperature by use of the exhaust steam, 1 per cent of fuel saving results.

The table which follows is taken from "Power."

Percentage of Saving in Fuel by Heating Feed-Water by Waste Steam, Steam at 70 Pounds Gauge Pressure.

Initial Temperature Feed.	Temperature of Water Entering Boiler.											
	120°	130°	140°	150°	160°	170°	180°	190°	200°	210°	220°	250°
35°	7.24	8.09	8.95	9.89	10.66	11.52	12.38	13.24	14.09	14.95	15.81	19.40
40°	6.84	7.69	8.56	9.42	10.28	11.14	12.00	12.87	13.73	14.59	15.45	18.89
45°	6.44	7.30	8.16	9.03	9.90	10.76	11.62	12.49	13.36	14.22	15.09	18.37
50°	6.03	6.89	7.76	8.64	9.51	10.38	11.24	12.11	12.98	13.85	14.72	17.87
55°	5.63	6.49	7.37	8.24	9.11	9.99	10.85	11.73	12.60	13.48	14.35	17.38
60°	5.21	6.08	6.96	7.84	8.72	9.60	10.47	11.34	12.22	13.10	13.98	16.86
65°	4.80	5.67	6.56	7.44	8.32	9.20	10.08	10.96	11.84	12.72	13.60	16.35
70°	4.38	5.26	6.15	7.03	7.92	8.80	9.68	10.57	11.45	12.34	13.22	15.84
75°	3.96	4.84	5.73	6.62	7.51	8.40	9.28	10.17	11.06	11.95	12.84	15.33
80°	3.54	4.42	5.32	6.21	7.11	8.00	8.88	9.78	10.67	11.57	12.46	14.82
85°	3.11	4.00	4.90	5.80	6.70	7.59	8.48	9.38	10.28	11.18	12.07	14.32
90°	2.68	3.58	4.48	5.38	6.28	7.18	8.07	8.98	9.88	10.78	11.68	13.81
95°	2.25	3.15	4.05	4.96	5.86	6.77	7.66	8.57	9.47	10.38	11.29	13.31
100°	1.81	2.71	3.62	4.53	5.44	6.35	7.25	8.16	9.07	9.98	10.88	12.80

Pump Exhaust.

In many plants the only available exhaust steam comes from the steam pumps used for elevator service, boiler-feeding, etc.; or in condensing plants from the air-pumps, water-supply, and boiler feed-pumps. It should also be remembered that all direct-acting steam pumps are large consumers of steam, taking several boiler h. p. for each indicated h. p., and that the exhaust steam from them will heat about six times the same quantity by weight of cold water, from 50° to 212° F., and that these pumps, or the independent condenser pumps, are more economical when all the exhaust from them is used for heating feed-water than the best kind of triple expansion condensing engines. With the pumps all the heat not used in doing work can be conserved and returned to the boiler in the feed-water, whereas even with triple expansion engines at least 80 per cent of the total heat in the steam is carried away in the condensing water.

While the supply of exhaust from these pumps may not be sufficient to raise the temperature to the highest point, yet the saving is large and constant.

These results do not take any account of the purifying action in the "open" heaters on the feed-water, the improved condition of which, by diminishing the average deposit within the boiler, materially increases both the boiler capacity and the economy; while the more uniform temperature accompanying the use of a hot feed reduces the repairs and lengthens the life of all boilers.

If the quantity of water passing through the heater is only what is required to furnish steam for the engine from which the exhaust comes, more than four-fifths of this exhaust steam will remain uncondensed, and will thus become available for other purposes, such as heating buildings, dryer systems, etc.; in which case the returns can be sent back to the boiler by suitable means.

FUEL ECONOMIZERS.

Performance of a Green Economizer with a Smoky Coal.

(D. K. Clark, S. E., p, 286.)

From tests by M. W. Grosseteste, covering a period of three weeks on a Green economizer, using a smoke-making coal, with a constant rate of combustion under the boilers, it is apparent that there is a great advantage in cleaning the pipes daily — the elevation of temperature having been increased by it from 88° to 153°. In the third week, without cleaning, the elevation of temperature relapsed in three days to the level of the first week; even on the first day it was quickly reduced by as much as half the extent of relapse. By cleaning the pipes daily an increased elevation of temperature of 65° F. was obtained, whilst a gain of 6% was effected in the evaporative efficiency.

The action of Green's economizer was tested by M. W. Grosseteste for a period of three weeks. The apparatus consists of four ranges of vertical pipes, 6½ feet high, 3¾ inches in diameter outside, nine pipes in each range, connected at top and bottom by horizontal pipes. The water enters all the tubes from below, and leaves them from above. The system of pipes is enveloped in a brick casing, into which the gaseous products of combustion are introduced from above, and which they leave from below. The pipes are cleared of soot externally by automatic scrapers. The capacity for water is 24 cubic feet, and the total external heating-surface is 290 square feet. The apparatus is placed in connection with a boiler having 355 square feet of surface.

Green's Economizer. — Results of Experiments on its Efficiency as Affected by the State of the Surface.

(W. Grosseteste.)

TIME. February and March.	Temperature of Feed-water.			Temperatnre of Gaseous Products.		
	Entering Feed-heater.	Leaving Feed-heater.	Difference.	Entering Feed-heater.	Leaving Feed-heater.	Difference.
	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.
1st Week	73.5°	161.5°	88.0°	849°	261°	588°
2d Week	77.0	230.0	153.0	882	297	585
3d Week — Monday . .	73.4	196.0	122.6	831	284	547
Tuesday . .	73.4	181.4	108.0	871	309	562
Wednesday	79.0	178.0	99.0	—	—	—
Thursday .	80.6	170.6	90.0	952	329	623
Friday . .	80.6	169.0	88.4	889	338	551
Saturday .	79.0	172.4	93.4	901	351	550

	1st Week.	2d Week.	3d Week.
Coal consumed per hour	214 lbs.	216 lbs.	213 lbs.
Water evaporated from 32° F. per hour	1424	1525	1428
Water per pound of coal	6.65	7.06	6.70

The Fuel Economizer Company, Matteawan, N.Y., describe the construction of Green's economizer, thus: The economizer consists of a series of sets of cast-iron tubes about 4 inches in diameter and 9 feet in length, made in sections (of various widths) and connected by "top" and "bottom headers," these again being coupled by "top" and "bottom branch pipes" running lengthwise, one at the top and the other at the bottom, on opposite sides and outside the brick chamber which encloses the apparatus. The waste gases are led to the economizer by the ordinary flue from the boilers to the chimney.

The feed-water is forced into the economizer by the boiler pump or injector, at the lower branch pipe nearest the point of exit of gases, and emerges from the economizer at the upper branch pipe nearest the point where the gases enter.

Each tube is provided with a geared scraper, which travels continuously up and down the tubes at a slow rate of speed, the object being to keep the external surface clean and free from soot, a non-conductor of heat.

The mechanism for working the scrapers is placed on the top of the economizer, outside the chamber, and the motive power is supplied either by a belt from some convenient shaft or small independent engine or motor. The power required for operating the gearing, however, is very small.

The apparatus is fitted with blow-off and safety valves, and a space is provided at the bottom of the chamber for the collection of the soot, which is removed by the scrapers.

One boiler plant equipped with the Green economizer gave, under test, these results.

The total area of heating surface in the plant was 3,126 square feet, and the number of tubes in the economizer 160. The results were as follows: —

Particulars of Test.	Economizer working, Dec. 15.	Economizer not working, Dec. 16.
1. Duration of test . . . . hours	11.5	11.5
2. Weight of dry coal consumed . . . . . lbs.	8,743	9,694
3. Percentage of ash and refuse . . . per cent	7.5	7.7
4. Weight of coal consumed per hour per square foot grate surface . . . . lbs.	15.2	16.8
5. Weight of water evaporated . . . . . lbs.	84,078	82,725
6. Horse-power developed on basis of 30 lbs. per h.p. fed at 100° and evaporated at 70 lbs., h.p.	247.0	243.5
7. Average boiler pressure (above atmosphere), lbs.	68.2	67.2
8. Average temperature of feed-water entering economizer . . . . deg. Fahr.	84.2	. . .
9. Average temperature of feed-water entering boilers . . . . deg. Fahr.	196.2	82.0
10. Number of degrees feed-water was heated by economizer . . . . deg. Fahr.	112.	. . .
11. Average temperature of flue gases entering economizer . . . . deg. Fahr.	435.	. . .
12. Average temperature of flue gases entering chimney . . . . deg. Fahr.	279.	452.0
13. Number degrees flue gases were cooled by economizer . . . . deg. Fahr.	156.	. . .
14. Lbs. water evaporated per lb. of coal, as observed	9.617	8.533
15. Equivalent evaporation per lb. of coal from and at 212°	11.204	9.955
16. Percentage gained by using the economizer per cent	12.5	. . .

The steam in this test contained 1.3 per cent of moisture.

W. S. Hutton gives the following results of tests of a steam boiler with and without an economizer.

	With Economizer.	Without Economizer.
Duration of test, hours	11½	11½
Weight of coal, pounds	7856	10282
Steam pressure, pounds	58	57
Temp. water entering economizer, degrees	88	. . .
" " " boiler, degrees	225	85
Degrees feed-water heated by economizer	137	. . .
Temp. gases entering economizer, degrees	618	. . .
" " " chimney, degrees	365	645
Degrees gases cooled by economizer	253	. . .
Evaporation per lb. coal, from and at 212°, pounds	10.613	8.235
Saving by economizer, per cent	28.9	

Green's Fuel Economizer. — Clark gives the following average results of comparative trials of three boilers at Wigan used with and without economizers:

	Without Economizers.	With Economizers.
Coal per square foot of grate per hour	21.6	21.4
Water at 100° evaporated per hour	73.55	79.32
Water at 212° per pound of coal	9.60	10.56

Showing that in burning equal quantities of coal per hour the rapidity of evaporation is increased 9.3% and the efficiency of evaporation 10% by the addition of the economizer.

The average temperature of the gases and of the feed-water before and after passing the economizer were as follows:

	With 6-ft. grate.		With 4-ft. grate.	
	Before.	After.	Before.	After.
Average temperature of gases	649	340	501	312
Average temperature of feed-water	47	157	41	137

Taking averages of the two grates, to raise the temperature of the feed-water 100°, the gases were cooled down 250°.

STEAM SEPARATORS.

Carefully conducted experiments have shown that water, oil, or other liquids passing through pipes along with steam do not remain thoroughly mixed with the steam itself, but that the major portion of these liquids follows the inner contour of the pipe, especially in the case of horizontal pipes.

From this it would necessarily follow that a rightly designed separator to meet these conditions must interrupt the run of the liquid by breaking the continuity of the pipe, and offering a receptacle into which the liquid will flow freely, or fall by gravity — that this appliance must further offer the opportunity for the liquid to come to rest out of the current of steam, for it is not enough to simply provide a well or a tee in the pipe, since the current would jump or draw the liquid over this opening, especially if the velocity was high.

It is also evident that means must be provided in this appliance for interrupting the progress of those particles of the liquid which are traveling in the current of the steam, and do this in such a way that these particles will also be detained and allowed to fall into the receptacle provided, which receptacle must be fully protected from the action of the current of the steam; otherwise, the separated particles of water or oil will be picked up and carried on past the separator.

To prevent the current from jumping the liquid over the well, and to interrupt the forward movement of those particles traveling in or with the current, it follows that some obstruction must be interposed in the path of the current.

Steam separators should always be placed as near as possible to the steam inlet to the cylinder of the engine. Oil separators are placed in the run of the exhaust pipe from engines and pumps, for the purpose of removing the oil from the steam before it is used in any way where the presence of oil would cause trouble.

Prof. R. C. Carpenter conducted a series of tests on separators of several makes in 1891. The following table shows results under various conditions of moisture:

Make of Separator.	Test with Steam of about 10% of Moisture.			Tests with Varying Moisture.		
	Quality of Steam Before.	Quality of Steam After.	Efficiency per cent.	Quality of Steam Before.	Quality of Steam After.	Average Efficiency.
B	87.0%	98.8%	90.8	66.1 to 97.5%	97.8 to 99 %	87.6
A	90.1	98.0	80.0	51.9 " 98	97.9 " 99.1	76.4
D	89.6	95.8	59.6	72.2 " 96.1	95.5 " 98.2	71.7
C	90.6	93.7	33.0	67.1 " 96.8	93.7 " 98.4	63.4
E	88.4	90.2	15.5	68.6 " 98.1	79.3 " 98.5	36.9
F	88.9	92.1	28.8	70.4 " 97.7	84.1 " 97.9	28.4

Conclusions from the tests were: 1. That no relation existed between the volume of the several separators and their efficiency.

2. No marked decrease in pressure was shown by any of the separators, the most being 1.7 lbs. in E.

3. Although changed direction, reduced velocity, and perhaps centrifugal force are necessary for good separation, still some means must be provided to lead the water out of the current of the steam.

A test on a different separator from those given above was made by Mr. Charles H. Parker, at the Boston Edison Company's plant, in November, 1897, and the following results obtained:

Length of run	3-4 hrs.
Average pressure of steam	158 lbs. per sq. in.
Temperature of upper thermometer in calorimeter on outlet of separator	368.5° F.
Temperature of lower thermometer in calorimeter on outlet of separator	291.7° F.
Normal temperature of lower thermometer, when steam is at rest	292.9° F.
Degrees cooling as shown by lower thermometer	1.2° F.
Moisture in steam delivered by separator as shown by cooling of lower thermometer	.06 per cent.
Water discharged from separator per hour	52 lbs.
Steam and entrained water passing through engine, as shown by discharge from air pump of surface condenser	7359 lbs.
Steam and entrained water entering separator	7411 lbs.
Moisture taken out by separator	.72
Total moisture in steam (.06 plus .72)	.78 per cent.
Efficiency of separator	92.3 per cent.

SAFETY VALVES.

Calculation of Weight, etc., for Lever Safety-Valve.

Let $W =$ weight of ball at end of lever, in pounds;
$w =$ weight of lever itself, in pounds;
$V =$ weight of valve and spindle, in pounds;
$L =$ distance between fulcrum and center of ball, in inches;
$l =$ distance between fulcrum and center of valve, in inches;
$g =$ distance between fulcrum and center of gravity of lever, in inches;
$A =$ area of valve, in square inches;
$P =$ pressure of steam, in pounds per square inch at which valve will open.

$$\text{Then } PA \times l = W \times L + w \times g + V \times l;$$

$$\text{whence } P = \frac{WL + wg + Vl}{Al};$$

$$W = \frac{PAl - wg - Vl}{L};$$

$$L = \frac{PAl - wg - Vl}{W}.$$

Example.—Diameter of valve, 4 inches; distance from fulcrum to center of ball, 36 inches; to center of valve, 4 inches; to center of gravity of lever, 16 inches; weight of valve and spindle, 6 lbs.; weight of lever, 10 lbs.; required the weight of ball to make the blowing-off pressure 100 lbs. per square inch; area of 4-inch valve = 12.566 square inches. Then

$$W = \frac{PAl - wg - Vl}{L} = \frac{100 \times 12.566 \times 4 - 10 \times 16 - 6 \times 4}{36} = 134.5 \text{ lbs.}$$

Rules Governing Safety-Valves.

(Rule of U. S. Supervising Inspectors of Steam-vessels as amended 1894.)

The distance from the fulcrum to the valve-stem must in no case be less than the diameter of the valve-opening; the length of the lever must not be more than ten times the distance from the fulcrum to the valve-stem; the width of the bearings of the fulcrum must not be less than three-quarters of an inch; the length of the fulcrum-link must not be less than four inches; the lever and fulcrum-link must be made of wrought iron or steel, and the knife-edged fulcrum points and the bearings for these points must be made of steel and hardened; the valve must be guided by its spindle, both above and below the ground seat and above the lever, through supports either made of composition (gun-metal) or bushed with it; and the spindle must fit loosely in the bearings or supports.

Lever safety-valves to be attached to marine boilers shall have an area of not less than 1 square inch to 2 square feet of the grate surface in the boiler, and the seats of all such safety-valves shall have an angle of inclination of 45° to the center line of their axes.

Spring-loaded safety-valves shall be required to have an area of not less than 1 square inch to 3 square feet of grate surface of the boiler, except as hereinafter otherwise provided for water-tube or coil and sectional boilers, and each spring-loaded valve shall be supplied with a lever that will raise the valve from its seat a distance of not less than that equal to one-eighth the diameter of the valve-opening, and the seats of all such safety-valves shall have an angle of inclination to the center line of their axes af 45°. All spring-loaded safety-valves for water-tube or coil and sectional boilers required to carry a steam-pressure exceeding 175 lbs. per square inch shall be required to have an area of not less than 1 square inch to 6 square feet of the grate surface of the boiler. Nothing herein shall be construed so as to prohibit the use of two safety-values on one water-tube or coil and sectional boiler, provided the combined area of such valves is equal to that required by rule for one such valve.

Rule on Safety-Valves in Philadelphia Ordinances.— Every boiler when fired separately, and every set or series of boilers when placed over one fire, shall have attached thereto, without the interposition of any other valve, two or more safety-valves, the aggregate area of which shall have such relations to the area of the grate and the pressure within the boiler as is expressed in schedule A.

SCHEDULE A.—Least aggregate area of safety-valve (being the least sectional area for the discharge of steam) to be placed upon all stationary boilers with natural or chimney draught (see note *a*).

$$A = \frac{22.5G}{P + 8.62},$$

in which A is area of combined safety-valves in inches; G is area of grate in square feet; P is pressure of steam in pounds per square inch to be carried in the boiler above the atmosphere.

The following table gives the results of the formula for one square foot of grate, as applied to boilers used at different pressures:

Pressures per square inch:	10	20	30	40	50	60	70	80	90	100	110	120	150	175
Valve area in square inches corresponding to one square foot of grate:	1.2	.79	.58	.46	.38	.33	.29	.25	.23	.21	.19	.17	.14	.12

[NOTE *a*.]—Where boilers have a forced or artificial draught, the inspector must estimate the area of grate at the rate of one square foot of grate surface for each 16 lbs. of fuel burned on the average per hour.

The various rules given to determine the proper area of a safety-valve do not take into account the effective discharge area of the valve. A correct rule should make the product of the diameter and lift proportional to the weight of steam to be discharged.

Mr. A. G. Brown (*The Indicator and its Practical Working*) gives the following as the lift of the lever safety-valve for 100 lbs. gauge pressure. Taking the effective area of opening at 70 per cent of the product of the rise and the circumference

Diameter of valve, inches	2	2½	3	3½	4	4½	5	6
Rise of valve, inches . .	.0583	.0523	.0507	.0492	.0478	.0462	.0446	.043

For "pop" safety-valves, Mr. Brown gives the following table for the rise, effective area, and quantity of steam discharged per hour, taking the effective area at 50 per cent of the actual on account of the obstruction which the lip of the valve offers to the escape of the steam.

Di. valve in.	1	1½	2	2½	3	3½	4	4½	5	6
Lift inches.	.125	.150	.175	.200	.225	.250	.275	.300	.325	.375
Area, sq. in.	.196	.354	.550	.785	1.061	1.375	1.728	2.121	2.553	3.535
Gauge-press.	Steam discharged per hour, lbs.									
30 lbs.	474	856	1330	1897	2563	3325	4178	5128	6173	8578
50	669	1209	1878	2680	3620	4695	5901	7242	8718	12070
70	861	1556	2417	3450	4660	6144	7596	9324	11220	15535
90	1050	1897	2947	4207	5680	7370	9260	11365	13685	18945
100	1144	2065	3208	4580	6185	8322	10080	12375	14895	20625
120	1332	2405	3736	5332	7202	9342	11735	14410	17340	24015
140	1516	2738	4254	6070	8200	10635	13365	16405	19745	27340
160	1696	3064	4760	6794	9175	11900	14955	18355	22095	30595
180	1883	3400	5283	7540	10180	13250	16595	20370	24520	33950
200	2062	3724	5786	8258	11150	14465	18175	22310	26855	37185

If we also take 30 lbs. of steam per hour, at 100 lbs. gauge-pressure = 1 h.p., we have from the above table:

Diameter inches .	1	1½	2	2½	3	3½	4	4½	5	6
Horse-power . .	38	69	107	153	206	277	336	412	496	687

A boiler having ample grate surface and strong draft may generate double the quantity of steam its rating calls for; therefore in determining the proper size of safety-valve for a boiler this fact should be taken into consideration and the effective discharge of the valve be double the rated steam-producing capacity of the boiler.

The Consolidated Safety-valve Co.'s circular gives the following rated capacity of its nickel-seat "pop" safety-valves:

Size, in. . .	1	1¼	1½	2	2½	3	3½	4	4½	5	5½
Boiler H.P. from	8	10	20	35	60	75	100	125	150	175	200
Boiler H.P. to	10	15	30	50	75	100	125	150	175	200	275

RULES FOR CONDUCTING BOILER TESTS.

The Committee of the A. S. M. E. on Boiler-tests recommended the following revised code of rules for conducting boiler trials. (Trans. vol. xx.)

CODE OF 1897.

Preliminaries to a Trial.

I. *Determine at the outset* the specific object of the proposed trial, whether it be to ascertain the capacity of the boiler, its efficiency as a steam generator, its efficiency and its defects under usual working conditions, the economy of some particular kind of fuel, or the effect of changes of design, proportion, or operation; and prepare for the trial accordingly.

II. *Examine the boiler*, both outside and inside; ascertain the dimensions of grates, heating surfaces, and all important parts; and make a full record, describing the same, and illustrating special features by sketches. The area of heating surfaces is to be computed from the outside diameter of water-tubes and the inside diameter of fire-tubes. All surfaces below the mean water level which have water on one side and products of combustion on the other are to be considered water-heating surface, and all surfaces above the mean water level which have steam on one side and products of combustion on the other are to be considered as superheating surface.

III. *Notice the general condition* of the boiler and its equipment, and record such facts in relation thereto as bear upon the objects in view.

If the object of the trial is to ascertain the maximum economy or capacity of the boiler as a steam generator, the boiler and all its appurtenances should be put in first-class condition. Clean the heating surface inside and outside, remove clinkers from grates and from sides of the furnace. Remove all dust, soot, and ashes from the chambers, smoke connections, and flues. Close air leaks in the masonry and poorly-fitted cleaning-doors. See that the damper will open wide and close tight. Test for air leaks by firing a few shovels of smoky fuel and immediately closing the damper, observing the escape of smoke through the crevices, or by passing the flame of a candle over cracks in the brickwork.

IV. *Determine the character of the coal* to be used. For tests of the efficiency or capacity of the boiler for comparison with other boilers the coal should, if possible, be of some kind which is commercially regarded as a standard. For New England and that portion of the country east of the Allegheny Mountains, good anthracite egg coal, containing not over 10 per cent of ash, and semi-bituminous Clearfield (Pa.), Cumberland (Md.), and Pocahontas (Va.) coals are thus regarded. West of the Allegheny Mountains, Pocahontas (Va.), and New River (W. Va.) semi-bituminous, and Youghiogheny or Pittsburg bituminous coals are recognized as standards.* There is no special grade of coal mined in the Western States which is widely recognized as of superior quality or considered as a standard coal for boiler testing. Big Muddy Lump, an Illinois coal mined in Jackson County, Ill., is

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* *These coals are selected because they are about the only coals which contain the essentials of excellence of quality, adaptability to various kinds of furnaces, grates, boilers, and methods of firing, and wide distribution and general accessibility in the markets.*

suggested as being of sufficiently high grade to answer the requirements in districts where it is more conveniently obtainable than the other coals mentioned above.

For tests made to determine the performance of a boiler with a particular kind of coal, such as may be specified in a contract for the sale of a boiler, the coal used should not be higher in ash and in moisture than that specified, since increase in ash and moisture above a stated amount is apt to cause a falling off of both capacity and economy in greater proportion than the proportion of such increase.

V. *Establish the correctness of all apparatus* used in the test for weighing and measuring. These are:

1. Scales for weighing coal, ashes, and water.
2. Tanks, or water meters for measuring water. Water meters, as a rule, should only be used as a check on other measurements. For accurate work, the water should be weighed or measured in a tank.
3. Thermometers and pyrometers for taking temperatures of air, steam, feed-water, waste gases, etc.
4. Pressure gauges, draft gauges, etc.

The kind and location of the various pieces of testing apparatus must be left to the judgment of the person conducting the test; always keeping in mind the main object, i.e., to obtain authentic data.

VI. *See that the boiler is thoroughly heated* before the trial to its usual working temperature. If the boiler is new and of a form provided with a brick setting, it should be in regular use at least a week before the trial, so as to dry and heat the walls. If it has been laid off and become cold, it should be worked before the trial until the walls are well heated.

VII. *The boiler and connections* should be proved to be free from leaks before beginning a test, and all water connections, including blow and extra feed pipes, should be disconnected, stopped with blank flanges, or bled through special openings beyond the valves, except the particular pipe through which water is to be fed to the boiler during the trial. During the test the blow-off and feed-pipes should remain exposed.

If an injector is used, it should receive steam directly through a felted pipe from the boiler being tested.*

If the water is metered after it passes the injector, its temperature should be taken at the point at which it enters the boiler. If the quantity is determined before it goes to the injector, the temperature should be determined on the suction side of the injector, and if no change of temperature occurs other than that due to the injector, the temperature thus determined is properly that of the feed-water. When the temperature changes between the injector and the boiler, as by the use of a heater or by radiation, the temperature at which the water enters and leaves the injector and that at which it enters the boiler should all be taken. The final temperature corrected for the heat received from the injector will be the true feed-water temperature. Thus if the injector receives water at 50° and delivers it at 120° into a heater which raises it to 210°, the corrected temperature is $210 - (120 - 50) = 140°$.

See that the steam main is so arranged that water of condensation cannot run back into the boiler.

VIII. *Starting and Stopping a Test.* — A test should last at least ten hours of continuous running, but, if the rate of combustion exceeds 25 pounds of coal per square foot of grate per hour it may be stopped when a total of 250 pounds of coal has been burned per square foot of grate surface. A longer test may be made when it is desired to ascertain the effect of widely varying conditions, or the performance of a boiler under the working conditions of a prolonged run. The conditions of the boiler and furnace in all respects should be, as nearly as possible, the same at the end as at the beginning of the test. The steam pressure should be the same; the water level the

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* *In feeding a boiler undergoing test with an injector taking steam from another boiler, or the main steam pipe from several boilers, the evaporative results may be modified by a difference in the quality of the steam from such source compared with that supplied by the boiler being tested, and in some cases the connection to the injector may act as a drip for the main steam pipe. If it is known that the steam from the main pipe is of the same quality as that furnished by the boiler undergoing the test, the steam may be taken from such main pipe.*

same; the fire upon the grates should be the same in quantity and condition; and the walls, flues, etc., should be of the same temperature. Two methods of obtaining the desired equality of conditions of the fire may be used, viz.: those which were called in the Code of 1885 "the standard method" and "the alternate method," the latter being employed where it is inconvenient to make use of the standard method.

IX. *Standard Method.* — Steam being raised to the working pressure, remove rapidly all the fire from the grate, close the damper, clean the ash-pit, and as quickly as possible start a new fire with weighed wood and coal, noting the time and the water level while the water is in a quiescent state, just before lighting the fire.

At the end of the test remove the whole fire, which has been burned low, clean the grates and ash-pit, and note the water level when the water is in a quiescent state, and record the time of hauling the fire. The water level should be as nearly as possible the same as at the beginning of the test. If it is not the same, a correction should be made by computation, and not by operating the pump after the test is completed.

X. *Alternate Method.* — The boiler being thoroughly heated by a preliminary run, the fires are to be burned low and well cleaned. Note the amount of coal left on the grate as nearly as it can be estimated; note the pressure of steam and the water level, and note this time as the time of starting the test. Fresh coal which has been weighed should now be fired. The ash-pits should be thoroughly cleaned at once after starting. Before the end of the test the fires should be burned low, just as before the start, and the fires cleaned in such a manner as to leave the bed of coal of the same depth, and in the same condition, on the grates, as at the start. The water level and steam pressures should previously be brought as nearly as possible to the same point as at the start, and the time of ending of the test should be noted just before fresh coal is fired. If the water level is not the same as at the start, a correction should be made by computation, and not by operating the pump after the test is completed.

XI. *Uniformity of Conditions.* — In all trials made to ascertain maximum economy or capacity, the conditions should be maintained uniformly constant. Arrangements should be made to dispose of the steam so that the rate of evaporation may be kept the same from beginning to end. This may be accomplished in a single boiler by carrying the steam through a waste steam pipe, the discharge from which can be regulated as desired. In a battery of boilers, in which only one is tested, the draft can be regulated on the remaining boilers, leaving the test boiler to work under a constant rate of production.

Uniformity of conditions should prevail as to the pressure of steam, the height of water, the rate of evaporation, the thickness of fire, the times of firing and quantity of coal fired at one time, and as to the intervals between the times of cleaning the fires.

XII. *Keeping the Records.* — Take note of every event connected with the progress of the trial, however unimportant it may appear. Record the time of every occurrence and the time of taking every weight and every observation.

The coal should be weighed and delivered to the fireman in equal proportions, each sufficient for not more than one hour's run, and a fresh portion should not be delivered until the previous one has all been fired. The time required to consume each portion should be noted, the time being recorded at the instant of firing the last of each portion. It is desirable that at the same time the amount of water fed into the boiler should be accurately noted and recorded, including the height of the water in the boiler, and the average pressure of steam and temperature of feed during the time. By thus recording the amount of water evaporated by successive portions of coal, the test may be divided into several periods if desired, and the degree of uniformity of combustion, evaporation, and economy analyzed for each period. In addition to these records of the coal and the feed-water, half hourly observations should be made of the temperature of the feed-water, of the flue gases, of the external air in the boiler-room, of the temperature of the furnace when a furnace pyrometer is used, also of the pressure of steam, and of the readings of the instruments for determining the moisture in the steam. A log should be kept on properly prepared blanks containing columns for record of the various observations.

When the "standard method" of starting and stopping the test is used, the hourly rate of combustion and of evaporation and the horse-power may be computed from the records taken during the time when the fires are in active condition. This time is somewhat less than the actual time which elapses between the beginning and end of the run. This method of computation is necessary, owing to the loss of time due to kindling the fire at the beginning and burning it out at the end.

XIII. *Quality of Steam.* — The percentage of moisture in the steam should be determined by the use of either a throttling or a separating steam calorimeter. The sampling nozzle should be placed in the vertical steam pipe rising from the boiler. It should be made of ½-inch pipe, and should extend across the diameter of the steam pipe to within half an inch of the opposite side, being closed at the end and perforated with not less than twenty ⅛-inch holes equally distributed along and around its cylindrical surface, but none of these holes should be nearer than ½ inch to the inner side of the steam pipe. The calorimeter and the pipe leading to it should be well covered with felting. Whenever the indications of the throttling or separating calorimeter show that the percentage of moisture is irregular, or occasionally in excess of three per cent, the results should be checked by a steam separator placed in the steam pipe as close to the boiler as convenient, with a calorimeter in the steam pipe just beyond the outlet from the separator. The drip from the separator should be caught and weighed, and the percentage of moisture computed therefrom added to that shown by the calorimeter.

Superheating should be determined by means of a thermometer placed in a mercury well inserted in the steam pipe. The degree of superheating should be taken as the difference between the reading of the thermometer for superheated steam and the readings of the same thermometer for saturated steam at the same pressure as determined by a special experiment, and not by reference to steam tables.

XIV. *Sampling the Coal and Determining its Moisture.* — As each barrow load or fresh portion of coal is taken from the coal pile, a representative shovelful is selected from it and placed in a barrel or box in a cool place and kept until the end of the trial. The samples are then mixed and broken into pieces not exceeding one inch in diameter, and reduced by the process of repeated quartering and crushing until a final sample weighing about five pounds is obtained, and the size of the larger pieces is such that they will pass through a sieve with ¼-inch meshes. From this sample two one-quart, air-tight glass preserving jars, or other air-tight vessels which will prevent the escape of moisture from the sample, are to be promptly filled, and these samples are to be kept for subsequent determinations of moisture and of heating value, and for chemical analyses. During the process of quartering, when the sample has been reduced to about 100 pounds, a quarter to a half of it may be taken for an approximate determination of moisture. This may be made by placing it in a shallow iron pan, not over three inches deep, carefully weighing it, and setting the pan in the hottest place that can be found on the brickwork of the boiler setting or flues, keeping it there for at least twelve hours, and then weighing it. The determination of moisture thus made is believed to be approximately accurate for anthracite and semi-bituminous coals, and also for Pittsburg or Youghiogheny coal; but it cannot be relied upon for coals mined west of Pittsburg, or for other coals containing inherent moisture. For these latter coals it is important that a more accurate method be adopted. The method recommended by the Committee for all accurate tests, whatever the character of the coal, is described as follows:

Take one of the samples contained in the glass jars, and subject it to a thorough air-drying in a warm room, weighing it before and after, thereby determining the quantity of surface moisture it contains. Then crush the whole of it by running it through an ordinary coffee mill, adjusted so as to produce somewhat coarse grains (less than $\frac{1}{16}$ inch), thoroughly mix the crushed sample, select from it a portion of from 10 to 50 grams, weigh it in a balance which will easily show a variation as small as 1 part in 1,000, and dry it in an air or sand bath at a temperature between 240 and 280 degrees Fahr. for one hour. Weigh it and record the loss, then heat and weigh it again repeatedly, at intervals of an hour or less, until the minimum weight has been reached and the weight begins to increase by oxidation of a portion of the coal. The difference between the original and the minimum weight is taken as the moisture in the air-dried coal. This moisture should preferably be made on duplicate samples, and the results should agree within 0.3 to 0.4 of one per cent, the mean of the two determinations being taken as the correct result. The sum of the percentage of moisture thus found and the percentage of surface moisture previously determined is the total moisture.

XV. *Treatment of Ashes and Refuse.*—The ashes and refuse are to be weighed in a dry state. For elaborate trials a sample of the same should be procured and analyzed.

XVI. *Calorific Tests and Analysis of Coal.*—The quality of the fuel should be determined either by heat test or by analysis, or by both.

The rational method of determining the total heat of combustion is to burn the sample of coal in an atmosphere of oxygen gas, the coal to be sampled as directed in Article XIV. of this code.

The chemical analysis of the coal should be made only by an expert chemist. The total heat of combustion computed from the results of the ultimate analysis may be obtained by the use of Dulong's formula (with constants modified by recent determinations), viz.: $14{,}600\ C + 62{,}000 \left(H - \frac{O}{8}\right) + 4{,}000\ S$, in which C, H, O, and S refer to the proportions of carbon, hydrogen, oxygen, and sulphur respectively, as determined by the ultimate analysis.*

It is recommended that the analysis and the heat test be each made by two independent laboratories, and the mean of the two results, if there is any difference, be adopted as the correct figures.

It is desirable that a proximate analysis should also be made to determine the relative proportions of volatile matter and fixed carbon in the coal.

XVII. *Analysis of Flue Gases.*—The analysis of the flue gases is an especially valuable method of determining the relative value of different methods of firing, or of different kinds of furnaces. In making these analyses, great care should be taken to procure average samples—since the composition is apt to vary at different points of the flue. The composition is also apt to vary from minute to minute, and for this reason the drawings of gas should last a considerable period of time. Where complete determinations are desired, the analyses should be intrusted to an expert chemist. For approximate determinations the Orsat or the Hempel apparatus may be used by the engineer.

XVIII. *Smoke Observations.*—It is desirable to have a uniform system of determining and recording the quantity of smoke produced where bituminous coal is used. The system commonly employed is to express the degree of smokiness by means of percentages dependent upon the judgment of the observer. The Committee does not place much value upon a percentage method, because it depends so largely upon the personal element, but if this method is used, it is desirable that, so far as possible, a definition be given in explicit terms as to the basis and method employed in arriving at the percentage.

XIX. *Miscellaneous.*—In tests for purposes of scientific research, in which the determination of all the variables entering into the test is desired, certain observations should be made which are in general unnecessary for ordinary tests. These are the measurement of the air supply, the determination of its contained moisture, the determination of the amount of heat lost by radiation, of the amount of infiltration of air through the setting, and (by condensation of all the steam made by the boiler) of the total heat imparted to the water.

As these determinations are not likely to be undertaken except by engineers of high scientific attainments, it is not deemed advisable to give directions for making them.

XX. *Calculations of Efficiency.*—Two methods of defining and calculating the efficiency of a boiler are recommended. They are:

1. $$\text{Efficiency of the boiler} = \frac{\text{Heat absorbed per lb. combustible}}{\text{Heating value of 1 lb. combustible}}.$$

2. $$\text{Efficiency of the boiler and grate} = \frac{\text{Heat absorbed per lb. coal}}{\text{Heating value of 1 lb. coal}}.$$

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* *Favre and Silberman give 14,544 B.T.U. per pound carbon; Berthelot 14,647 B.T.U. Favre and Silberman give 62,032 B.T.U. per pound hydrogen; Thomson 61,816 B.T.U.*

The first of these is sometimes called the efficiency based on combustible, and the second the efficiency based on coal. The first is recommended as a standard of comparison for all tests, and this is the one which is understood to be referred to when the word "efficiency" alone is used without qualification. The second, however, should be included in a report of a test, together with the first, whenever the object of the test is to determine the efficiency of the boiler and furnace together with the grate (or mechanical stoker), or to compare different furnaces, grates, fuels, or methods of firing.

The heat absorbed per pound of combustible (or per pound coal) is to be calculated by multiplying the equivalent evaporation from and at 212° per pound combustible (or coal) by 965.7. (Appendix XXI.)

XXI. *The Heat Balance.*—An approximate "heat balance," or statement of the distribution of the heating value of the coal among the several items of heat utilized and heat lost, may be included in the report of a test when analyses of the fuel and of the chimney gases have been made. It should be reported in the following form :

Heat Balance, or Distribution of the Heating Value of the Combustible.

Total Heat Value of 1 lb. of Combustible . . . . . . B. T. U.

	B. T. U	Per Cent.
1. Heat absorbed by the boiler = evaporation from and at 212° per pound of combustible × 965.7.		
2. Loss due to moisture in coal = per cent of moisture referred to combustible ÷ 100 × $[(212 - t) + 966 + 0.48 (T - 212)]$ (t = temperature of air in the boiler-room, T = that of the flue gases).		
3. Loss due to moisture formed by the burning of hydrogen = per cent of hydrogen to combustible ÷ 100 × 9 × $[(212 - t) + 966 + 0.48 (T - 212)]$.		
4.* Loss due to heat carried away in the dry chimney gases = weight of gas per pound of combustible × 0.24 × $(T - t)$.		
5.† Loss due to incomplete combustion of carbon $= \frac{CO}{CO_2 + CO} \times \frac{\text{per cent } C \text{ in combustible}}{100} \times 10{,}150$.		
6. Loss due to unconsumed hydrogen and hydrocarbons, to heating the moisture in the air, to radiation, and unaccounted for. (Some of these losses may be separately itemized if data are obtained from which they may be calculated.)		
Totals		100.00

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* *The weight of gas per pound of carbon burned may be calculated from the gas analysis as follows:*

$$\text{Dry gas per pound carbon} = \frac{11\,CO_2 + 8\,O + 7\,(CO + N)}{3\,(CO_2 + CO)},$$ *in which* CO_2, CO, O, *and* N *are the percentages by volume of the several gases. As the sampling and analyses of the gases in the present state of the art are liable to considerable errors, the result of this calculation is usually only an approximate one. The heat balance itself is also only approximate for this reason, as well as for the fact that it is not possible to determine accurately the percentage of unburned hydrogen or hydrocarbons in the flue gases.*

The weight of dry gas per pound of combustible is found by multiplying the dry gas per pound of carbon by the percentage of carbon in the combustible, and dividing by 100.

† CO_2 *and* CO *are respectively the percentage by volume of carbonic acid and carbonic oxide in the flue gases. The quantity 10,150 = No. heat units generated by burning to carbonic acid one pound of carbon contained in carbonic oxide.*

XXII. *Report of the Trial.*—The data and results should be reported in the manner given in either one of the two following tables, omitting lines where the tests have not been made as elaborately as provided for in such tables. Additional lines may be added for data relating to the specific object of the test. The extra lines should be classified under the headings provided in the tables, and numbered, as per preceding line, with sub letters, *a*, *b*, etc. The Short Form of Report, Table No. 2, is recommended for commercial tests and as a convenient form of abridging the longer form for publication when saving of space is desirable.

Table No. 1.

Data and Results of Evaporative Test.

Arranged in accordance with the complete form advised by the Boiler Test Committee of the American Society of Mechanical Engineers.

Made by . . . . of . . . . boiler at . . . . . . to determine . . . .
Principal conditions governing the trial . . . .
. . . .
. . . .
Kind of fuel . . . .
Kind of furnace . . . .
State of the weather . . . .
1. Date of trial . . . .
2. Duration of trial . . . . hours

Dimensions and Proportions.

(A complete description of the boiler should be given on an annexed sheet.)

3. Grate surface . . . width . . . length . . . area . . sq. ft.
4. Water-heating surface . . . . “
5. Superheating surface . . . . “
6. Ratio of water-heating surface to grate surface . . . . .
7. Ratio of minimum draft area to grate surface . . . . .

Average Pressures.

8. Steam pressure by gauge . . . . lbs.
9. Force of draft between damper and boiler . . . . ins. of water
10. Force of draft in furnace . . . . “ “
11. Force of draft or blast in ash-pit . . . . “ “

Average Temperatures.

12. Of external air . . . . deg.
13. Of fireroom . . . . “
14. Of steam . . . . “
15. Of feed-water entering heater . . . . “
16. Of feed-water entering economizer . . . . “
17. Of feed-water entering boiler . . . . “
18. Of escaping gases from boiler . . . . “
19. Of escaping gases from economizer . . . . “

Fuel.

20. Size and condition . . . .
21. Weight of wood used in lighting fire . . . . lbs.
22. Weight of coal as fired*. . . . . “

---

* *Including equivalent of wood used in lighting the fire, not including unburnt coal withdrawn from furnace at times of cleaning and at end of test. One pound of wood is taken to be equal to 0.4 pound of coal, or, in case greater accuracy is desired, as having a heat value equivalent to the evaporation of 6 pounds of water from and at 212° per pound (6 × 965.7 = 5,794 B.T.U.).*

23. Percentage of moisture in coal [*] . . . . per cent.
24. Total weight of dry coal consumed . . . . lbs.
25. Total ash and refuse . . . . lbs.
26. Total combustible consumed . . . .
27. Percentage of ash and refuse in dry coal . . . . per cent

Proximate Analysis of Coal.

	Of Coal.	Of Combustible.
28. Fixed carbon	per cent.	per cent.
29. Volatile matter	"	"
30. Moisture	"	——
31. Ash	"	——
	100 per cent	100 per cent.
32. Sulphur, separately determined	"	"

Ultimate Analysis of Dry Coal.

33. Carbon (C) . . . . per cent.
34. Hydrogen (H) . . . . "
35. Oxygen (O) . . . . "
36. Nitrogen (N) . . . . "
37. Sulphur (S) . . . . "

100 per cent.

38. Moisture in sample of coal as received . . . . "

Analysis of Ash and Refuse.

39. Carbon . . . . per cent.
40. Earthy matter . . . . "

Fuel per Hour.

41. Dry coal consumed per hour . . . . lbs.
42. Combustible consumed per hour . . . . "
43. Dry coal per square foot of grate surface per hour . . . "
44. Combustible per square foot of water-heating surface per hour . . . . "

Calorific Value of Fuel.

45. Calorific value by oxygen calorimeter, per lb. of dry coal . B. T. U.
46. Calorific value by oxygen calorimeter, per lb. of combustible "
47. Calorific value by analysis, per lb. of dry coal[†] . . . . . "
48. Calorific value by analysis, per lb. of combustible . . . . "

Quality of Steam.

49. Percentage of moisture in steam . . . . per cent.
50. Number of degrees of superheating . . . . deg.
51. Quality of steam (dry steam = unity) . . . .

Water.

52. Total weight of water fed to boiler [‡] . . . . lbs.
53. Equivalent water fed to boiler from and at 212° . . . . . "
54. Water actually evaporated, corrected for quality of steam "
55. Factor of evaporation [§] . . . . "
56. Equivalent water evaporated into dry steam from and at 212°. (Item 54 ÷ Item 55) . . . . "

---

[*] *This is the total moisture in the coal as found by drying it artificially.*

[†] *See formula for calorific value under Article XVI. of Code.*

[‡] *Corrected for inequality of water level and of steam pressure at beginning and end of test.*

[§] *Factor of evaporation* $= \frac{H-h}{965.7}$, *in which H and h are respectively the total heat in steam of the average observed pressure, and in water of the average observed temperature of the feed.*

Water per Hour

57. Water evaporated per hour, corrected for quality of steam lbs.
58. Equivalent evaporation per hour from and at 212° . . . . "
59. Equivalent evaporation per hour from and at 212° per square foot of water-heating surface . . . . "

Horse-Power.

60. Horse-power developed. (34½ lbs. of water evaporated per hour into dry steam from and at 212° equals one horse-power) * . . . . H.P.
61. Builders' rated horse-power . . . . "
62. Percentage of builders' rated horse-power developed . . . per cent.

Economic Results.

63. Water apparently evaporated per lb. of coal under actual conditions. (Item 53 ÷ Item 22) . . . . lbs.
64. Equivalent evaporation from and at 212° per lb. of coal (including moisture). (Item 56 ÷ Item 22) . . . . . "
65. Equivalent evaporation from and at 212° per lb. of dry coal. (Item 56 ÷ Item 24) . . . . "
66. Equivalent evaporation from and at 212° per lb. of combustible. (Item 56 ÷ Item 26) . . . . "
(If the equivalent evaporation, Items 64, 65, and 66, is not corrected for the quality of steam, the fact should be stated.)

Efficiency.

67. Efficiency of the boiler; heat absorbed by the boiler per lb. of combustible divided by the heat value of one lb. of combustible † . . . . per cent.
68. Efficiency of boiler, including the grate; heat absorbed by the boiler, per lb. of dry coal fired, divided by the heat value of one lb. of dry coal ‡ . . . .

Cost of Evaporation.

69. Cost of coal per ton of 2,240 lbs. delivered in boiler room . $
70. Cost of fuel for evaporating 1,000 lbs. of water under observed conditions . . . . $
71. Cost of fuel used for evaporating 1,000 lbs. of water from and at 212° . . . . $

Smoke Observations.

72. Percentage of smoke as observed . . . .
73. Weight of soot per hour obtained from smoke meter . . .
74. Volume of soot obtained from smoke meter per hour . .

Table No. 2.

Data and Results of Evaporative Test.

Arranged in accordance with the Short Form advised by the Boiler Test Committee of the American Society of Mechanical Engineers.

Made by . . . . on . . . . boiler, at . . . . . to determine . . . .

---

* *Held to be the equivalent of 30 lbs. of water per hour evaporated from 100° Fahr. into dry steam at 70 lbs. gauge pressure.*

† *In all cases where the word "combustible" is used, it means the coal without moisture and ash, but including all other constituents. It is the same as what is called in Europe "coal dry and free from ash."*

‡ *The heat value of the coal is to be determined either by an oxygen calorimeter or by calculation from ultimate analysis. When both methods are used the mean value is to be taken.*

Grate surface	sq. ft.
Water-heating surface	“
Superheating surface	“
Kind of fuel	
Kind of furnace	

Total Quantities.

1.	Date of trial	
2.	Duration of trial	hours.
3.	Weight of coal as fired	lbs.
4.	Percentage of moisture in coal	per cent.
5.	Total weight of dry coal consumed	lbs.
6.	Total ash and refuse	“
7.	Percentage of ash and refuse in dry coal	per cent.
8.	Total weight of water fed to the boiler	lbs.
9.	Water actually evaporated, corrected for moisture or superheat in steam	“

Hourly Quantities.

10.	Dry coal consumed per hour	lbs.
11.	Dry coal per hour per square foot of grate surface	“
12.	Water fed per hour	“
13.	Equivalent water evaporated per hour from and at 212° corrected for quality of steam	“
14.	Equivalent water evaporated per square foot of water-heating hour	“

Average Pressures, Temperatures, etc.

15.	Average boiler pressure	lbs. per sq. in.
16.	Average temperature of feed-water	deg.
17.	Average temperature of escaping gases	“
18.	Average force of draft between damper and boiler	ins. of water
19.	Percentage of moisture in steam, or number of degrees of superheating	

Horse-Power.

20.	Horse-power developed (Item 13 ÷ 34½)	H.P.
21.	Builders' rated horse-power	“
22.	Percentage of builders' rated horse-power	per cent.

Economic Results.

23.	Water apparently evaporated per pound of coal under actual conditions. (Item 8 ÷ Item 3)	lbs.
24.	Equivalent water actually evaporated from and at 212° per pound of coal as fired. (Item 9 ÷ Item 3)	“
25.	Equivalent evaporation from and at 212° per pound of dry coal. (Item 9 ÷ Item 5)	“
26.	Equivalent evaporation from and at 212° per pound of combustible. [Item 9 ÷ (Item 5 — Item 6)] (If Items 23, 24, and 25 are not corrected for quality of steam, the fact should be stated.)	“

Efficiency.

27.	Heating value of the coal per pound	B. T. U.
28.	Efficiency of boiler (based on combustible)	“
29.	Efficiency of boiler, including grate (based on coal)	“

Cost of Evaporation.

30.	Cost of coal per ton of 2,240 pounds delivered in boiler-room	$
31.	Cost of coal required for evaporation of 1,000 pounds of water from and at 212°	$

DETERMINATION OF THE MOISTURE IN STEAM.

The determination of the quality of steam supplied by a boiler is one of the most important items in a boiler test. The three conditions to be determined are:

a. If the steam is *saturated*, i.e., contains the quantity of heat due to the pressure.
b. If the steam is *wet*, i.e., contains less than the amount of heat due to the pressure.
c. If the steam is superheated, i.e., contains more than the amount of heat due to the pressure.

There are several methods of determining the quality of steam; one being to condense all the steam evaporated by a boiler in a surface condenser, and weigh the condensing water, taking the temperature at its entrance to and exit from the condenser. Another is by use of a barrel calorimeter, in which a sample of the steam is condensed directly in a barrel partly filled with cold water, the added weight and temperature taken, and by use of a formula the quality of steam can be determined.

Both the above-named methods are now practically obsolete, as their place has been taken by the *throttling* calorimeter, used for steam in which the moisture does not exceed 3 per cent, and the *separating* calorimeter, for steam containing a greater amount of moisture.

Throttling Calorimeter.

In its simplest form this instrument can be made up from pipe fittings, the only special parts necessary being the throttling nozzle, which is readily made by boring out a piece of brass rod that is the same diameter as a half-inch steam pipe, leaving a small hole in one end, say $\frac{1}{16}$ inch diameter. The inside end of the small hole should be tapered with the end of a drill so as not to cause eddies; and the thermometer well, which is a small piece of brass pipe, plugged at one end, and fitted into a half-inch brushing to fit into place. The following cut hows the instrument as made up from fittings. The whole must be carefully covered with some non-conductor, as hair felt.

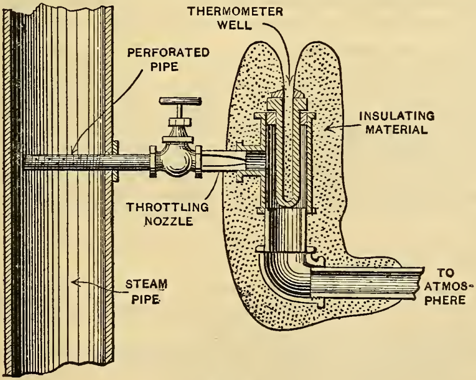

FIG. 6.

For more accurate work the instruments designed by George H. Barrus, M.E., and Prof. R. C. Carpenter, are to be preferred. Professor Carpenter's instrument is shown in the following cut, and differs from the primitive instrument previously described only by the addition of the *manometer*, which determines the pressure of the steam above the atmosphere in the body of the calorimeter. With a free exit to the air the pressure in the calorimeter may be taken as that of the atmosphere.

Carpenter's Throttling Calorimeter.

(¼ size. Schaeffer & Budenberg.)

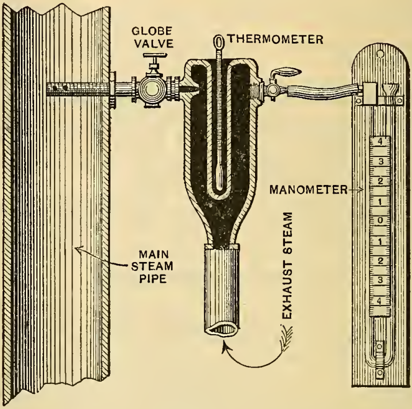

FIG. 7.

The perforated pipe for obtaining the sample of steam to be tested should preferably be inserted in a vertical pipe, and should reach nearly across its diameter.

Directions for Use. — Connect as shown in the preceding cuts, fill the thermometer cup with cylinder oil and insert the thermometer. Turn on the Globe valve for ten minutes or more in order to bring the temperature of the instrument to full heat, after which note the reading of the thermometer in the calorimeter, and of the attached manometer or of a barometer. The steam gauge should be carefully calebrated to see that it is correct. A barometer reading taken at the time the calorimeter is in use, gives greater accuracy in working up the results than taking the average atmospheric pressure as 14.65 pounds. Pressure in pounds may be determined from the mercury column of the barometer and manometer by dividing the inches rise by 2.03, or taking one pound for each two inches of mercury.

Following is the formula for determining the quality of steam by use of the *throttling calorimeter.*

$H =$ total heat in a pound of steam at the pressure in the pipe.
$h =$ total heat in a pound of steam at the pressure in the calorimeter.
$L =$ latent heat in a pound of steam at the pressure in the pipe.
$t =$ temperature in the calorimeter.
$b =$ temperature of boiling point at calorimeter pressure (taken as 212° with the "fittings" instrument).
$0.48 =$ specific heat of superheated steam.
$x =$ quality of the steam.
$y =$ percentage of moisture in the steam.

$$y = \frac{H - h - .48\,(t - b)}{L} \times 100.$$

$$x = 100 - y.$$

If h be taken as 212°, as it can be with but slight error, then

$$y = \frac{H - 1146.6 - .48\,(t - 212)}{L} \times 100.$$

Following are tables calculated from the above formula.

Moisture in Steam.

Determinations by Throttling Calorimeter.

$(t - b)$	Gauge-pressures.											
	5	10	20	30	40	50	60	70	75	80	85	90
	Per Cent of Moisture in Steam.											
0°	0.51	0.90	1.54	2.06	2.50	2.90	3.24	3.56	3.71	3.86	3.99	4.13
10°	0.01	0.39	1.02	1.54	1.97	2.36	2.71	3.02	3.17	3.32	3.45	3.58
20°	. . .	. . .	.51	1.02	1.45	1.83	2.17	2.48	2.63	2.77	2.90	3.03
30°	. . .	. . .	.00	.50	.92	1.30	1.64	1.94	2.09	2.23	2.35	2.49
40°	. . .	. . .	. . .	. . .	.39	.77	1.10	1.40	1.55	1.69	1.80	1.94
50°	. . .	. . .	. . .	. . .	. . .	.24	.57	.87	1.01	1.15	1.26	1.40
60°	. . .	. . .	. . .	. . .	. . .	. . .	.03	.33	.47	.60	.72	.85
70°	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	.06	.17	.31

$(t - b)$	Gauge-pressure.											
	100	110	120	130	140	150	160	170	180	190	200	250
	Per Cent of Moisture in Steam.											
0°	4.39	4.63	4.85	5.08	5.29	5.49	5.68	5.87	6.05	6.22	6.39	7.16
10°	3.84	4.08	4.29	4.52	4.73	4.93	5.12	5.30	5.48	5.65	5.82	6.58
20°	3.29	3.52	3.74	3.96	4.17	4.37	4.56	4.74	4.91	5.08	5.25	6.00
30°	2.74	2.97	3.18	3.41	3.61	3.80	3.99	4.17	4.34	4.51	4.67	5.41
40°	2.19	2.42	2.63	2.85	3.05	3.24	3.43	3.61	3.78	3.94	4.10	4.83
50°	1.64	1.87	2.08	2.29	2.49	2.68	2.87	3.04	3.21	3.37	3.53	4.25
60°	1.09	1.32	1.52	1.74	1.93	2.12	2.30	2.48	2.64	2.80	2.96	3.67
70°	.55	.77	.97	1.18	1.38	1.56	1.74	1.91	2.07	2.23	2.38	3.09
80°	.00	.22	.42	.63	.82	1.00	1.18	1.34	1.50	1.66	1.81	2.51
90°	. . .	. . .	. . .	.07	.26	.44	.61	.78	.94	1.09	1.24	1.93
100°	. . .	. . .	. . .	. . .	. . .	. . .	.05	.21	.37	.52	.67	1.34
110°	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. .	.10	.76

The easiest method of making the determinations from the observations is by use of the following diagram, prepared by Professor Carpenter.

Find in the vertical column at the left the pressure observed in the main pipe + atmospheric pressure (the absolute pressure), then move horizontally to the right until over the line giving the degree of superheat $(t - b)$, and the quality of steam will be found in a curve corresponding to one of those shown, and which may be interpolated where results do not come on one of the lines laid down.

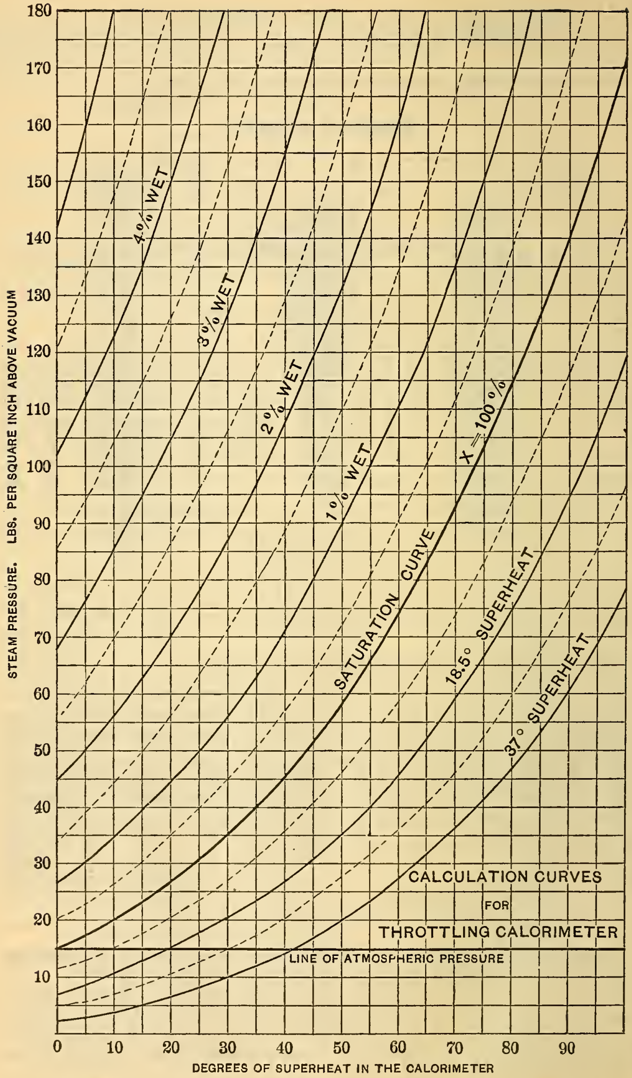

DIAGRAM GIVING RESULTS FROM THROTTLING CALORIMETER WITHOUT COMPUTATION

FIG 8.

By putting a valve in the discharge pipe of the calorimeter, being careful that when open it offers no obstruction to a free passage of the steam, determinations may be made from temperatures without reference to a steam table, and by using the following diagram by Professor Carpenter no calculation is necessary.

a. Determine the boiling-point of the instrument by opening supply and discharge valves, and showering the instrument with cold water to produce moisture in the calorimeter, in which case the boiling-point will be 212° or thereabouts.

b. Determine temperature due to the boiler pressure by closing the discharge-valve, leaving the supply-valve open, and obtain the full boiler pressure in the calorimeter.

c. Open the discharge-valve and let the thermometer settle to the temperature due to the superheat.

Deduct the temperature of the boiling-point from this last temperature to obtain the degrees superheat.

Suppose the boiling-point of the calorimeter to be 213°, the following diagram will give the result directly from the temperatures.

To use the diagram when the boiling-point differs from 212°, add to the temperature of superheat the difference between the true boiling-point and 212°, if less than 212°; and subtract the difference if the true boiling-point be greater than 212; use the result as before.

Separating Calorimeter.

This instrument separates the moisture from the sample of steam, and the percentage is then found by the ordinary formula.

$$\frac{\text{amount of moisture} \times 100}{\text{total steam discharged as sample}} = \text{per cent moisture.}$$

One of the most convenient forms of this type of calorimeter is the one designed by Professor Carpenter, and shown in Fig. 10.

The sample of steam is let into the instrument through the angle valve 6, the moisture gathers in the inner chamber, its weight in pounds and hundredths being shown on the scale 12, and the dry steam flows out through the small calibrated orifice 8.

By Napier's law the flow of steam through an orifice is proportional to the absolute pressure, until the back pressure equals .58 that of the supply.

The gauge 9 at the right shows in the outer scale the flow of steam through the orifice 8 in a period of 10 minutes' time.

After attaching the instrument to the pipe from which sample is taken through a perforated pipe as with the throttling or other instrument, it must be thoroughly wrapped with hair, felt, or other insulator. Steam is then turned on through the angle valve, and time enough allowed to thoroughly heat the instrument.

In taking an observation, first observe and record height of water on scale 12, then let the steam flow for 10 minutes, observing the average position of the pointer on the flow-gauge; at the end of 10 minutes observe the height of water in gauge 12, and the difference between this and the first observation will be the amount of moisture in the sample; the percentage of moisture will then be found as follows:

$$\frac{\text{difference in scale 12} \times 100}{\text{difference on scale 12} + \text{average for 10 minutes on the flow-gauge}}$$

$$= \%\ \text{moisture.}$$

For tests and data on "Calorimeters," see papers in Trans. A.S.M.E., by Messrs G. H. Barrus, A. A. Goubert, and Professors Carpenter, Denton, Jacobus, and Peabody.

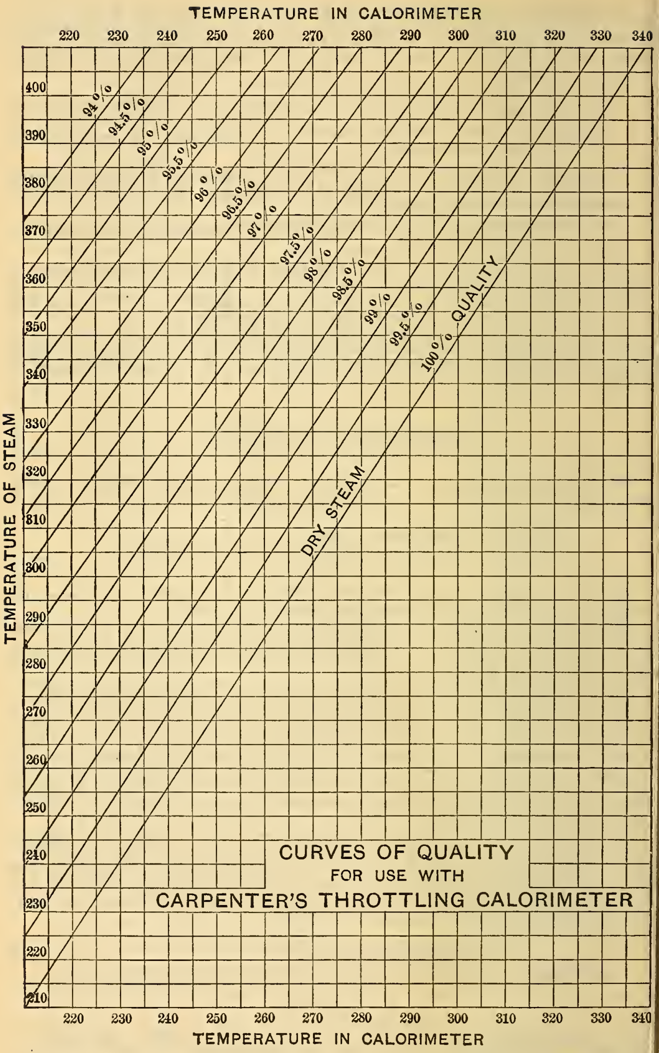

DIAGRAM FOR COMPUTING RESULTS WITH THROTTLING CALORIMETER.
FIG. 9

Quality of Steam Shown by Color of Issuing Jet.

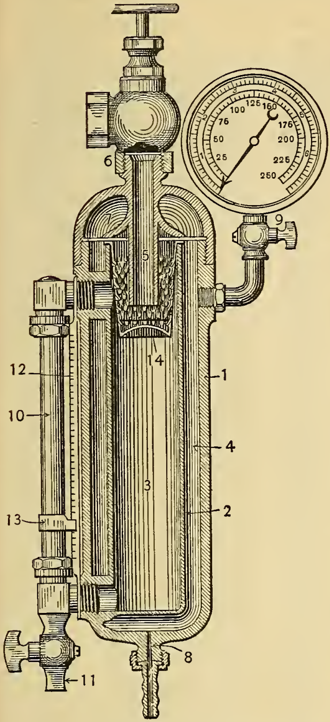

FIG. 10. Carpenter's New Evaporating Calorimeter. (Schaeffer & Budenberg.)

Prof. J. E. Denton (Trans. A. S. M. E., vol. x., p. 349) has demonstrated that jets of steam escaping from an orifice in a boiler or steam reservoir show unmistakable change of appearance to the eye when the steam varies less than one per cent from the condition of saturation either in the direction of wetness or superheating. Consequently if a jet of steam flow from a boiler into the atmosphere under circumstances such that very little loss of heat occurs through radiation, etc., and the jet be transparent close to the orifice, or be even a grayish white color, the steam may be assumed to be so nearly dry that no portable condensing calorimeter will be capable of measuring the amount of water therein. If the jet be strongly white, the amount of water may be roughly judged up to about 2 per cent, but beyond this a calorimeter only can determine the exact amount of moisture. With a little experience any one may determine by this method the conditions of steam within the above limits. A common brass pet cock may be used as an orifice, but it should, if possible, be set into the steam drum of the boiler and never be placed farther away from the latter than four feet, and then only when the intermediate reservoir or pipe is well covered, for a very short travel of dry steam through a naked pipe will cause it to become perceptibly moist.

FACTORS OF EVAPORATION.

In order to facilitate the calculation of reducing the actual rate of evaporation of water from a certain temperature into steam of a certain pressure, into the rate from water at 212° F. into steam of 212° a table of *factors of evaporation* is made up from the formula $\frac{H - h}{965.7}$ where H is the total heat of steam at the observed pressure, and h the total heat of feed-water of the observed temperature.

Table of Factors of Evaporation.

(Compiled by W. Wallace Christie.)

Gauge Pressure. Temp. of Feed.	0 lbs.	10 lbs.	20 lbs.	30 lbs.	40 lbs.	45 lbs.	50 lbs.	52 lbs.	54 lbs.
212° F.	1.0003	1.0088	1.0149	1.0197	1.0237	1.0254	1.0271	1.0277	1.0283
209	1.0035	1.0120	1.0180	1.0228	1.0268	1.0286	1.0302	1.0309	1.0315
206	1.0066	1.0151	1.0212	1.0260	1.0299	1.0317	1.0334	1.0340	1.0346
203	1.0098	1.0183	1.0243	1.0291	1.0331	1.0349	1.0365	1.0372	1.0378
200	1.0129	1.0214	1.0275	1.0323	1.0362	1.0380	1.0397	1.0403	1.0409
197	1.0160	1.0246	1.0306	1.0354	1.0394	1.0412	1.0428	1.0434	1.0441
194	1.0192	1.0277	1.0338	1.0385	1.0425	1.0443	1.0460	1.0466	1.0472
191	1.0223	1.0308	1.0369	1.0417	1.0457	1.0474	1.0491	1.0497	1.0503
188	1.0255	1.0340	1.0400	1.0448	1.0488	1.0506	1.0522	1.0528	1.0535
185	1.0286	1.0371	1.0432	1.0480	1.0519	1.0537	1.0554	1.0560	1.0566
182	1.0317	1.0403	1.0463	1.0511	1.0551	1.0568	1.0585	1.0591	1.0598
179	1.0349	1.0434	1.0495	1.0542	1.0582	1.0600	1.0616	1.0623	1.0629
176	1.0380	1.0465	1.0526	1.0574	1.0613	1.0631	1.0648	1.0654	1.0660
173	1.0411	1.0497	1.0557	1.0605	1.0645	1.0663	1.0679	1.0685	1.0692
170	1.0443	1.0528	1.0589	1.0636	1.0676	1.0694	1.0710	1.0717	1.0723
167	1.0474	1.0559	1.0620	1.0668	1.0707	1.0725	1.0742	1.0748	1.0754
164	1.0505	1.0591	1.0651	1.0699	1.0739	1.0756	1.0773	1.0780	1.0786
161	1.0537	1.0622	1.0682	1.0730	1.0770	1.0788	1.0804	1.0811	1.0817
158	1.0568	1.0653	1.0714	1.0762	1.0801	1.0819	1.0836	2.0842	1.0848
155	1.0599	1.0684	1.0745	1.0793	1.0833	1.0850	1.0867	1.0873	1.0880
152	1.0631	1.0716	1.0776	1.0824	1.0864	1.0882	1.0898	1.0905	1.0911
149	1.0662	1.0747	1.0808	1.0855	1.0895	1.0913	1.0930	1.0936	1.0942
146	1.0693	1.0778	1.0839	1.0887	1.0926	1.0944	1.0961	1.0967	1.0973
143	1.0724	1.0810	1.0870	1.0918	1.0958	1.0975	1.0992	1.0998	1.1005
140	1.0756	1.0841	1.0901	1.0949	1.0989	1.1007	1.1023	1.1030	1.1036
137	1.0787	1.0872	1.0933	1.0980	1.1020	1.1038	1.1055	1.1061	1.1067
134	1.0818	1.0903	1.0964	1.1012	1.1051	1.1069	1.1086	1.1092	1.1098
131	1.0849	1.0934	1.0995	1.1043	1.1083	1.1100	1.1117	1.1123	1.1130
128	1.0881	1.0966	1.1026	1.1074	1.1114	1.1132	1.1148	1.1155	1.1161
125	1.0912	1.0997	1.1057	1.1105	1.1145	1.1163	1.1179	1.1186	1.1192
122	1.0943	1.1028	1.1089	1.1136	1.1176	1.1194	1.1211	1.1217	1.1223
119	1.0974	1.1059	1.1120	1.1168	1.1207	1.1225	1.1242	1.1248	1.1254
116	1.1005	1.1090	1.1151	1.1199	1.1239	1.1256	1.1273	1.1279	1.1286
113	1.1036	1.1122	1.1182	1.1230	1.1270	1.1288	1.1304	1.1310	1.1317
110	1.1068	1.1153	1.1213	1.1261	1.1301	1.1319	1.1335	1.1342	1.1348
107	1.1099	1.1184	1.1245	1.1292	1.1332	1.1350	1.1366	1.1373	1.1379
104	1.1130	1.1215	1.1276	1.1323	1.1363	1.1381	1.1398	1.1404	1.1410
101	1.1161	1.1246	1.1307	1.1355	1.1394	1.1412	1.1429	1.1435	1.1441
98	1.1192	1.1277	1.1338	1.1386	1.1426	1.1443	1.1460	1.1466	1.1473
95	1.1223	1.1309	1.1369	1.1417	1.1457	1.1475	1.1491	1.1497	1.1504
92	1.1255	1.1340	1.1400	1.1448	1.1488	1.1506	1.1522	1.1529	1.1535
89	1.1286	1.1371	1.1431	1.1479	1.1519	1.1537	1.1553	1.1560	1.1566
86	1.1317	1.1402	1.1463	1.1510	1.1550	1.1568	1.1584	1.1591	1.1597
83	1.1348	1.1433	1.1494	1.1541	1.1581	1.1599	1.1616	1.1622	1.1628
80	1.1379	1.1464	1.1525	1.1573	1.1612	1.1630	1.1647	1.1653	1.1659
77	1.1410	1.1495	1.1556	1.1604	1.1644	1.1661	1.1678	1.1684	1.1690
74	1.1441	1.1526	1.1587	1.1635	1.1675	1.1692	1.1709	1.1715	1.1722
71	1.1472	1.1558	1.1618	1.1666	1.1706	1.1723	1.1740	1.1746	1.1753
68	1.1504	1.1589	1.1649	1.1697	1.1737	1.1755	1.1771	1.1778	1.1784
65	1.1535	1.1620	1.1680	1.1728	1.1768	1.1786	1.1802	1.1809	1.1815
62	1.1566	1.1651	1.1711	1.1759	1.1799	1.1817	1.1833	1.1840	1.1846
59	1.1597	1.1682	1.1743	1.1790	1.1830	1.1848	1.1864	1.1871	1.1877
56	1.1628	1.1713	1.1774	1.1821	1.1861	1.1879	1.1896	1.1902	1.1908
53	1.1659	1.1744	1.1805	1.1852	1.1892	1.1910	1.1927	1.1933	1.1939
50	1.1690	1.1775	1.1836	1.1884	1.1923	1.1941	1.1958	1.1964	1.1970
47	1.1721	1.1806	1.1867	1.1915	1.1954	1.1972	1.1989	1.1995	1.2001
44	1.1752	1.1837	1.1898	1.1946	1.1986	1.2003	1.2020	1.2026	1.2032
41	1.1783	1.1868	1.1929	1.1977	1.2017	1.2034	1.2051	1.2057	1.2064
38	1.1814	1.1900	1.1960	1.2008	1.2048	1.2065	1.2082	1.2088	1.2095
35	1.1845	1.1931	1.1991	1.2039	1.2079	1.2096	1.2113	1.2119	1.2126
32	1.1876	1.1962	1.2022	1.2070	1.2110	1.2128	1.2144	1.2151	1.2157

Table of Factors of Evaporation.

Gauge Pressure. Temp. of Feed.	56 lbs.	58 lbs.	60 lbs.	65 lbs.	70 lbs.	75 lbs.	80 lbs.	85 lbs.	90 lbs.	95 lbs.
212° F.	1.0290	1.0295	1.0301	1.0315	1.0329	1.0341	1.0353	1.0365	1.0376	1.0387
209	1.0321	1.0327	1.0333	1.0346	1.0360	1.0372	1.0385	1.0397	1.0408	1.0419
206	1.0352	1.0358	1.0364	1.0378	1.0391	1.0403	1.0416	1.0428	1.0439	1.0450
203	1.0384	1.0390	1.0396	1.0464	1.0423	1.0435	1.0448	1.0460	1.0471	1.0482
200	1.0415	1.0421	1.0427	1.0441	1.0454	1.0466	1.0479	1.0491	1.0502	1.0513
197	1.0447	1.0453	1.0458	1.0477	1.0486	1.0498	1.0511	1.0522	1.0533	1.0544
194	1.0478	1.0484	1.0490	1.0504	1.0517	1.0529	1.0542	1.0553	1.0565	1.0576
191	1.0510	1.0515	1.0521	1.0535	1.0549	1.0561	1.0573	1.0585	1.0596	1.0607
188	1.0541	1.0547	1.0553	1.0566	1.0580	1.0592	1.0605	1.0616	1.0628	1.0639
185	1.0572	1.0578	1.0584	1.0598	1.0611	1.0623	1.0636	1.0648	1.0659	1.0670
182	1.0604	1.0610	1.0615	1.0629	1.0643	1.0655	1.0668	1.0679	1.0690	1.0701
179	1.0635	1.0641	1.0647	1.0660	1.0674	1.0686	1.0699	1.0710	1.0722	1.0733
176	1.0666	1.0672	1.0678	1.0692	1.0705	1.0717	1.0730	1.0742	1.0753	1.0764
173	1.0698	1.0704	1.0709	1.0723	1.0737	1.0749	1.0762	1.0773	1.0784	1.0795
170	1.0729	1.0735	1.0741	1.0754	1.0768	1.0780	1.0793	1.0804	1.0816	1.0827
167	1.0760	1.0766	1.0772	1.0786	1.0799	1.0811	1.0824	1.0836	1.0847	1.0858
164	1.0792	1.0798	1.0803	1.0817	1.0831	1.0843	1.0856	1.0867	1.0878	1.0889
161	1.0823	1.0829	1.0835	1.0848	1.0862	1.0874	1.0887	1.0898	1.0910	1.0921
158	1.0854	1.0860	1.0866	1.0880	1.0893	1.0905	1.0918	1.0929	1.0941	1.0952
155	1.0886	1.0892	1.0897	1.0911	1.0925	1.0937	1.0949	1.0961	1.0972	1.0983
152	1.0917	1.0923	1.0929	1.0942	1.0956	1.0968	1.0981	1.0992	1.1004	1.1015
149	1.0948	1.0954	1.0960	1.0974	1.0987	1.0999	1.1012	1.1023	1.1035	1.1046
146	1.0979	1.0985	1.0991	1.1005	1.1018	1.1030	1.1043	1.1055	1.1066	1.1077
143	1.1011	1.1017	1.1022	1.1036	1.1050	1.1062	1.1074	1.1086	1.1097	1.1108
140	1.1042	1.1048	1.1054	1.1067	1.1081	1.1093	1.1106	1.1117	1.1129	1.1140
137	1.1073	1.1079	1.1085	1.1099	1.1112	1.1124	1.1137	1.1148	1.1160	1.1171
134	1.1104	1.1110	1.1116	1.1130	1.1143	1.1155	1.1168	1.1180	1.1191	1.1202
131	1.1136	1.1142	1.1147	1.1161	1.1175	1.1187	1.1199	1.1210	1.1222	1.1233
128	1.1167	1.1173	1.1179	1.1192	1.1206	1.1218	1.1231	1.1242	1.1253	1.1264
125	1.1198	1.1204	1.1210	1.1223	1.1237	1.1249	1.1262	1.1273	1.1285	1.1296
122	1.1229	1.1235	1.1241	1.1255	1.1268	1.1280	1.1293	1.1294	1.1316	1.1327
119	1.1260	1.1266	1.1272	1.1286	1.1299	1.1311	1.1324	1.1336	1.1347	1.1358
116	1.1292	1.1298	1.1303	1.1317	1.1331	1.1343	1.1355	1.1366	1.1378	1.1389
113	1.1323	1.1329	1.1334	1.1348	1.1362	1.1374	1.1387	1.1398	1.1409	1.1420
110	1.1354	1.1360	1.1366	1.1374	1.1393	1.1405	1.1418	1.1429	1.1441	1.1452
107	1.1385	1.1391	1 1397	1.1411	1.1424	1.1436	1.1449	1.1460	1.1472	1.1483
104	1.1416	1.1422	1.1428	1.1442	1.1455	1.1467	1.1480	1.1491	1.1503	1.1514
101	1.1447	1.1453	1.1459	1.1473	1.1486	1.1498	1.1511	1.1523	1.1534	1 1545
98	1.1479	1.1485	1.1490	1.1504	1.1518	1.1530	1.1542	1.1554	1.1565	1.1576
95	1.1510	1.1516	1.1521	1.1535	1.1549	1.1561	1.1574	1.1583	1.1596	1.1607
92	1.1541	1.1547	1.1553	1.1566	1.1580	1.1592	1.1605	1.1616	1.1628	1.1639
89	1.1572	1.1578	1.1584	1.1598	1.1611	1.1623	1.1636	1.1647	1.1659	1.1670
86	1.1603	1.1609	1.1615	1.1629	1.1642	1.1654	1.1667	1.1678	1.1690	1.1701
83	1.1634	1.1640	1.1646	1.1660	1.1673	1.1685	1.1698	1.1709	1.1721	1.1732
80	1.1665	1.1671	1.1677	1.1691	1.1704	1.1716	1.1729	1.1741	1.1752	1.1763
77	1.1696	1.1702	1.1708	1.1722	1.1735	1.1747	1.1760	1.1772	1.1783	1.1794
74	1.1728	1.1734	1.1739	1.1753	1.1767	1.1779	1.1791	1.1803	1.1814	1.1825
71	1.1759	1.1765	1.1770	1.1784	1.1798	1.1810	1.1823	1.1834	1.1845	1.1856
68	1.1790	1.1796	1.1802	1.1815	1.1829	1.1841	1.1854	1.1865	1.1877	1.1888
65	1.1821	1.1827	1.1833	1.1846	1.1860	1.1872	1.1885	1.1896	1.1908	1.1919
62	1.1852	1.1858	1.1864	1.1877	1.1891	1.1903	1.1916	1.1927	1.1939	1.1950
59	1.1883	1.1889	1.1895	1.1909	1.1922	1.1934	1.1947	1.1958	1.1970	1.2981
56	1.1914	1.1920	1.1926	1.1940	1.1953	1.1965	1.1978	1.1989	1.2001	1.2012
53	1.1945	1.1951	1.1957	1.1971	1.1984	1.1996	1.2009	1.2020	1.2032	1.2043
50	1.1976	1.1982	1.1988	1.2002	1.2015	1.2027	1.2040	1.2052	1.2063	1.2074
47	1.2007	1.2013	1.2019	1.2033	1.2046	1.2058	1.2071	1.2083	1.2094	1.2105
44	1.2039	1.2044	1.2050	1.2064	1.2078	1.2090	1.2102	1.2114	1.2125	1.2136
41	1.2070	1.2076	1.2081	1.2095	1.2109	1.2121	1.2133	1.2145	1.2156	1.2167
38	1.2101	1.2107	1.2112	1.2126	1.2140	1.2162	1.2164	1.2176	1.2187	1.2198
35	1.2132	1.2138	1.2143	1.2157	1.2171	1.2183	1.2196	1.2207	1.2218	1.2229
32	1.2163	1.2169	1.2175	1.2188	1.2202	1.2214	1.2227	1.2239	1.2249	1.2260

Table of Factors of Evaporation.

Gauge Pressure. Temp. of Feed.	100 Lbs.	105 Lbs.	115 Lbs.	125 Lbs.	135 Lbs.	145 Lbs.	155 Lbs.	165 Lbs.	185 Lbs.
212° F,	1.0397	1.0407	1.0427	1.0445	1.0462	1.0478	1.0493	1.0509	1.0536
209	1.0429	1.0438	1.0458	1.0476	1.0493	1.0509	1.0524	1.0540	1.0567
206	1.0460	1.0470	1.0489	1.0510	1.0527	1.0543	1.0558	1.0574	1.0601
203	1.0492	1.0502	1.0521	1.0540	1 0557	1.0573	1.0588	1.0604	1.0631
200	1.0523	1.0533	1.0552	1.0571	1.0588	1.0604	1.0619	1.0635	1.0662
197	1.0555	1.0565	1.0584	1.0602	1.0619	1.0635	1.0650	1.0666	1.0693
194	1.0586	1.0596	1.0615	1.0635	1.0652	1.0668	1.0683	1.0699	1.0726
191	1.0617	1.0627	1.0647	1.0665	1.0682	1.0698	1.0713	1.0729	1.0756
188	1.0649	1.0659	1.0678	1.0696	1.0713	1.0729	1.0744	1.0760	1.0787
185	1.0680	1.0690	1.0709	1.0728	1.0745	1.0761	1.0776	1.0792	1.0819
182	1.0712	1.0722	1.0741	1.0759	1.0776	1.0792	1.0807	1.0823	1.0850
179	1.0743	1.0753	1.0772	1·0790	1.0807	1.0823	1.0838	1.0854	1.0881
176	1.0774	1.0784	1.0803	1.0822	1.0839	1.0855	1.0870	1.0886	1.0913
173	1.0806	1.0816	1.0835	1.0853	1.0870	1.0886	1.0901	1.0917	1.0944
170	1.0837	1.0847	1.0866	1.0884	1.0901	1.0917	1.0932	1.0948	1.0975
167	1.0868	1.0878	1.0897	1.0916	1.0933	1.0949	1.0964	1.0980	1.1007
164	1.0900	1.0910	1.0929	1.0946	1.0963	1.0979	1.0994	1.1010	1.1037
161	1.0931	1.0941	1.0960	1.0979	1.0996	1.1012	1.1027	1.1043	1.1070
158	1.0962	1.0972	1.0991	1.1010	1.1027	1.1043	1.1058	1.1074	1.1101
155	1.0993	1.1003	1.1023	1.1041	1.1058	1.1074	1.1089	1.1105	1.1132
152	1.1025	1.1035	1.1054	1.1073	1.1090	1.1107	1.1122	1.1138	1.1165
149	1.1056	1.1066	1.1085	1.1103	1.1120	1.1136	1.1151	1.1167	1.1194
146	1.1087	1.1097	1.1116	1.1135	1.1152	1.1168	1.1183	1.1199	1.1226
143	1.1118	1.1129	1.1148	1.1166	1.1183	1.1199	1.1214	1.1230	1.1257
140	1.1150	1.1160	1.1179	1.1197	1.1214	1.1230	1.1245	1.1261	1.1288
137	1.1181	1.1191	1.1210	1.1228	1.1245	1.1262	1.1277	1.1293	1.1320
134	1.1212	1.1222	1.1241	1.1260	1.1277	1.1293	1.1308	1.1324	1.1351
131	1.1243	1.1253	1.1273	1.1291	1.1308	1.1324	1.1339	1.1355	1.1382
128	1.1275	1.1285	1.1304	1.1322	1,1339	1.1355	1.1370	1.1386	1.1413
125	1.1306	1.1316	1.1335	1.1353	1.1370	1.1386	1.1401	1.1417	1.1444
122	1 1337	1.1347	1.1366	1.1384	1.1401	1.1417	1.1438	1.1448	1.1475
119	1.1368	1.1378	1.1397	1.1415	1.1432	1.1449	1.1464	1.1480	1.1507
116	1.1399	1.1409	1.1429	1.1447	1.1464	1.1480	1.1495	1.1511	1.1538
113	1.1431	1.1441	1.1460	1.1478	1.1495	1.1511	1.1526	1.1542	1.1569
110	1.1462	1.1472	1.1491	1.1509	1.1516	1.1542	1.1557	1.1573	1.1600
107	1.1493	1.1503	1.1522	1.1540	1.1557	1.1573	1.1588	1.1604	1.1631
104	1.1524	1.1534	1.1553	1.1571	1.1588	1.1605	1.1619	1.1635	1.1662
101	1.1555	1.1565	1.1584	1.1602	1.1620	1.1636	1.1652	1.1668	1.1695
98	1.1586	1.1596	1.1616	1.1634	1.1651	1.1667	1.1683	1.1699	1.1726
95	1.1618	1.1628	1.1647	1.1665	1.1682	1.1698	1.1713	1.1729	1.1756
92	1.1649	1.1660	1.1678	1.1696	1.1713	1.1729	1.1744	1.1760	1.1787
89	1.1680	1.1690	1.1709	1.1727	1.1744	1.1760	1.1775	1.1791	1.1818
86	1.1711	1.1721	1.1740	1.1758	1.1775	1.1791	1.1806	1.1822	1.1849
83	1.1742	1.1752	1.1771	1.1789	1.1806	1.1823	1.1837	1.1853	1.1880
80	1.1773	1.1783	1.1802	1.1820	1.1837	1.1854	1.1869	1.1885	1.1912
77	1.1804	1.1814	1.1834	1.1852	1.1869	1.1885	1.1900	1.1916	1.1943
74	1.1835	1.1845	1.1865	1.1883	1.1900	1.1916	1.1932	1.1948	1.1975
71	1.1867	1.1877	1.1896	1.1914	1.1931	1.1947	1.1961	1.1977	1.2004
68	1.1898	1.1908	1.1927	1.1945	1.1962	1.1978	1.1993	1.2009	1.2036
65	1.1929	1.1939	1.1958	1.1976	1.1993	1.2009	1.2024	1.2040	1.2067
62	1.1960	1.1970	1.1989	1.2007	1.2024	1.2040	1.2055	1.2071	1.2098
59	1.1991	1.2001	1.2020	1.2038	1.2055	1.2071	1.2086	1.2102	1.2129
56	1.2022	1.2032	1.2051	1.2069	1.2086	1.2102	1.2117	1.2133	1.2160
53	1.2053	1.2063	1.2082	1.2100	1.2117	1.2134	1.2148	1.2164	1.2191
50	1.2084	1.2094	1.2113	1.2131	1.2148	1.2165	1.2180	1.2196	1.2223
47	1.2115	1.2125	1.2144	1.2163	1.2180	1.2196	1.2211	1.2227	1.2254
44	1.2146	1.2156	1.2176	1.2194	1.2211	1.2227	1.2242	1.2258	1.2285
41	1.2177	1.2187	1.2207	1.2225	1.2242	1.2258	1.2273	1.2289	1.2316
38	1.2208	1.2219	1 2238	1.2256	1.2273	1.2289	1.2304	1.2320	1.2347
35	1.2240	1.2250	1 2269	1 2287	1.2304	1.2320	1.2335	1.2351	1.2378
32	1.2271	1.2281	1.2300	1.2318	1.2335	1.2351	1.2366	1.2382	1.2409

PROPERTIES OF SATURATED STEAM.

(Compiled by W. W. Christie.)

Pounds per Square Inch.			Heat Units in one Pound above 32° F.			Volume.		
Gauge Pressure.	Absolute Pressure.	Temp. ° F. at Pressure.	h in the Water.	L Latent Heat of Vaporization.	H = L + h Total Heat in Steam.	Relative Cu. Ft. in 1 Cu. Ft. of Water.	Specific Cu. Ft, in one Lb. of Steam.	Weight of one Cubic Foot of Steam.
. . .	1	102.	70.1	1042.9	1113.0	20620	319.600	.0030
. . .	2	126.2	94.4	1026.0	1120.4	10720	172.417	.0058
. . .	3	141.6	109.8	1015.2	1125.1	7326	117.723	.0085
. . .	4	153.0	121.4	1007.2	1128.6	5600	89.799	.0112
. . .	5	162.3	130.7	1000.7	1131.4	4535	72.792	.0137
. . .	6	170.1	138.5	995.2	1133.8	3814	61.311	.0163
. . .	7	176.9	145.4	990.4	1135.8	3300	53.000	.0189
. . .	8	182.9	151.4	986.2	1137.7	2910	46.771	.0214
. . .	9	188.3	156.9	982.4	1139.3	2607	41.858	.0239
. . .	10	193.2	161.9	978.9	1140.8	2360	37.904	.0264
. . .	11	197.7	166.5	975.7	1142.2	2157	34.659	.0289
. . .	12	201.9	170.7	972.8	1143.5	1988	31.932	.0313
. . .	13	205.8	174.7	970.0	1144.7	1846	29.593	.0337
. . .	14	209.5	178.4	967.4	1145.8	1722	27.624	.0362
.304	15	213.0	181.9	964.9	1146.9	1612	25.858	.0387
1.3	16	216.3	185.2	962.6	1147.9	1514	24.335	.0413
2.3	17	219.4	188.4	960.4	1148.8	1427	22.985	.0437
3.3	18	222.3	191.4	958.3	1149.7	1350.6	21.781	.0462
4.3	19	225.2	194.2	956.3	1150.6	1282.1	20.701	.0487
5.3	20	227.9	197.0	954.4	1151.4	1220.3	19.725	.0511
6.3	21	230.5	199.6	952.5	1152.2	1164.4	18.839	.0536
7.3	22	233.0	202.2	950.8	1153.0	1113.5	18.033	.0561
8.3	23	235.4	204.6	949.0	1153.7	1066.9	17.293	.0585
9.3	24	237.7	207.0	947.4	1154.4	1024.1	16.615	.0610
10.3	25	240.0	209.3	945.8	1155.1	984.8	15.988	.0634
11.3	26	242.1	211.5	944.2	1155.8	948.4	15.409	.0658
12.3	27	244.2	213.6	942.7	1156.4	914.6	14.871	.0683
13.3	28	246.3	215.7	941.3	1157.0	883.2	14.371	.0707
14.3	29	248.3	217.7	939.9	1157.6	854.0	13.904	.0731
15.3	30	250.2	219.7	938.9	1158.2	826.8	13.467	.0755
16.3	31	252.1	221.6	937.1	1158.8	801.2	13.058	.0779
17.3	32	253.9	223.5	935.9	1159.3	777.2	12.674	.0803
18.3	33	255.7	225.3	934.6	1159.9	754.7	12.312	.0827
19.3	34	257.4	227.1	933.3	1160.4	733.5	11.971	.0851
20.3	35	259.1	228.8	932.1	1160.9	713.4	11.649	.0875
21.3	36	260.8	230.5	931.0	1161.5	694.5	11.344	.0899
22.3	37	262.4	232.1	929.8	1161.9	676.6	11.055	.0922
23 3	38	264.0	233.8	928.6	1162.4	659.7	10.756	.0946
24.3	39	265.6	235.3	927.5	1162.9	643.6	10.521	.0970
25.3	40	267.1	236.9	926.4	1163.4	628.2	10.259	.0994
26.3	41	268.6	238.4	925.4	1163.8	613.4	10.037	.1017
27.3	42	270.0	239.9	924.3	1164.3	599.3	9.811	.1041

PROPERTIES OF SATURATED STEAM — *Continued.*

Pounds per Square Inch.		Temp. °F. at Pressure.	Heat Units in one Pound above 32° F.			Volume.		Weight of one Cubic Foot of Steam.
Gauge Pressure.	Absolute Pressure.		h in the Water.	L Latent Heat of Vaporization.	$H = L + h$ Total Heat in Steam.	Relative Cu. Ft. in 1 Cu. Ft. of Water.	Specific Cu. Ft. in one Lb. of Steam.	
28.3	43	271.5	241.4	923.3	1164.7	586 1	9.596	.1064
29.3	44	272.9	242.8	922.3	1165.1	573.7	9.391	.1088
30.3	45	274.3	244.2	921.3	1165.6	561.8	9.196	.1111
31.3	46	275.6	245.6	920.3	1166.0	550.4	9.006	.1134
32.3	47	276.9	247.0	919.4	1166.4	539.5	8.826	.1158
33.3	58	278.2	248.3	918.4	1166.8	529.0	8.653	.1181
34.3	49	279.5	249.6	917.5	1167.2	518.6	8.487	.1204
35.3	50	280.8	250.9	916.6	1167.6	508.5	8.326	.1227
36.3	51	282.1	252.2	915.7	1167.9	499.1	8.173	.1251
37.3	52	283.3	253.5	914.8	1168.3	490.1	8.025	.1274
38.3	53	284.5	254.7	913.9	1168.7	481.4	7.882	.1297
39.3	54	285.7	255.9	913.1	1169.0	472.9	7.745	.1320
40.3	55	286.9	257.1	912.2	1169.4	464.7	7.612	.1343
41.3	56	288.0	258.3	911.4	1169.7	457.0	7.484	.1366
42.3	57	289.1	259.5	910.6	1170.1	449.6	7.360	.1388
43.3	58	290.3	260.6	909.8	1170.4	442.4	7.241	.1411
44.3	59	291.4	261.7	909.0	1170.8	435.3	7.125	.1434
45.3	60	292.5	262.9	908.2	1171.1	428.5	7.013	.1457
46.3	61	293.6	264.0	907.4	1171.4	422.0	6.905	.1479
47.3	62	294.6	265.1	906.7	1171.8	415.6	6.800	.1502
48.3	63	295.7	266.1	905.9	1172.1	409.4	6.699	.1524
49.3	64	296.7	267.2	905.2	1172.4	403.5	6.600	.1547
50.3	65	297.7	268.3	904.4	1172.7	397.7	6.505	.1569
51.3	66	298.7	269.3	903.7	1173.0	392.1	6.412	.1592
52.3	67	299.7	270.3	903.0	1173.3	386.6	6.322	.1614
53.3	68	300.7	271.3	902.3	1173.6	381.3	6.234	.1637
54.3	69	301.7	272.3	901.5	1173.9	376.1	6.149	.1659
55.3	70	302.7	273.3	900.9	1174.2	371.2	6.066	.1681
56.3	71	303.6	274.3	900.2	1174.5	366.4	5.986	.1703
57.3	72	304.6	275.3	899.5	1174.8	361.7	5.907	.1725
58.3	73	305.5	276.2	898.8	1175.1	357.1	5.831	.1748
59.3	74	306.4	277.2	898.1	1175.4	352.6	5.757	.1770
60.3	75	307.3	278.1	897.5	1175.6	348.3	5.684	.1792
61.3	76	308.2	279.0	896.8	1175.9	344.1	5.614	.1814
62.3	77	309.1	280.0	896.2	1176.2	340.0	5.546	·1836
63.3	78	310.0	280.9	895.5	1176.5	336.0	5.479	.1857
64.3	79	310.9	281.8	894.9	1176.7	332.1	5.413	.1879
65.3	80	311.8	282.7	894.3	1177.0	328.3	5.342	.1901
66.3	81	312.6	283.5	893.7	1177.3	324.6	5.287	.1923
67.3	82	313.5	284.4	893.1	1177.5	320.9	5·227	.1945
68.3	83	314.3	285.3	892.4	1177.8	317.3	5.167	.1967
69.3	84	315.1	286.1	891.8	1178.0	313.9	5.110	1988

PROPERTIES OF SATURATED STEAM — *Continued.*

Pounds per Square Inch.		Temp. °F. at Pressure.	Heat Units in one Pounds above 32° F.			Volume.		Weight of one Cubic Foot of Steam.
Gauge Pressure.	Absolute Pressure.		h in the Water.	L Latent Heat of Vapori-zation.	$H = L + h$ Total Heat in Steam.	Relative Cu. Ft. in 1 Cu. Ft. of Water.	Specific Cu. Ft. n 1 Lb. of Steam.	
70.3	85	316.0	287.0	891.2	1178.3	310.5	5.053	.2010
71.3	86	316.8	287.8	890.6	1178.5	307.2	4.998	.2032
72.3	87	317.6	288.7	890.1	1178.8	304.0	4.943	.2053
73.3	88	318.4	289.5	889.5	1179.0	300.8	4.891	.2075
74.3	89	319.2	290.3	888.9	1179.3	297.7	4.839	.2097
75.3	90	320.0	291.1	888.3	1179.5	294.7	4.788	.2118
76.3	91	320.8	291.9	887.8	1179.8	291.8	4.739	.2139
77.3	92	321.6	292.7	887.2	1180.0	288.9	4.690	.2160
78.3	93	322.3	293.5	886.6	1180.2	286.1	4.643	.2182
79.3	94	323.1	294.3	886.1	1180.4	283.3	4.596	.2204
80.3	95	323.8	295.1	885.5	1180.7	280.6	4.551	.2224
81.3	96	324.6	295.9	885.0	1180.9	278.0	4.506	.2245
82.3	97	325.3	296.6	884.5	1181.1	275.4	4.462	.2266
83.3	98	326.1	297.4	883.9	1181.4	272.8	4.419	.2288
84.3	99	326.8	298.1	883.4	1181.6	270.3	4.377	.2309
85.3	100	327.5	298.9	882.9	1181.8	267.9	4.336	.2330
86.3	101	328.2	299.6	882.3	1182.0	265.5	4.296	.2351
87.3	102	329.0	300.4	881.8	1182.2	263.2	4.256	.2371
88.3	103	329.7	301.1	881.3	1182.5	260.9	4.217	.2392
89.3	104	330.4	301.8	880.8	1182.7	258.7	4.179	.2413
90.3	105	331.1	302.5	880.3	1182.9	256.5	4.142	.2434
91.3	106	331.8	303.3	879.8	1183.1	254.3	4.105	.2454
92.3	107	332.4	304.0	879.3	1183.3	252.2	4.069	.2475
93.3	108	333.1	304.7	878.8	1183.5	250.1	4.033	.2496
94.3	109	333.8	305.4	878.3	1183.7	248.0	3.998	.2516
95.3	110	334.5	306.1	877.8	1183.9	246.0	3.964	.2537
96.3	111	335.1	306.8	877.3	1184.1	244.0	3.931	.2558
97.3	112	335.8	307.4	876.9	1184.3	242.0	3.897	.2578
98.3	113	336.5	308.1	876.4	1184.5	240.1	3.865	.2599
99.3	114	337.1	308.8	875.9	1184.7	238.2	3.833	.2619
100.3	115	337.8	309.5	875.4	1184.9	236.3	3.802	.2640
101.3	116	338.4	310.1	875.0	1185.1	234.5	3.771	.2661
102.3	117	339.1	310.8	874.5	1185.3	232.7	3.740	.2681
103.3	118	339.7	311.4	874.0	1185.5	231.0	3.711	.2702
104.3	119	340.3	312.1	873.6	1185.7	229.3	3.681	.2722
105.3	120	340.9	312.7	873.1	1185.9	227.6	3.652	.2742
106.3	121	341.6	313.4	872.7	1186.1	226.0	3.624	.2762
107.3	122	342.2	314.0	872.5	1186.3	224.4	3.596	.2782
108.3	123	342.8	314.7	871.8	1186.5	222.8	3.568	.2802
109.3	124	343.4	315.3	871.3	1186.6	221.2	3.541	.2822
110.3	125	344.0	315.9	870.9	1186.8	219.7	3.515	.2842
111.3	126	344.6	316.6	870.4	1187.0	218.2	3.488	.2862

PROPERTIES OF SATURATED STEAM — *Continued.*

Pounds per Square Inch.		Temperature °F. at Pressure.	Heat Units in one Pound above 32° F.			Volume.		Weight of one Cubic Foot of Steam.
Gauge Pressure.	Absolute Pressure.		*h* in the Water.	L Latent Heat of Vapori-zation.	H = L + *h* Total Heat in Steam.	Relative Cu. Ft. in 1 Cu Ft. of Water.	Specific Cu. Ft. in 1 Lb. of Steam.	
112.3	127	345.2	317.2	870.0	1187.2	216.7	3.463	.2882
113.3	128	345.8	317.8	869.6	1187.4	215.2	3.437	.2902
114.3	129	346.4	318.4	869.1	1187.6	213.7	3.412	.2922
115.3	130	347.0	319.0	868.7	1187.8	212.3	3.387	.2942
116.3	131	347.6	319.6	868.3	1187.9	210.9	3.363	.2961
117.3	132	348.2	320.2	867.8	1188.1	209.5	3.339	.2981
118.3	133	348.8	320.8	867.4	1188.3	208.1	3.315	.3001
119.3	134	349.3	321.4	867.0	1188.5	206.7	3.292	.3020
120.3	135	349.9	322.0	866.6	1188.6	205.4	3.269	.3040
121.3	136	350.5	322.6	866.2	1188.8	204.1	3.247	.3060
122.3	137	351.0	323.2	865.7	1189.0	202.8	3.224	.3079
123.3	138	351.7	323.8	865.3	1189.1	201.5	3.202	.3099
124.3	139	352.2	324.3	864.9	1189.3	200.2	3.180	.3118
125.3	140	352.7	324.9	864.5	1189.5	199.0	3.159	.3138
126.3	141	353.3	325.5	864.1	1189.7	197.8	3.138	.3158
127.3	142	353.8	326.1	863.7	1189.8	196.6	3.117	.3178
128.3	143	354.4	326.8	863.3	1190.0	195.4	3.097	.3199
129.3	144	354.9	327.2	862.9	1190.2	194.2	3.076	.3219
130.3	145	355.5	327.8	862.5	1190.3	193.0	3.056	.3239
131.3	146	356.0	328.3	862.1	1190.4	191.9	3.037	.3259
132.3	147	356.5	328.9	861.7	1190.6	190.8	3.017	.3279
133.3	148	357.1	329.4	861.4	1190.8	189.7	2.998	.3299
134.3	149	357.6	330.0	861.0	1191.0	188.6	2.980	.3319
135.3	150	358.1	330.5	860.6	1191.1	187.5	2.961	.3340
136.3	151	358.6	331.1	860.2	1191.3	186.4	2.942	.3358
137.3	152	359.2	331.6	859.8	1191.4	185.3	2.924	.3376
138.3	153	359.7	332.2	859.4	1191.6	184.3	2.906	.3394
139.3	154	360.2	332.7	859.1	1191.8	183.3	2.888	.3412
140.3	155	360.7	333.2	858.7	1191.9	182.3	2.871	.3430
141.3	156	361.2	333.7	858.3	1192.1	181.3	2.853	.3448
142.3	157	361.7	334.3	857.9	1192.2	180.3	2.837	.3466
143.3	158	362.2	334.8	857.6	1192.4	179.3	2.819	.3484
144.3	159	362.7	335.3	857 2	1192.5	178.3	2.804	.3502
145.3	160	363.2	335.8	856.8	1192.7	177.3	2.787	.3520
146.3	161	363.7	336.3	856.5	1192.8	176.4	2.770	.3539
147.3	162	364.2	336.9	856.1	1193.0	175.5	2.755	.3558
148.3	163	364.7	337.4	855.7	1193.1	174.6	2.737	.3577
149.3	164	365.2	337.9	855.4	1193.3	173.7	2.722	.3596
150.3	165	365.7	338.4	855.0	1193.5	172.8	2.706	.3614
151.3	166	366.2	338.9	854.7	1193.6	171.9	2.691	.3633
152.3	167	366.7	339.4	854.3	1193.7	171.0	2.676	.3652
153.3	168	367.1	339.9	853.9	1193.9	170.1	2.661	.3671

PROPERTIES OF SATURATED STEAM — *Continued.*

Pounds per Square Inch.		Temperature °F. at Pressure.	Heat Units in One Pound above 32° F.			Volume.		Weight of one Cubic Foot of Steam.
Gauge Pressure.	Absolute Pressure.		h in the Water.	L Latent Heat of Vaporization.	$H = L + h$ Total Heat in Steam.	Relative Cu. Ft. in 1 Cu. Ft. of Water.	Specific Cu. Ft. in 1 Lb. of Steam.	
154.3	169	367.6	340.4	853.6	1194.0	169.2	2.646	.3690
155.3	170	368.1	340.9	853.2	1194.2	168.4	2.633	.3709
156.3	171	368.6	341.4	852.9	1194.3	167.6	2.617	.3727
157.3	172	369.1	341.9	852.6	1194.5	166.8	2.603	.3745
158.3	173	369.5	342.4	852.2	1194.6	166.0	2.589	.3763
159.3	174	370.0	342.8	851.9	1194.8	165.2	2.575	.3781
160.3	175	370.5	343.3	851.5	1194.9	164.4	2.561	.3799
161.3	176	370.9	343.8	851.2	1195.0	163.6	2.547	.3817
162.3	177	371.4	344.3	850.8	1195.2	162.8	2.533	.3835
163.3	178	371.9	344.8	850.5	1195.3	162.0	2.521	.3853
164.3	179	372.3	345.3	850.2	1195.5	161.2	2.507	.3871
165.3	180	372.8	345.7	849.8	1195.6	160.4	2.494	.3889
166.3	181	373.2	346.2	849.5	1195.7	159.7	2.480	.3907
167.3	182	373.7	346.7	849.2	1195.9	159.0	2.468	.3925
168.3	183	374.1	347.1	848.8	1196.0	158.3	2.455	.3944
169.3	184	374.6	347.6	848.5	1196.2	157.6	2.443	.3962
170.3	185	375.0	348.1	848.2	1196.3	156.9	2.430	.3980
171.3	186	375.5	348.6	847.8	1196.4	156.2	2.418	.3999
172.3	187	375.9	349.0	847.5	1196.6	155.5	2.406	.4017
173.3	188	376.4	349.5	847.2	1196.7	154.8	2.394	.4035
174.3	189	376.8	349.9	846.9	1196.8	154.1	2.382	.4053
175.3	190	377.2	350.4	846.5	1197.0	153.4	2.370	.4072
176.3	191	377.7	350.8	846.2	1197.1	152.7	2.358	.4089
177.3	192	378.1	351.3	845.9	1197.2	152.0	2.347	.4107
178.3	193	378.5	351.7	845.6	1197.4	151.3	2.335	.4125
179.3	194	379.0	352.2	845.3	1197.5	150.7	2.324	.4143
180.3	195	379.4	352.6	845.0	1197.6	150.1	2.312	.4160
181.3	196	379.9	353.1	844.6	1197.8	149.5	2.302	.4178
182.3	197	380.3	353.5	844.3	1197.9	148.9	2.290	.4196
183.3	198	380.7	354.0	844.0	1198.0	148.3	2.279	.4214
184.3	199	381.1	354.4	843.7	1198.1	147.7	2.269	.4231
185.3	200	381.5	354.8	843.4	1198.3	147.1	2.258	.4249
186.3	201	381.9	355.3	843.1	1198.4	146.5	2.248	.4266
187.3	202	382.4	355.7	842.8	1198.5	145.9	2.238	.4283
188.3	203	382.8	356.1	842.5	1198.7	145.3	2.227	.4300
189.3	204	383.2	356.6	842.2	1198.8	144.7	2.216	.4318
190.3	205	383.6	357.0	841.8	1198.9	144.1	2.204	.4335
191.3	206	384.0	357.4	841.5	1199.0	143.5	2.196	.4352
192.3	207	384.4	357.9	841.2	1199.2	142.9	2.186	.4369
193.3	208	384.8	358.3	841.0	1199.3	142.3	2.176	.4386
194.3	209	385.2	358.7	840.7	1199.4	141.8	2.166	.4403
195.3	210	385.6	359.1	840.4	1199.5	141.3	2.157	.4421

CONDENSATION IN STEAM-PIPES.

(W. W. C.)

No very satisfactory figures are found for the absolute condensation losses in steam pipes, most of reported tests being compared with hair felt.

0.012 lbs. per 24 hours per sq. ft. of pipe per degree Fahr., difference in temperature of steam and external air, which may be used in calculations, is based on the following :

Test by.	Sq. ft. Surface.	Lbs. of Water.		Difference in temperature Deg. F.	Lbs. Water per degree 24 hours.	Covering.
		in 24 hrs.	per sq. ft. in 24 hrs.			
Bedle & Bauer.	4130	11315	2.74	262	.0104	Asbestos.
Norris.	3892	9360	2.40	234	.0103	Asbestos.
Brill.				308	.0105	Magnesia sect'l.
Norton.				315	.0125	Magnesia.

The last test by C. L. Norton (Trans. A. S. M. E., 1898) was made with the utmost care. Mr. Norton found that a pipe boxed in with charcoal 1 inch minimum thickness was 20 per cent better insulated than when magnesia was used, corroborating Mr. Reinhart's statements concerning his experience using flue dust to insulate pipes.

Aboard Ship. — The battleship "Shikishima" carries 25 Belleville boilers capable under full steam of developing 15,000 I.H.P. in the main engines besides working the auxiliaries, each boiler supplying steam for 150 I.H.P. When at anchor, one boiler under easy steam, i.e., evaporating from 9 lb. to 10 lbs. of water from and at 212° F., per pound of coal — was just able to work one 48 K.W. steam dynamo at about half power, together with one feed pump, and the air and circulating pumps connected with the auxiliary condenser, into which the dynamo engine exhausted, besides working a fire and bilge pump occasionally.

The dynamo was about 160 ft. of pipe length away from the boiler, the total range of steam pipe length connected being 500–600 ft.

Performing the first-mentioned service with only one boiler under steam, the coal burned varied from 3½ to 5 tons per day of 18 hours, for about 65 I.H.P., or about 7 lbs. per indicated horse-power at the best to 10 lbs. at the worst, an average of 8 lbs. and over, which shows that more than half the fuel must have been expended in keeping the pipes warm. All pipes were well covered and below decks, and machinery in first-class condition. (London-Engr.)

Heating Pipes. — To determine the boiler H.P. necessary for heating, it may be assumed that each sq. ft. of radiating surface will condense about 0.3 lbs. of steam per hour as a maximum when in active service ; thus 20,000 sq. ft. times 0.3 = 6000 lbs. of condensation, which divided by 30 gives 200 boiler horse-power.

Condensed steam in which there is no oil may be returned to the boiler with the feed-water to be re-evaporated.

OUTFLOW OF STEAM FROM A GIVEN INITIAL PRESSURE INTO VARIOUS LOWER PRESSURES.

(D. K. Clark.)

Absolute Pressure in Boiler per Sq. Inch.	Outside Pressure per Sq. Inch.	Ratio of Expansion.	Velocity of Outflow at Constant Density.	Actual Velocity of Outflow Expanded.	Weight Discharged per Sq. In. of Orifice per Minute.
Lbs.	Lbs.	Ratio.	Ft. per Sec.	Ft. per Sec.	Lbs.
75	74	1.012	227.5	230	16.68
75	72	1.037	386.7	401	28.35
75	70	1.063	490	521	35.93
75	65	1.136	660	749	48.38
75	61.62	1.198	736	876	53.97
75	60	1.219	765	933	56.12
75	50	1.434	873	1252	64.
75	45	1.575	890	1401	65.24
75	43.46, 58 %	1.624	890.6	1446.5	65.3
75	15	1.624	890.6	1446.5	65.3
75	0	1.624	890.6	1446.5	65.3

When, however, steam of varying initial pressure is discharged into the atmosphere — pressures of which the atmospheric pressure is not more than 58 per cent — the velocity of outflow at constant density, that is, supposing the initial density to be maintained, is given by the formula —

$$V = 3.5953 \sqrt{h},$$

where $V =$ the velocity of outflow in feet per minute, as for steam of the initial density. $h =$ the height in feet of a column of steam of the given absolute initial pressure of uniform density, the weight of which is equal to the pressure on the unit of base.

The following table is calculated from this formula:

OUTFLOW OF STEAM INTO THE ATMOSPHERE.

(D. K. Clark.)

Absolute Initial Pressure in Boiler in Lbs. per Sq. Inch.	Outside Pressure in Lbs. per Sq. Inch.	Ratio of Expansion in Nozzle.	Velocity of Outflow at Constant Density.	Actual Velocity of Outflow, Expanded.	Weight Discharged per Sq. Inch of Orifice per Min.
Lbs.	Lbs.	Ratio.	Ft. per Sec.	Ft. per Sec.	Lbs.
25.37	14.7	1.624	863	1401	22.81
30	14.7	1.624	867	1408	26.84
40	14.7	1.624	874	1419	35.18
45	14.7	1.624	877	1424	39.78
50	14.7	1.624	880	1429	44.06
60	14.7	1.624	885	1437	52.59
70	14.7	1.624	889	1444	61.07
75	14.7	1.624	891	1447	65.30
90	14.7	1.624	895	1454	77.94
100	14.7	1.624	898	1459	86.34
115	14.7	1.624	902	1466	98.76
135	14.7	1.624	906	1472	115.61
155	14.7	1.624	910	1478	132.21
165	14.7	1.624	912	1481	140.46
215	14.7	1.624	919	1493	181.58

STEAM PIPES.

Rankine says the velocity of steam flow in pipes should not exceed 6000 feet per minute (100 feet per second). As increased size of pipe means increased loss by radiation, care should be taken that in order to decrease the velocity of flow, the losses by radiation do not become considerable.

The quantity discharged per minute may be approximately found by Rankine's formula ("Steam Engine," p. 298), $W = 60\,ap \div 70 = 6\,ap \div 7$, in which W = weight in pounds, a = area of orifice in square inches, and p = absolute pressure. The results must be multiplied by $k = 0.93$ for a short pipe, and by $k = 0.63$ for their openings as in a safety valve.

Where steam flows into a pressure greater than two-thirds the pressure in the boiler, $W = 1.9\,ak\sqrt{(p-d)\,d}$, in which d = difference in pressure in pounds per square inch between the two sides, and a, p, and k as above. Multiply the results by 2 to reduce to h.p. To determine the necessary difference in pressure where a given h.p. is required to flow through a given opening,

$$d = \frac{p}{2} - \sqrt{\frac{p^2}{4} - \frac{HP^2}{14\,a^2k}}.$$

Flow of Steam Through Pipes.

(G. H. Babcock in "Steam.")

The approximate weight of any fluid which will flow in a minute through any given pipe with a given head or pressure may be found by the formula

$$W = 87\sqrt{\frac{D\,(p_1 - p_2)\,d^5}{L\left(1 + \frac{3.6}{d}\right)}}$$

in which W = weight in pounds, d = diameter in inches, D = density or weight per cubic foot, p_1 = initial pressure, p_2 = pressure at the end of the pipe, and L = length in feet.

The following table gives, approximately, the weight of steam per minute which will flow from various initial pressures, with one pound loss of pressure through straight smooth pipes, each having a length of 240 times its own diameter. For sizes below 6 inches, the flow is calculated from the actual areas of "standard" pipe of such nominal diameters.

For h.p. multiply the figures in the table by two. For any other loss of pressure, multiply by the square root of the given loss. For any other length of pipe, divide 240 by the given length expressed in diameters, and multiply the figures in the table by the square root of this quotient, which will give the flow for 1 pound loss of pressure. Conversely dividing the given length by 240 will give the loss of pressure for the flow given in the table.

Table of Flow of Steam Through Pipes.

Initial Pressure by Gauge. Lbs. per Sq. Inch.	Diameter of Pipe in Inches. Length of each = 240 Diameters.						
	¾	1	1½	2	2½	3	4
	Weight of Steam per Min. in Lbs., with 1 Lb. Loss of Pressure.						
1	1.16	2.07	5.7	10.27	15.45	25.38	46.85
10	1.44	2.57	7.1	12.72	19.15	31.45	58.05
20	1.70	3.02	8.3	14.94	22.49	36.94	68.20
30	1.91	3.40	9.4	16.84	25.35	41.63	76.84
40	2.10	3.74	10.3	18.51	27.87	45.77	84.49
50	2.27	4.04	11.2	20.01	30.13	49.48	91.34
60	2.43	4.32	11.9	21.38	32.19	52.87	97.60
70	2.57	4.58	12.6	22.65	34.10	56.00	103.37
80	2.71	4.82	13.3	23.82	35.87	58.91	108.74
90	2.83	5.04	13.9	24.92	37.52	61.62	113.74
100	2.95	5.25	14.5	25.96	39.07	64.18	118.47
120	3.16	5.63	15.5	27.85	41.93	68.87	127.12
150	3.45	6.14	17.0	30.37	45.72	75.09	138.61

Table of Flow of Steam Through Pipes.—*Continued.*

Initial Pressure by Gauge. Lbs. per Sq. Inch.	Diameter of Pipe in Inches. Length of Each = 240 Diameters.						
	5	6	8	10	12	15	18
	Weight of Steam per Min. in Lbs., with 1 Lb. Loss of Pressure.						
1	77.3	115.9	211.4	341.1	502.4	804	1177
10	95.8	143.6	262.0	422.7	622.5	996	1458
20	112.6	168.7	307.8	496.5	731.3	1170	1713
30	126.9	190.1	346.8	559.5	824.1	1318	1930
40	139.5	209.0	381.3	615.3	906.0	1450	2122
50	150.8	226.0	412.2	665.0	979.5	1567	2294
60	161.1	241.5	440.5	710.6	1046.7	1675	2451
70	170.7	255.8	466.5	752.7	1108.5	1774	2596
80	179.5	269.0	490.7	791.7	1166.1	1866	2731
90	187.8	281.4	513.3	828.1	1219.8	1951	2856
100	195.6	293.1	534.6	862.6	1270.1	2032	2975
120	209.9	314.5	573.7	925.6	1363.3	2181	3193
150	228.8	343.0	625.5	1009.2	1486.5	2378	3481

The loss of head due to getting up the velocity, to the friction of the steam entering the pipe and passing elbows and valves, will reduce the flow given in the table. The resistance at the opening and that at a globe valve are each about the same as that for a length of pipe equal to 114 diameters divided by a number represented by $1 + \frac{3.6}{d}$. For the sizes of pipes given in the table these corresponding lengths are :

¾	1	1½	2	2½	3	4	5	6	8	10	12	15	18
20	25	34	41	47	52	60	66	71	79	84	88	92	95

The resistance at an elbow is equal to ⅔ that of a globe valve. These equivalents — for opening, for elbows, and for valves — must be added in each instance to the actual length of pipe. Thus a 4-inch pipe, 120 diameters (40 feet) long, with a globe valve and three elbows, would be equivalent to $120 + 60 + 60 + (3 \times 40) = 360$ diameters long ; and $360 \div 240 = 1\frac{1}{2}$. It would therefore have 1½ lbs. loss of pressure at the flow given in the table, or deliver $(1 \div \sqrt{1\frac{1}{2}} = 8.16)$, 81.6 per cent of the steam with the same (1 lb.) loss of pressure.

Equation of Pipes (Steam).

It is frequently desirable to know what number of one size of pipes will equal in capacity another given pipe for delivery of steam or water. At the same velocity of flow two pipes deliver as the squares of their internal diameters, but the same head will not produce the same velocity in pipes of different sizes or lengths, the difference being usually stated to vary as the square root of the fifth power of the diameter. The friction of a fluid within itself is very slight, and therefore the main resistance to flow is the friction upon the sides of the conduit. This extends to a limited distance, and is, of course, greater in proportion to the contents of a small pipe than of a large. It may be approximated in a given pipe by a constant multiplied by the diameter, or the ratio of flow found by dividing some power of the diameter by the diameter increased by a constant. Careful comparisons of a large number of experiments, by different investigators, has developed the following as a close approximation to the relative flow in pipes of different sizes under similar conditions :

$$W \propto \frac{d^3}{\sqrt{d + 3.6}}$$

W being the weight of fluid delivered in a given time, and d being the internal diameter in inches.

The diameters of "standard" steam and gas pipe, however, vary from the nominal diameters, and in applying this rule it is necessary to take the true measurements, which are given in the following table :

Table of Standard Sizes Steam and Gas Pipes.

Size, Inches.	Diameter.		Size, Inches.	Diameter.		Size, Inches.	Diameter.	
	Internal.	External.		Internal.	External.		Internal.	External.
1/8	.27	.40	2½	2.47	2.87	9	8.94	9.62
1/4	.36	.54	3	3.07	3.5	10	10.02	10.75
3/8	.49	.67	3½	3.55	4	11	11	11.75
1/2	.62	.84	4	4.03	4.5	12	12	12.75
3/4	.82	1.05	4½	4.51	5	13	13.25	14
1	1.05	1.31	5	5.04	5.56	14	14.25	15
1¼	1.38	1.66	6	6.06	6.62	15	15.43	16
1½	1.61	1.90	7	7.02	7.62	16	16.4	17
2	2.07	2.37	8	7.98	8.62	17	17.32	18

The following table gives the number of pipes of one size required to equal in delivery other larger pipes of the same length and under the same conditions. The upper portion above the diagonal line of blanks pertains to "standard" steam and gas pipes, while the lower portion is for pipe of the actual internal diameters given. The figures given in the table opposite the intersection of any two sizes is the number of the smaller-sized pipes required to equal one of the larger.

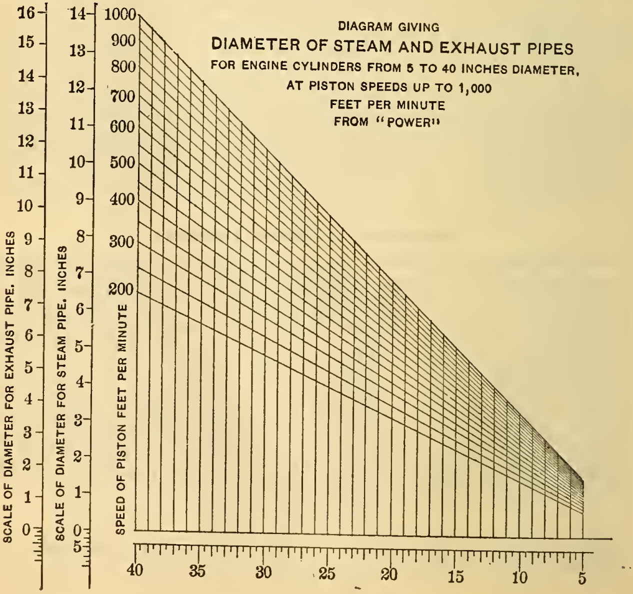

FIG. 11.

TABLE OF EQATION OF PIPES.

(Standard Steam and Gas Pipes.)

Dia.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Dia.
½		2.27	4.88	15.8	31.7	52.9	96.9	205	377	620	918	1292	1767	2488	3014	3786	4904	5927	7321	8535	9717	½
¾	2.60		2.05	6.97	14.0	23.3	42.5	90.4	166	273	405	569	779	1096	1328	1668	2161	2615	3226	3761	4282	¾
1	7.55	2.90		3.45	6.82	11.4	20.9	44.1	81.1	133	198	278	380	536	649	815	1070	1263	1576	1837	2092	1
1½	24.2	9.30	3.20		1.26	3.34	6.13	13.0	23.8	39.2	58.1	81.7	112	157	190	239	310	375	463	539	614	1½
2	54.8	21.0	7.25	2.26		1.67	3.06	6.47	11.9	19.6	29.0	40.8	55.8	78.5	95.1	119	155	187	231	269	307	2
2½	102	39.4	13.6	4.23	1.87		1.83	3.87	7.12	11.7	17.4	24.4	33.4	47.0	56.9	71.5	92.6	112	138	161	184	2½
3	170	65.4	22.6	7.03	3.11	1.66		2.12	3.89	6.39	9.48	13.3	20.9	23.7	31.2	39.1	50.6	61.1	75.5	88.0	100	3
4	376	144	49.8	15.5	6.87	3.67	2.21		1.84	3.02	4.48	6.30	8.61	12.1	14.7	18.5	23.9	28.9	35.7	41.6	47.4	4
5	686	263	90.9	28.3	12.5	6.70	4.03	1.83		1.65	2.44	3.43	4.69	6.60	8.00	10.0	13.0	15.7	19.4	22.6	25.8	5
6	1116	429	148	46.0	20.4	10.9	6.56	2.97	1.63		1.48	2.09	2.85	4.02	4.86	6.11	7.91	9.56	11.8	13.8	15.6	6
7	1707	656	226	70.5	31.2	16.6	10.0	4.54	2.49	1.51		1.41	1.93	2.71	3.28	4.12	5.34	6.45	7.97	9.31	10.6	7
8	2435	936	322	101	44.5	23.8	14.3	6.48	3.54	2.18	1.43		1.35	1.93	2.33	2.92	3.79	4.57	5.67	6.60	7.52	8
9	3335	1281	440	137	60.8	32.5	19.5	8.85	4.85	2.98	1.95	1.37		1.41	1.71	2.14	2.77	3.35	4.14	4.83	5.50	9
10	4393	1688	582	181	80.4	42.9	25.8	11.7	6.40	3.93	2.57	1.80	1.32		1.21	1.52	1.97	2.38	2.94	3.43	3.91	10
11	5642	2168	747	233	103	55.1	33.1	15.0	8.22	5.05	3.31	2.32	1.70	1.28		1.26	1.63	1.88	2.43	2.83	3.22	11
12	7087	2723	938	293	129	69.2	41.6	18.8	10.3	6.34	4.15	2.91	2.13	1.61	1.26		1.30	1.57	1.93	2.26	2.58	12
13	8657	3326	1146	358	158	84.5	50.7	23.0	12.6	7.75	5.07	3.56	2.60	1.98	1.53	1.22		1.21	1.49	1.74	1.98	13
14	10600	4070	1403	438	193	103	62.2	28.2	15.4	9.48	6.21	4.35	3.18	2.41	1.88	1.50	1.22		1.24	1.44	1.64	14
15	12824	4927	1698	530	234	125	75.3	34.1	18.7	11.5	7.52	5.27	3.85	2.92	2.27	1.81	1.48	1.21		1.17	1.35	15
16	14978	5758	1984	619	274	146	88.0	39.9	21.8	13.4	8.78	6.15	4.51	3.41	2.66	2.12	1.73	1.42	1.18		1.14	16
17	17537	6738	2322	724	320	171	103	46.6	25.6	15.7	10.3	7.20	5.27	3.99	3.11	2.47	2.03	1.66	1.37	1.17		
18	20327	7810	2691	840	371	198	119	54.1	29.6	18.2	11.9	8.35	6.11	4.63	3.60	2.87	2.35	1.92	1.59	1.36	1.16	
20	26676	10249	3532	1102	487	260	157	70.9	38.9	23.9	15.6	10.9	8.02	6.07	4.73	3.76	3.08	2.52	2.08	1.78	1.52	
24	42624	16376	5644	1761	778	416	250	113	62.1	38.2	25.0	17.5	12.8	9.70	7.55	6.01	4.92	4.02	3.32	2.84	2.43	
30	75453	28990	9990	3117	1378	736	443	201	110	67.6	44.2	31.0	22.7	17.2	13.4	10.7	8.72	7.14	5.88	5.03	4.30	
36	120100	46143	15902	4961	2193	1172	705	319	175	108	70.4	49.3	36.1	27.3	21.3	16.9	13.9	11.3	9.37	8.01	6.85	
42	177724	68282	23531	7341	3245	1734	1044	473	259	159	104	73.0	53.4	40.5	31.5	25.1	20.5	16.8	13.9	11.9	10.1	
48	249351	95818	33020	10301	4554	2434	1465	663	363	223	146	102	75.0	56.8	44.2	35.2	28.8	23.5	19.4	16.6	14.2	
Dia.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	

Actual internal diameters.

PROTECTION OF STEAM-HEATED SURFACES.

This table showing the losses of heat from a bare steam pipe, is the result of tests by Dr. C. E. Emery, made at the Massachusetts Institute of Technology.

Table of Loss of Heat from Steam Pipes.

Steam pressure, 75 lbs. Air, 60° F.

Thickness of Covering in Inches.	Outside Diameter of Pipe, without Felt.														
	2 in. diameter.			4 in. diameter.			6 in. diameter.			8 in. diameter.			12 in. diameter.		
	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in length per H. P. Lost.	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in Length per H. P. Lost.	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in Length per H. P. Lost.	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in Length per H. P. Lost.	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in Length per H. P. Lost.
0	219.0	1.00	152	390.8	1.00	86	624.1	1.000	53	729.8	1.000	46	1077.4	1.000	31
¼	100.7	.46	331	180.9	.46	182									
½	65.7	.30	507	117.2	.30	284	187.2	.300	177	219.6	.301	151	301.7	.280	114
1	43.8	.20	761	73.9	.18	451	111.0	.178	300	128.3	.176	259	185.3	.172	179
2	28.4	.13	1173	44.7	.11	745	66.2	.106	504	75.2	.103	443	98.0	.091	340
4	19.8	.09	1683	28.1	.07	1186	41.2	.066	808	46.0	.063	724	60.3	.056	553
6				23.4	.06	1424	33.7	.054	989	34.3	.047	972	45.2	.042	735

In a paper read before the A. S. M. E. in June, 1898, Prof. C. L. Norton of the Massachusetts Institute Technology, gave a series of tables showing the results of tests. For the sake of brevity the descriptions of the different materials are omitted. The tables follow:

Specimen.	Name.	B.T.U. Loss per Sq. Ft. Pipe Surfac per Min.	Ratio of Loss to Loss from Bare Pipe.	Thickness in Inches.	Weight in Oz. per Ft. of Length 4 In. Diam.
A . . .	Nonpareil Cork Standard .	2.20	15.9	1.00	27
B . . .	Nonpareil Cork Octagonal .	2.38	17.2	.80	16
C . . .	Manville High Pressure . .	2.38	17.2	1.25	54
D . . .	Magnesia	2.45	17.7	1.12	35
E . . .	Imperial Asbestos	2.49	18.0	1.12	45
F . . .	W. B.	2.62	18.9	1.12	59
G . . .	Asbestos Air Cell	2.77	20.0	1.12	35
H . . .	Manville Infusorial Earth .	2.80	20.2	1.50	. . .
I . . .	Manville Low Pressure . .	2.87	20.7	1.25	. . .
J . . .	Manville Magnesia Asbestos	2.88	20.8	1.50	65
K . . .	Magnabestos	2.91	21.0	1.12	48
L . . .	Molded Sectional	3.00	21.7	1.12	41
O . . .	Asbestos Fire Board . . .	3.33	24.1	1.12	35
P . . .	Calcite	3.61	26.1	1.12	66
	Bare Pipe	13.84	100.	. . .	. . .

Miscellaneous Substances.

Specimen.	B.T.U. per sq. ft. per min. at 200 lbs.	Specimens.	B.T.U. per sq. ft. per min. at 200 lbs.
Box A, 1 with sand	3.18	Pine wood 1 inch thick . .	3.56
2 with cork, powdered . .	1.75	Hair felt 1 inch thick . . .	2.51
3 with cork and infusorial earth	1.90	Cabot's seaweed quilt . . .	2.78
		Spruce 1 inch thick	3.40
4 with sawdust	2.15	Spruce 2 inches thick . .	2.31
5 with charcoal	2.00	Spruce 3 inches thick . . .	2.02
6 with ashes	2.46	Oak 1 inch thick	3.65
Brick wall 4 inches thick . .	5.18	Hard pine 1 inch thick . . .	3.72

Prof. R. C. Carpenter says that there is great difference in the flow of heat through a metal plate between different media. In discussing Professor Norton's paper he gave the values as shown in the following table as the result of experiments conducted in his laboratory.

Heat Transmitted in Thermal Units Through Clean Cast-Iron Plate $\frac{7}{16}$ Inch Thick. (Carpenter.)

Difference of Temperature. Degrees F.	Steam to Water.		Lard Oil to Water.		Air to Water.	
	Per Square Foot.		Per Square Foot.		Per Square Foot.	
	Per Deg per hour B. T. U	Total per minute B. T. U.	Per Deg. per hour B. T. U.	Total per minute B. T. U.	Per Deg. per hour B. T. U.	Total per minute B. T. U.
25	21	8.8	6.5	2.7	1.2	0.5
50	48	40	13	10.8	2.5	2.7
75	84	110	19.5	24.5	3.7	5.8
100	127	211	26	43.3	5.0	8.3
125	185	375	31.5	65.5	6.2	13
150	255	637	39	72.5	7.5	18.7
175			45.5	132	8.7	25.4
200			52	173	10	33
300			78	390	15	75
400					20	133
500					25	208

The above investigation indicates that the substance which surrenders the heat is of material importance, as is also the temperature of the surrounding media.

WROUGHT-IRON WELDED STEAM, GAS, AND WATER PIPE.

Table of Standard Dimensions.

Diameter.			Thickness.	Circumference.		Transverse Areas.			Length of Pipe per Square Foot of		Length of Pipe Containing one Cubic Foot.	Nominal Weight per Foot.	Number of Threads per Inch of Screw.
Nominal Internal.	Actual External.	Actual Internal.		External.	Internal.	External.	Internal.	Metal.	External Surface	Internal Surface			
Inches.	Inches.	Inches	Inches.	Inches.	Inches.	Sq. Ins.	Sq. Ins.	Sq. Ins.	Feet.	Feet.	Feet.	Pounds.	
⅛	.405	.27	.068	1.272	.848	.129	.0573	.0717	9.44	14.15	2513.	.241	27
¼	.54	.364	.088	1.696	1.144	.229	.1041	.1249	7.075	10.49	1383.3	.42	18
⅜	.675	.494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.73	751.2	.559	18
½	.84	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.13	472.4	.837	14
¾	1.05	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270.	1.115	14
1	1.315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.9	1.668	11½
1¼	1.66	1.38	.14	5.215	4.335	2.164	1.496	.668	2.301	2.768	96.25	2.244	11½
1½	1.9	1.611	.145	5.969	5.061	2.835	2.038	.797	2.01	2.371	70.66	2.678	11½
2	2.375	2.067	.154	7.461	6.494	4.43	3.356	1.074	1.608	1.848	42.91	3.609	11½
2½	2.875	2.468	.204	9.032	7.753	6.492	4.784	1.708	1.328	1.547	30.1	5.739	8
3	3.5	3.067	.217	10.996	9.636	9.621	7.388	2.243	1.091	1.245	19.5	7.536	8
3½	4.	3.548	.226	12.566	11.146	12.566	9.887	2.679	.955	1.077	14.57	9.001	8
4	4.5	4.026	.237	14.137	12.648	15.904	12.73	3.174	.849	.949	11.31	10.665	8
4½	5.	4.508	.246	15.708	14.162	19.635	15.961	3.674	.764	.848	9.02	12.34	8
5	5.563	5.045	.259	17.477	15.849	24.306	19.99	4.316	.687	.757	7.2	14.502	8
6	6.625	6.065	.28	20.813	19.054	34.472	28.888	5.584	.577	.63	4.98	18.762	8
7	7.625	7.023	.301	23.955	22.063	45.664	38.738	6.926	.501	.544	3.72	23.271	8
8	8.625	7.982	.322	27.096	25.076	58.426	50.04	8.386	.443	.478	2.88	28.177	8
9	9.625	8.937	.344	30.238	28.076	72.76	62.73	10.03	.397	.427	2.29	33.701	8
10	10.75	10.019	.366	33.772	31.477	90.763	78.839	11.924	.355	.382	1.82	40.065	8
11	12.	11.25	.375	37.699	35.343	113.098	99.402	13.696	.318	.339	1.456	45.95	8
12	12.75	12.	.375	40.055	37.7	127.677	113.098	14.579	.299	.319	1.27	48.985	8
13	14.	13.25	.375	43.982	41.626	153.938	137.887	16.051	.273	.288	1.04	53.921	8
14	15.	14.25	.375	47.124	44.768	176.715	159.485	17.23	.255	.268	.903	57.893	8
15	16.	15.25	.375	50.265	47.909	201.062	182.655	18.407	.239	.250	.788	61.77	8
. . .	18.	17.25	.375	56.549	54.192	254.47	233.706	20.764	.212	.221	.616	69.66	
. . .	20.	19.25	.375	62.832	60.476	314.16	291.04	23.12	.191	.198	.495	77.57	
. . .	22.	21.25	.375	69.115	66.759	380.134	354.657	25.477	.174	.179	.406	85.47	
. . .	24.	23.25	.375	75.398	73.042	452.39	424.558	27.832	.159	.164	.339	93.37	

WROUGHT-IRON WELDED EXTRA STRONG PIPE.

Table of Standard Dimensions.

Diameter.			Thickness.	Nearest Wire Gauge.	Circumference.		Transverse Areas.			Length of Pipe per Square Foot of		Nominal Weight per Foot.
Nominal Internal.	Actual External	Actual Internal.			External.	Internal.	External.	Internal.	Metal.	External Surface.	Internal Surface.	
Inches.	Inches.	Inches.	Inches.	No.	Inches.	Inches.	Sq. Ins.	Sq. Ins.	Sq. Ins.	Feet.	Feet.	Pounds.
1/8	.405	.205	.1	12½	1.272	.644	.129	.033	.086	9.433	18.632	.29
1/4	.54	.294	.123	11	1.696	.924	.229	.068	.161	7.075	12.986	.54
3/8	.675	.421	.127	10½	2.121	1.323	.358	.139	.219	5.657	9.07	.74
1/2	.84	.542	.149	9	2.639	1.703	.554	.231	.323	4.547	7.046	1.09
3/4	1.05	.736	.157	8½	3.299	2.312	.866	.452	.414	3.637	5.109	1.39
1	1.315	.951	.182	7	4.131	2.988	1.358	.71	.648	2.904	4.016	2.17
1¼	1.66	1.272	.194	6½	5.215	3.996	2.164	1.271	.893	2.301	3.003	3.
1½	1.9	1.494	.203	6	5.969	4.694	2.835	1.753	1.082	2.01	2.556	3.63
2	2.375	1.933	.221	5	7.461	6.073	4.43	2.935	1.495	1.608	1.975	5.02
2½	2.875	2.315	.28	2	9.032	7.273	6.492	4.209	2.283	1.328	1.649	7.67
3	3.5	2.892	.304	1	10.996	9.085	9.621	6.569	3.052	1.091	1.328	10.25
3½	4.	3.358	.321	0	12.566	10.549	12.566	8.856	3.71	.955	1.137	12.47
4	4.5	3.818	.341	0	14.137	11.995	15.904	11.449	4.455	.849	1.	14.97
5	5.563	4.813	.375	00	17.477	15.120	24.306	18.193	6.12	.687	.793	20.54
6	6.625	5.75	.437	000	20.813	18.064	34.472	25.967	8.505	.577	.664	28.58

Standard Sizes, etc., of Lap-Welded Charcoal-Iron Boiler-Tubes.

(Morris, Tasker & Company, Limited.)

External Diameter.	Internal Diameter.	Standard Thickness.	Internal Circumference.	External Circumference.	Internal Area.		External Area.		Length of Tube per Sq. Ft. of Inside Surface.	Length of Tube per Sq. Ft. of Outside Surface.	Length of Tube per Sq. Ft. of Mean Surface.	Weight per Lineal Foot.
Inches.	Inches.	Inches.	Inches.	Inches.	Sq. In.	Sq. Ft.	Sq. In.	Sq. Ft.	Feet.	Feet.	Feet.	Lbs.
1	.856	.072	2.689	3.142	.575	.004	.785	.0055	4.460	3.819	4.139	.708
1¼	1.106	.072	3.474	3.927	.960	.0067	1.227	.0085	3.455	3.056	3.255	.9
1½	1.334	.083	4.191	4.712	1.396	.0097	1.767	.0123	2.863	2.547	2.705	1.25
1¾	1.560	.095	4.901	5.498	1.911	.0133	2.405	.0167	2.448	2.183	2.315	1.665
2	1.804	.098	5.667	6.283	2.556	.0177	3.142	.0218	2.118	1.909	2.013	1.981
2¼	2.054	.098	6.484	7.069	3.314	.0230	3.976	.0276	1.850	1.698	1.774	2.238
2½	2.283	.109	7.172	7.854	4.094	.0284	4.909	.0341	1.673	1.528	1.600	2.755
2¾	2.533	.109	7.957	8.639	5.039	.035	5.940	.0412	1.508	1.390	1.449	3.045
3	2.783	.109	8.743	9.425	6.083	.0422	7.069	.0491	1.373	1.273	1.323	3.333
3¼	3.012	.119	9.462	10.210	7.125	.0495	8.296	.0576	1.268	1.175	1.221	3.958
3½	3.262	.119	10.248	10.995	8.357	.058	9.621	.0668	1.171	1.091	1.131	4.272
3¾	3.512	.119	11.033	11.781	9.687	.0673	11.045	.0767	1.088	1.018	1.053	4.590
4	3.741	.130	11.753	12.566	10.992	.0763	12.566	.0872	1.023	.955	.989	5.32
4½	4.241	.130	13.323	14.137	14.126	.0981	15.904	.1104	.901	.849	.875	6.01
5	4.720	.140	14.818	15.708	17.497	.1215	19.635	.1364	.809	.764	.786	7.226
6	5.699	.151	17.904	18.849	25.509	.1771	28.274	.1963	.670	.637	.653	9.346
7	6.657	.172	20.914	21.991	34.805	.2417	38.484	.2673	.574	.545	.560	12.435
8	7.636	.182	23.989	25.132	45.795	.318	50.265	.3490	.500	.478	.489	15.109
9	8.615	.193	27.055	28.274	58.291	.4048	63.617	.4418	.444	.424	.434	18.002
10	9.573	.214	30.074	31.416	71.975	.4998	78.540	.5454	.399	.382	.391	22.19
11	10.560	.22	33.175	34.557	87.479	.6075	95.033	.6601	.361	.347	.354	25.489
12	11.542	.229	36.26	37.699	103.749	.7205	113.097	.7854	.330	.318	.324	28.516
13	12.524	.238	39.345	40.840	123.187	.8554	132.732	.9213	.305	.293	.299	32.208
14	13.504	.248	42.414	43.982	143.189	.9943	153.938	1.069	.282	.272	.277	36.271
15	14.482	.259	45.496	47.124	164.718	1.1438	176.715	1.2272	.263	.254	.258	40.612
16	15.458	.271	48.562	50.265	187.667	1.3032	201.062	1.188	.247	.238	.242	45.199
17	16.432	.284	51.662	53.407	212.227	1.4738	226.980	1.5762	.232	.224	.228	49.902
18	17.416	.292	54.714	56.548	238.224	1.6543	254.469	1.7671	.219	.212	.215	54.816
19	18.400	.3	57.805	59.690	265.903	1.8465	283.529	1.969	.207	.200	.203	59.479
20	19.360	.32	60.821	62.832	294.373	2.0443	314.159	2.1817	.197	.190	.193	66.765
21	20.320	.34	63.837	65.973	324.311	2.2522	346.361	2.4053	.188	.181	.184	73.404

In estimating the effective steam-heating or boiler surface of tubes, the surface in contact with air or gases of combustion (whether internal or external to the tubes) is to be taken.

For heating liquids by steam, superheating steam, or transferring heat from one liquid or gas to another, the mean surface of the tubes is to be taken.

Collapsing Pressure in Cylindrical Boiler-Flues.

$P =$ collapsing pressure in pounds per square inch.
$t =$ thickness of iron plate in inches.
$L =$ length of tube or flue in feet.
$D =$ diameter of tube or flue in inches.

$$\text{Then } P = 806.300\,\frac{t^{2.19}}{LD} \quad \text{(Fairbairn.)}$$

Approximately $P = \frac{(kt)^2}{LD}$ in which k is a constant $= 790$ in $\frac{3}{16}$ inch plate; 800 in ¼ inch; 810 in $\frac{5}{16}$ inch; 820 in ⅜ inch; 830 in $\frac{7}{16}$ inch; 840 in ½ inch; 850 in $\frac{9}{16}$ inch; and 860 in ⅝ inch plate.

STANDARD PIPE FLANGES.

A. S. M. E. and Master Steam and Hot Water Fitters' Association standard, adopted July 18, 1894. Medium pressure includes pressures ranging below 75 pounds. High pressure ranges up to 200 pounds per square inch.

Pipe Size, Inches.	Pipe Thickness, $\frac{P+100}{4s}d + .333\left(1-\frac{d}{100}\right)$	Thickness, nearest Fraction, Inches.	Stress on Pipe per Square Inch @ 200 Lbs.	Radius of Fillet, Inches.	Flange Diameters, Inches.	Flange Thickness, Inches.	Width Flange Face, Inches.	Bolt Circle Diameter, Inches.	Number of Bolts.	Bolt Diameter, Inches.	Bolt Length, Inches.	Stress on each Bolt, per Square Inch, at Bottom of Thread @ 200 Lbs.
2	.409	$\frac{7}{16}$	460	⅛	6	⅝	2	4¾	4	⅝	2	825
2½	.429	$\frac{7}{16}$	550	⅛	7	$\frac{11}{16}$	2⅛	5¼	4	⅝	2¼	1050
3	.448	$\frac{7}{16}$	690	⅛	7½	¾	2¼	6	4	⅝	2½	1330
3½	.466	½	700	⅛	8½	$\frac{13}{16}$	2¼	6½	4	⅝	2½	2530
4	.486	½	800	⅛	9	$\frac{15}{16}$	2⅜	7¼	4	¾	2¾	2100
4½	.498	½	900	⅛	9¼	$\frac{15}{16}$	2⅜	7¾	8	¾	3	1430
5	.525	½	1000	⅛	10	$\frac{15}{16}$	2½	8½	8	¾	3	1630
6	.563	$\frac{9}{16}$	1060	⅛	11	1	2⅝	9⅝	8	¾	3	2360
7	.60	⅝	1120	⅛	12½	$1\frac{1}{16}$	2⅝	10¾	8	¾	3¼	3200
8	.639	⅝	1280	⅛	13½	1⅛	2¾	11¾	8	¾	3½	4190
9	.678	$\frac{11}{16}$	1310	$\frac{3}{16}$	15	1⅛	2⅞	13	12	¾	3½	3610
10	·713	¾	1330	$\frac{3}{16}$	16	$1\frac{3}{16}$	3	14¼	12	⅞	3⅝	2970
12	.79	$\frac{13}{16}$	1470	$\frac{3}{16}$	19	1¼	3¼	16½	12	⅞	3¾	4280
14	.864	⅞	1600	$\frac{3}{16}$	21	1⅜	3½	18¾	12	1	4¼	4280
15	.904	$\frac{15}{16}$	1600	$\frac{3}{16}$	22¼	1⅜	3⅝	20	16	1	4¼	3660
16	.946	1	1600	$\frac{3}{16}$	23½	$1\frac{7}{16}$	3¾	21¼	16	1	4¼	4210
18	1.02	$1\frac{1}{16}$	1690	$\frac{3}{16}$	25	$1\frac{9}{16}$	3½	22¾	16	1⅛	4¾	4540
20	1.09	1⅛	1780	$\frac{3}{16}$	27½	$1\frac{11}{16}$	3⅝	25	20	1⅛	5	4490
22	1.18	$1\frac{3}{16}$	1850	¼	29½	$1\frac{13}{16}$	3⅝	27¼	20	1¼	5½	4320
24	1.25	1¼	1920	¼	31½ 32	1¼ 1⅞	3¾ 4	29¼ 29½	20	1¼	5½	5130
26	1.30	$1\frac{5}{16}$	1980	¼	33¾ 34¼	1⅞ 2	3⅞ 4⅛	31¼ 31¾	24	1¼	5¾	5030
28	1.38	1⅜	2040	¼	36 36½	$1\frac{15}{16}$ $2\frac{1}{16}$	4 4¼	33½ 34	28	1¼	6	5000
30	1.48	1½	2000	¼	38 38¾	1½ 2⅛	4 4⅜	35½ 36	28	1⅜	6¼	4590
36	1.71	1¾	1920	¼	44½ 45¾	1¾ 2⅜	4¼ 4⅞	42 42¾	32	1⅜	6½	5790
42	1.87	2	2100	¼	51 52¾	1⅞ 2⅝	4½ 5⅜	48½ 49½	36	1½	7¼	5700
48	2.17	2¼	2130	¼	57½ 59½	2 2¾	4¾ 5¾	54¾ 56	44	1½	7¾	6090

NOTES. — Sizes up to 24 inches are designed for 200 lbs. or less.

Sizes from 24 to 48 inches are divided into two scales, one for 200 lbs., the other for less.

The sizes of bolts given are for high pressure. For medium pressures the diameters are ⅛ inch less for pipes 2 to 20 inches diameter inclusive, and ¼ inch less for larger sizes, except 48-inch pipe, for which the size of bolt is 1⅜ inches.

When two lines of figures occur under one heading, the single columns up to 24 inches are for both medium and high pressures. Beginning with 24 inches, the left-hand columns are for medium and the right-hand lines are for high pressures.

The sudden increase in diameters at 16 inches is due to the possible insertion of wrought-iron pipe, making with a nearly constant width of gasket a greater diameter desirable.

When wrought-iron pipe is used, if thinner flanges than those given are sufficient, it is proposed that bosses be used to bring the bolts up to the standard lengths. This avoids the use of a reinforcement around the pipe.

Figures in the third, fourth, fifth, and last columns refer only to pipe for 200 lbs. pressure.

In drilling valve flanges a vertical line parallel to the spindles should be midway between two holes on the upper side of the flanges.

STEAM ENGINES.

Steam engines are often classed according to the number of cylinders the steam passes in succession, and which are different in size,

Simple expansion,
Compound,
Triple,
Quadruple.

Any one of the above classes, if run non-condensing, is called low-pressure, or non-condensing; and if run with condenser is called high-pressure, or condensing.

Nowadays the above classes are made in two types: *high speed*, including all engines running above, say, 150 revolutions per minute; and *low speed*, all those running at less than 150 revolutions.

This division is scarcely correct, as some of the long-stroke engines running at 125 revolutions have more than 1000 feet piston speed, while few of the so-called *high speed* machines exceed 600 feet per minute piston speed.

In selecting an engine for electrical work it is necessary to see that the machine is extra heavy in all its parts; especially so for electric railway work, as the changes in load are often great and sudden, and in case of short circuit, engines are liable to be called on for tremendous increase in output, and should have no weak parts. This especially applies to fly-wheels, of which a large number have burst on the large, slow-running engines used in railway power-houses.

Bearings should all be of extra large size, especially so on the main shaft journals of large direct-connected units.

The selection of size (horse-power) depends largely upon the rating of the connected electrical machinery and the number of hours it runs, much being left to the judgment of the advising engineer. For direct-connected units it is not necessary to install an engine of greater rated capacity than the rated output of the generator, as the engine will easily care for overload on the generator if rated at ¼ cut-off, as is usual.

Some builders of engines rate their sizes for connections to dynamos so as to supply 1½ h. p per k.w. capacity of the dynamo.

The selection of condensing or high-pressure engines has in the past depended largely on availability of an adequate supply of water for condensing purposes; but to-day the cooling tower with water enough to fill a supply-tank once, and a regular supply for boiler-feed, is a very satisfactory arrangement.

Summary of Tests of Steam Engines of Various Types.

By Prof. R. C. Carpenter.

Style of Engine.	No. of Test.	H.P. of Engines.	Steam per I.H.P. per Hour.	Actual coal per I.H.P. per Hour.	Mean Observed I.H.P.	Per Cent Observed H.P. to Capacity.	Boiler Evap. per lb. Combus. B.& A. 212.	Kind of Coal.
Simple non-condensing slide valve.	6	200	34.8	4.47	110	55	11.50	Pea A.
	1	405	34.5	6.54	257	63.4	9.11	Culm
	7	1975	35.7	4.60	862	51.	9.46	Soft Pa.
	11	300	37.3	4.49	90	44.	12.20	" "
	11	300	34.3	4.72	95	46.7	10.20	" Ill.
	24	1000	31.8	5.38	717	71.7	9.15	"
	31	270	41.5	5.50	126	47.5	10.60	Hard, Buck
	33	270	31.6	4.61	147	54.5	10.70	" Pea
Average.			35.1	5.07		54.2	10.24	
Simple non-condensing Corliss.	17	300	30.1	3.09	139	46	11.45	Clearfield
	19	150	26.9	3.5	90	60	9.73	Hard, Buck
	22	350	28.	3.77	153	44.7	8.55	Soft, Ohio
Average.			28.3	3.45		50.3		
Compound non-condensing.	2	1000	30.5	4.22	603.5	60.3	9.03	1 Soft, 3 Hard
	4	1250	36.8	4.33	674	53.8	9.92	Culm and slack
	21	400	34.20	4.17	203	51.	10.23	Soft, Pa.
	24	1200	30.37	4.93	754	62.7	9.01	" Ill.
Average of.			32.28	4.55				
Compound condensing high-speed automatic.	*3a*	600	29.4	4.43	174	29	10.38	1 Soft, 3 hard
	3	600	23.2	3.50	190	32	9.93	" "
	8	400	20.2	3.14	154	38	8.29	Soft, Ohio
	8*b*	400	16.7	2.40	180	45	7.75	" "
	13	250	24.6	2.95	86	34.5	10.51	" Pa.
	16	350	22.7	3.41	164	47	9.50	Hard pea
	18	1200	25.6	3.61	904	75	10.58	" "
	21	400	29.3	3.81	188	47	10.23	Soft
Average.			23.96	3.41			9.64	
Compound condensing Corliss, Greene, McIntosh & Seymour, etc., etc.	10	825	22.7	4.06	482	58.2	8.29	Culm & Slack
	14	1000	21.9	2.56	277	27.7	10.96	" "
	14	1000	20.		314	31.4	10.96	" "
	28	350	16.64	2.10	182	52.2	11.80	Soft
	27	500	16.90	2.61	290	58.	9.36	"
	30	2000	14.5	1.80	814	40.7	10.7	"
	34	200	17.3	2.91	145	72.	11.14	‘
	35	1600	20.5	2.18			11.14	"
Average.			18.8	2.60			10.54	

Horse-power of Steam Engines.

Nominal Horse-power. — Now very little used.

D = dia. cyl. in inches.
A = area of piston in sq. inches.
L = length of stroke in feet.

$$\text{Watt gives, nominal H.P.} = \frac{D^2L}{47}.$$

$$\text{Boulton \& Watt, nominal H.P.} = \frac{D^2}{28}.$$

Kent gives as handy rule for estimating the h.p. of a single cylinder engine, $\frac{D^2}{2}$. This rule is correct when the product of the m.e.p. and piston speed = 21,000.

The above rule also applies to compound triple and quadruple engines, and is referred to the diameter of the low-pressure cylinder, and the h.p. of such an engine then becomes

$$\frac{(\text{dia. low-pres. cyl.})^2}{2} = \text{H.P. (roughly.)}$$

Indicated Horse Power: I.H.P. — The power developed in the cylinder of a steam engine is correctly determined only by use of the indicator, and comparisons and steam consumption are always calculated on that basis.

M.E.P. = mean pressure in pounds per square inch, as shown by the indicator card.
L = stroke of piston in feet.
n = number of revolutions per min.
a = effective area of head side of piston.
$a_{\prime}$ = effective area of crank side of piston.

$$\text{I.H.P.} = \frac{[(a \times \text{m.e.p.}) + (a_{\prime} \times \text{m.e.p.})] \times Ln}{33{,}000}.$$

For multiple cylinder engines, compute I.H.P. for each cylinder, and add results together for total power.

Brake Horse-power. — The brake horse-power (B.H.P.) of an engine is the actual or available horse-power at the engine pulley; at any given speed and given brake-load, the B.H.P is less than the corresponding I.H.P. by the horse-power required to drive the engine itself at the given speed, and with the pressures at the bearings, guides, etc., corresponding to the given brake-load.

If W = load in lbs. on brake lever or rope,
f = distance in feet of center of brake-wheel from line of action of brake-load,
N = revolutions per minute;

then $\text{B.H.P.} = \frac{WfN}{5252.1}$.

The mechanical efficiency of any given engine is less the greater the expansion ratio employed, and of two engines of the same type, developing the same power at the same speed, that which uses the higher degree of expansion will have the lower mechanical efficiency. The effect of this, though not usually important, is to make the best ratio of expansion in any given case somewhat less than that which makes the steam consumption per I.H.P.-hour a minimum.

The mechanical efficiencies on full load of modern engines range from 80 to 95 per cent. Large engines have, of course, higher mechanical efficiencies than small ones (a very small engine may have as low a mechanical efficiency as 40 to 50 per cent, but this is generally due to bad design and insufficient care being taken of the engine), simple than compound engines, and compound than triple engines — at any rate when not very large.

Prof. Thurston estimates that the total mechanical loss in non-condensing engines having balanced valves may be apportioned as follows: — main bearings 40 to 47 per cent, pistons and rods 33 per cent, crank-pins $5\frac{1}{2}$ per cent slide-valves and rolls $2\frac{1}{2}$ per cent, and eccentric straps 5 per cent. An unbalanced slide-valve may absorb 26 per cent, and in a condensing engine the air-pump 12 % of the total mechanical loss.

Cylinder Ratios in Compound Engines.

The object of building multiple cylinder engines is,
a, to use high steam pressure,
b, to get the greatest number of expansions from the steam,
c, to reduce the cylinder condensation.

Prof. Thurston says: "Maximum expansion, as nearly adiabatic as practicable, is the secret of maximum efficiency."

Although the theory of determining the sizes of cylinders is perfectly understood, yet there are so many causes for varying the results that practically to-day but little attention is given to calculations, the plan being to use dimensions such as have proved best practice in the past.

The proportions of cylinders are supposed to be such as to equally divide the number of expansions and work among them, and these dimensions have to be varied somewhat to meet the experience of the engineer.

Given the initial pressure (absolute) $i.P.$ and the terminal pressure (absolute) $t.P.$, then the total number of expansions is $E = \frac{i.P.}{t.P.}$, and the number of expansions for each cylinder is as follows:

For compound $\sqrt{E}$,
For triple expansion $\sqrt[3]{E}$,
For quadruple expansion $\sqrt[4]{E}$.

Better results are often obtained by cutting off a trifle earlier in the high-pressure cylinder; and this fact, in connection with the extent of reheaters and receivers, changes the actual ratios from the ideal to the practical ones shown in the following table:

Number of Expansions for Condensing Engines.

Type.	$i.P.$ Absolute.	Total Expansions.	Expansions in Each Cylinder. 1st.	2d.	3d.	4th.
Single cylinder	65	7	7.	—	—	—
Compound	145	22	4.8	4.6	—	—
Triple compound . . .	185	30	3.2	3.1	3.0	—
Quadruple compound .	265	48	2.7	2.65	2.6	2.55

For triple engines, Jay M. Whitham* recommends the following relative sizes of cylinders when the piston-speed is from 750 to 1,000 ft. per minute:

Boiler Pressure (above Atmosphere).	High-Pressure Cylinder.	Intermediate Cylinder.	Low-Pressure Cylinder.
130	1	2.25	5.00
140	1	2.40	5.85
150	1	2.55	6.90
160	1	2.70	7.25

The following are the maximum, average, and minimum values of the relative cylinder volumes of triple-expansion condensing engines, working with boiler pressures of 150 or 160 lbs. per square inch above atmosphere, on board 65 boats launched within the last three or four years: —

——	High-Pressure Cylinder.	Intermediate Cylinder.	Low-Pressure Cylinder.
Maximum value	1	2.84	7.56
Average "	1	2.58	6.71
Minimum "	1	1.89	4.59

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* *American Society of Mechanical Engineers, 1889.*

Table Showing Mean Effective Pressure Per Pound Absolute Initial Pressure.

	Apparent Ratio of Expansion	$\frac{1}{10}$ or .1	$\frac{2}{19}$ or .105	$\frac{1}{9}$ or .111	$\frac{2}{17}$ or .118	$\frac{1}{8}$ or .125	$\frac{2}{15}$ or .133	$\frac{1}{7}$ or .143	$\frac{2}{13}$ or .154	$\frac{1}{6}$ or .167	$\frac{2}{11}$ or .182	$\frac{1}{5}$ or .2	$\frac{2}{9}$ or .222	$\frac{1}{4}$ or .25	$\frac{3}{10}$ or .3	$\frac{1}{3}$ or .333	$\frac{3}{8}$ or .375	$\frac{2}{5}$ or .4	$\frac{1}{2}$ or .5	$\frac{3}{5}$ or .6	$\frac{5}{8}$ or .625	$\frac{2}{3}$ or .667	$\frac{7}{10}$ or .7	$\frac{3}{4}$ or .75
	Cut off at	10	9.5	9	8.5	8	7.5	7	6.5	6	5.5	5	4.5	4	3.33	3	2.67	2.5	2	1.67	1.6	1.5	1.43	1.33
Clearance	0	.330	.342	.355	.369	.385	.402	.421	.442	.465	.492	.522	.556	.596	.661	.699	.743	.766	.846	.906	.919	.937	.949	.966
	1	.344	.355	.368	.382	.397	.413	.432	.452	.475	.501	.530	.564	.603	.666	.704	.747	.770	.849	.909	.920	.937	.949	.966
	2	.357	.367	.379	.394	.408	.424	.442	.462	.484	.509	.538	.571	.609	.671	.708	.750	.773	.851	.911	.921	.936	.952	.964
	3	.369	.379	.391	.405	.419	.434	.452	.471	.493	.517	.545	.577	.615	.676	.712	.753	.776	.853	.913	.922	.940	.951	.966
	4	.381	.392	.402	.416	.429	.443	.461	.480	.502	.525	.552	.583	.621	.681	.716	.756	.779	.855	.914	.923	.939	.954	.969
	5	.392	.402	.413	.426	.439	.452	.470	.489	.510	.532	.559	.589	.626	.685	.720	.759	.782	.857	.914	.925	.938	.952	.966
	6	.403	.412	.423	.436	.448	.461	.479	.497	.517	.539	.566	.595	.631	.689	.724	.762	.785	.859	.914	.925	.941	.950	.970
	7	.413	.422	.433	.445	.457	.470	.487	.505	.524	.546	.572	.601	.636	.693	.728	.765	.787	.861	.915	.925	.941	.953	.966
	8	.423	.431	.442	.454	.466	.478	.495	.512	.531	.553	.578	.607	.641	.697	.731	.768	.789	.862	.915	.926	.944	.951	.969
	9	.432	.440	.451	.463	.474	.486	.503	.519	.538	.560	.584	.613	.646	.701	.734	.770	.791	.863	.916	.924	.943	.954	.970
	10	.441	.449	.460	.471	.482	.494	.510	.526	.545	.566	.590	.618	.651	.704	.737	.772	.793	.864	.916	.929	.941	.957	.966
	11	.450	.458	.469	.479	.490	.502	.517	.533	.552	.572	.595	.623	.655	.707	.740	.774	.795	.865	.917	.929	.946	.955	.969
	12	.458	.466	.476	.487	.497	.509	.524	.540	.559	.578	.600	.627	.659	.710	.743	.776	.797	.866	.920	.927	.943	.958	.971
	13	.466	.474	.483	.494	.504	.516	.531	.547	.565	.584	.605	.631	.663	.713	.746	.778	.799	.867	.920	.931	.946	.955	.967
	14	.474	.482	.490	.501	.511	.523	.538	.553	.570	.589	.610	.635	.667	.716	.749	.780	.801	.868	.921	.930	.944	.957	.970
	15	.482	.489	.497	.508	.518	.529	.544	.559	.574	.594	.615	.639	.671	.719	.752	.781	.803	.869	.919	.929	.947	.955	.972

Receiver Capacity. — In compound engines with cranks at right angles the receiver capacity should be from 1 to 1.5 times that of the high-pressure cylinder (Seaton), or not less than the capacity of the low-pressure cylinder ("Practical Engineer"). When the cranks are opposite, the receiver capacity need not exceed that of the steam passage from the high-pressure to the low-pressure cylinder. The general effect of large receiver capacity is to cause a drop between the pressure at the end of the high-pressure expansion stroke and the beginning of the high-pressure exhaust stroke and low-pressure admission, thus increasing the power developed in the high-pressure, and decreasing the power developed in the low-pressure cylinder; this leads to a loss of power in the engine, and one which — at any rate in engines with cranks at right angles — is greater the more the receiver capacity exceeds that necessary for free passage of the steam.

Steam Ports and Passages. — The areas of these should be such that the mean linear velocity of the steam does not exceed 5,000 to 6,000 feet per minute; hence, if

$D =$ diameter of cylinder in inches,
$A =$ area of cylinder in square inches,
$a =$ area of port or passage in square inches,
$S =$ piston-speed in feet per minute;

$$a = \frac{AS}{6{,}000} = \frac{E^2S}{7{,}640}$$

for mean velocity of steam 6,000 feet per minute;

$$a = \frac{AS}{5{,}000} = \frac{D^2S}{6{,}370}$$

for mean velocity of steam 5,000 feet per minute.

The lengths of the steam passages between the cylinders and valves should be as small as possible, in order to minimize clearance and resistance to flow of steam.

Condensers and Pumps.

Condensers are principally of two types, viz., Jet Condensers, in which the steam and condensing water mix in a common vessel, from which both are pumped by the air-pump; and Surface Condensers, in which the steam generally passes into a chamber containing a number of brass tubes, through which the condensing water is made to circulate. The latter form is usually adopted where water is bad, as it enables the same feed-water to be passed through the boiler over and over again.

The capacity of a jet condenser should not be less than one-fourth of the low-pressure cylinder, but need not exceed one-half, unless the engines are very quick running; one-third is a good average ratio. Large condensers require more time for forming the vacuum, while small condensers are liable to flood and overflow back to the cylinders. The amount of condensing water required per pound of steam condensed varies with the temperature of the exhaust, of the "hot-well," and of the condensing water. (The "hot-well" is the receptacle into which the air-pump delivers the water from the condenser.) The feed-water is obtained from the "hot-well," which should be maintained at 110° to 120° F. Sometimes even 130° F. can be obtained with care.

The amount of cooling or tube surface depends upon the difference between the temperature of the exhaust steam and the average temperature of the cooling water, and on the thermal conductivity and thickness of the metal tubes. For copper and brass tubes in good condition the rate of transmission is about 1,000 units (equivalent to about 1 lb. of steam condensed) per square foot per 1° F. difference of temperature per hour. With the hot-well at 110° and the cooling water at 60°, the average difference is 25°, and 25 lbs. of steam should be condensed per hour per square foot. In practice allowance must be made for the working conditions of the tubes, and half the above, *i.e.*, $\frac{1}{2}$ lb. of steam per 1° F. difference is nearer the usual allowance; and under the above conditions about 12.5 lbs. of steam would be condensed per square foot per hour, which is considered very fair work.

The tubes are generally of brass, No. 18 S.W.G. thick, and from $\frac{1}{2}$ to 1 in. diameter, according to the length of the tubes; they are usually $\frac{3}{4}$ in. in diameter, and spaced at a pitch of 1¼ in., while the tube-plates, which are also of brass, are 1⅛ to 1¼ in. thick for ¾ in tubes. The length of the tubes, when unsupported between plates, should not exceed 120 diameters.

If $H =$ total heat of 1 lb. of exhaust steam in B. T.U.,
$t =$ temperature F.° of hot-well,
$t_1 =$ temperature F.° of cooling water on entering,
$t_2 =$ temperature F.° of cooling water on leaving,
$Q_1 =$ quantity in lbs. of cooling water per lb. of steam for jet condenser,
$Q_2 =$ ditto for surface condenser;

$$Q_1 = \frac{H - t}{t - t_1},$$

$$t = \frac{H + Q_1 t_1}{1 + Q_1} \text{ for jet condenser,}$$

$$Q_2 = \frac{H - t}{t_2 - t_1},$$

$$t = H - Q_2 (t_2 - t_1), \text{ for surface condensers.}$$

N.B. $H - t = 1{,}050$ approximately.

Values of Q_1 and Q_2 for different temperatures of cooling water, when $H = 1150$, $t = 110$, and $t_2 = 100$ in case of Q_2:—

	Values of t_1.				
	40	50	60	70	80
Q_1	15	17	21	26	35
Q_2	17	21	26	35	52

Area of injection orifice should be such as to allow a velocity of flow of water not exceeding 1,500 feet per minute. It is better to have a large orifice and to control the flow of water by an injection valve.

Area of orifice in square inches.
= lbs. water per minute ÷ 650 to 750.
= area of piston ÷ 250.

The cooling or circulating water in surface condensers should travel some 20 ft. lineally through the tubes. In small condensers, where this is not convenient, and the water only circulates twice through short tubes, the rate of flow must be reduced.

A replenishing cock should be fitted to allow of the passage of part of the circulating water into the air-pump suction to provide for water lost in drains, blowing off, leakage, etc. This may have one-tenth the area of the feed-pipe.

A cock should be fitted close to the exhaust inlet for introducing caustic soda when required to dissolve grease off the tubes.

Assume your engine to require 20 pounds of steam per horse-power per hour, or one-third of a pound per minute, and to exhaust at atmospheric pressure. One pound of steam at atmospheric pressure contains 1146.1 heat units above 32°. One pound of water at this temperature contains approximately 120 — 32 = 88 heat units above 32°, so that to change a pound of steam at atmospheric pressure into water at 120°, we should have to take from it 1146.1 — 88 = 1058.1 heat units, and for one-third of a pound, 1058.1 ÷ 3 = 352.7 heat units. Suppose the injection water to be 60°. In heating to 120° each pound will absorb approximately 60 heat units, so that it would take 352.7 ÷ 60 = 5.88 pounds of injection water per minute per horse-power under the assumed conditions. A higher terminal pressure, higher temperature of injection, less efficiency in the engine, or lower hot-well temperature, will increase this figure.

In order to cover all conditions, makers and dealers figure that a condenser should be able to supply from a gallon to a gallon and a half of injection water per minute for each indicated horse-power developed. The capacity of a single-acting vertical air-pump should be from one-tenth to one-twelfth that of the cylinder; of a double-acting horizontal pump, from one-sixteenth to one-nineteenth.

Ejector Condensers are made on the principle of steam injectors except that the action is reversed, the cooling water taking the place of the steam in the injector, and the exhaust steam that of the feed-water. In order to ensure their successful working, the cooling water should be supplied at a head of 15 feet to 25 feet, either from a tank above or from a centrifugal or other pump. The amount of cooling water required is about the same as for jet condensing; the vacuum is from 20 in. to 25 in.

Air-pumps are used to draw the condensed water from the condenser to the hot-well, together with the air originally contained in the water, or which may find its way in through glands, etc., and with jet condensers they also draw the cooling water. A cubic foot of ordinary water contains about .05 cubic foot of air at atmospheric pressure, which expands in the condenser to about .4 cubic foot of air; hence the term air-pump.

The efficiency of a single-acting air-pump may be taken at .6 to .4, and generally .5, while that of the double-acting pump may be .5 to .3, say .4 on average. For jet condensing, the volume of the air-pump should be theoretically 1.4 times the volume of condensed + cooling water; for good working it should be from twice to thrice that required by theory. Or if

v = volume of condensed water per minute in cubic feet,
V = volume of cooling water per minute in cubic feet,
n = number of strokes (useful) of air-pump per minute,
A = volume of air-pump in cubic feet;

$$A = 2.8\,\frac{v+V}{n} \text{ for single-acting pumps,}$$

$$= 3.5\,\frac{v+V}{n} \text{ for double-acting pumps.}$$

Since, for surface condensing, the air-pump does not draw the cooling water, and as the feed-water, being used over again, should not contain so much air, it would appear that the air-pump might be much smaller than for jet condensing. However, surface condensers are frequently arranged for use as jet condensers in case of mishap, and with surface condensing a better vacuum is expected, so that for surface condensing the air-pump is only slightly less than for jet condensing. In actual practice the air-pump is made from one-tenth to one-twenty-fifth the capacity of the low-pressure cylinder, according to the number of expansions and nature of condenser, while a comparison of a number of marine engines by different makers shows a ratio of one-sixteenth to one twenty-first.

If expansion joints are used in the exhaust pipe, a copper bellows joint is better than the ordinary gland and stuffing-box type, through which air is apt to leak.

Air-pump valves should have sufficient area that the full quantity of cooling and condensed water in jet condensation in passing does not exceed a velocity of 400 feet per minute; in practice the area is larger than this. A large number of small valves is perhaps better than one or two large valves which are sluggish, owing to their inertia. The clearance space between head and foot valves should not exceed one-fifteenth the capacity of the pump as ordinarily constructed.

If a = area through foot valves in square inches,
a_1 = area through head valves in square inches,
d = diameter of discharge pipe in inches,
D = diameter of the air-pump in inches,
S = speed (useful) in feet per minute;

$$a = \frac{1}{1{,}000}\,D^2S.$$

$$a_1 = \frac{1}{800}\,D^2S.$$

$$d = \frac{1}{35}\,D\sqrt{S}.$$

If there be no air vessel or receiver, d should be 10 per cent larger.

An air-pipe should be fitted to the hot-well one-fourth the diameter of the discharge pipe.

Circulating Pumps. — The size of these depend chiefly on conditions mentioned for air-pumps, and they may bear a constant relation to the air-pump as to size, or to the L.P. cylinders.

Air-pump.	*Circulating Pump.*	*Ratio.*
Single acting	Single acting	.6
Single acting	Double acting	.31
Double acting	Double acting	.52

or if $V =$ volume of cooling water in cubic feet per minute,
$S =$ length of stroke in feet,
$n =$ number of strokes (useful) per minute,
$C =$ capacity of pump in cubic feet,
$D =$ diameter of pump in inches;

$$C = \frac{V}{n},$$

$$D = 13.55 \sqrt{\frac{V}{nS}}.$$

Circulating pump valves should be of sufficient area that the mean velocity of flow does not exceed 3 or 4 feet per sec. High velocities tend to wear out the valves, and cause undue resistance in the pump. In the suction and delivery pipes the velocity should not exceed 500 feet per minute, or for large and easy leads 600 feet per minute. Better results, however, will be obtained by using larger pipes, so as to reduce the velocity, especially if the pipes are long. For single-acting pumps the suction may be smaller than the delivery, if the pump be below the water-level.

If $a =$ minimum area through valves in square inches,
$d =$ minimum diameter of pipe in inches,
$A =$ area of pump in square inches,
$D =$ diameter of pump in inches,
$S =$ mean speed (useful) of pump in feet per minute;

$$a = \frac{AS}{180},$$

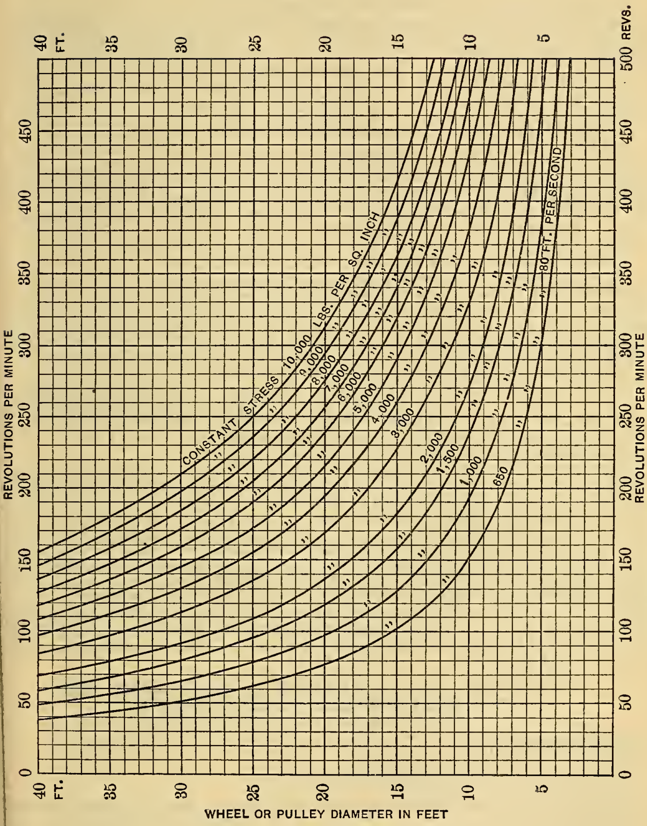
$$d = \frac{D\sqrt{S}}{K},$$

where K varies from 22 for small pumps to 25 for large pumps, while for the suction of single-acting pumps it may be 27.

Air chambers should always be fitted, which for single-acting pumps may be twice the capacity of the pump. An air-pipe should be fitted to the highest points of the water passages for escape of air to enable the condenser and pipes to run full. If the speed of the circulating pump cannot be varied independently, it is advisable to fit a water valve between the two ends of the pump, so that the discharge may be varied to suit the requirements.

Strainers should be fitted to the inlet of the suction pipe, and the aggregate area of the passages should be from two to four times the area of the pipe, according to the velocity of flow in the pipe. Owing to difficulty experienced in cleaning strainers when under water, they are sometimes fixed in a cast-iron vessel near the suction entrances to the pump, with a door arranged in some convenient position for cleaning.

Foot Valve. — When the water level is below that of the pump, a foot valve should be fitted just above the surface of the water. A door should be provided for examining the valve without disturbing the suction pipe. Or an air ejector may be used to charge the pump.



CENTRIFUGAL TENSION IN FLY-WHEELS AND PULLEYS

FIG. 12

WATER-POWER.

In determining the feasibility of utilizing water-power to operate electrically the industries of any particular town or city, careful consideration must be given to the following points, viz.: 1. The amount of water-power permanently available. 2. The cost of developing this power. 3. The interest on this amount. 4. The total demand for power. 5. The amounts and relative locations of the various kinds of power. 6. The cost of steam plants now in operation. 7. The interest on this amount. 8. Cost of fuel for plants now in operation. 9. Cost of operating present plants. Labor. 10. Cost of maintenance of present plants. 11. The amounts and kinds of electric power already in operation. 12. The distance of transmission. 13. The estimated cost of the hydraulic machinery. 14. The guaranteed efficiency and regulation of the hydraulic machinery. 15. Estimated cost of electric machinery. 16. Estimated cost of line construction. 17. Total cost of operating hydraulic and electric machinery. 18. Total cost of maintenance of hydraulic and electric plants. 19. The interest on the total estimated cost of proposed plant. 20. The estimated gross income.

Charles T. Main makes the following general statements as to the value of a water-power: "The value of an undeveloped variable power is usually nothing if its variation is great, unless it is to be supplemented by a steam-plant. It is of value then only when the cost per horse-power for the double-plant is less than the cost of steam-power under the same conditions as mentioned for a permanent power, and its value can be represented in the same manner as the value of a permanent power has been represented.

"The value of a developed power is as follows: If the power can be run cheaper than steam, the value is that of the power, plus the cost of plant, less depreciation. If it cannot be run as cheaply as steam, considering its cost, etc., the value of the power itself is nothing, but the value of the plant is such as could be paid for it new, which would bring the total cost of running down to the cost of steam-power, less depreciation."

Mr. Samuel Webber, *Iron Age*, Feb. and March, 1893, criticises the statements of Mr. Main and others who have made comparisons of costs of steam and of water-power unfavorable to the latter. He says: "They have based their calculations on the cost of steam, on large compound engines of 1000 or more h. p. and 120 pounds pressure of steam in their boilers, and by careful 10-hour trials succeeded in figuring down steam to a cost of about $20 per h. p., ignoring the well-known fact that its average cost in practical use, except near the coal mines, is from $40 to $50. In many instances dams, canals, and modern turbines can be all completed at a cost of $100 per h. p.; and the interest on that, and the cost of attendance and oil, will bring water-power up to but about $10 or $12 per annum; and with a man competent to attend the dynamo in attendance, it can probably be safely estimated at not over $15 per h. p.

SYNOPSIS OF REPORT REQUIRED ON WATER-POWER PROPERTY.

Location.

Geographical, etc.
Sketch of river and its tributaries.
Surrounding country and physical features.
Sources; lakes, springs, etc.
Water's head; area drained, nature of, whether forest, swamp, snow-covered mountains, etc.
Elevation of head waters and of mouth.
Length from main source to mouth.
Accessibility; how and by what routes.

Reports.

Reports of U. S. Coast or Geological Survey.
Reports of Engineers U. S. Army.
Any other reports.
Any estimate by engineers and for what purpose.
When it first attracted attention and for what reason.
History.

Rainfall.

Average for several years for the drainage area. Maximum, what month. Minimum, what month. Comparison with other similar localities.

Volume of Water.

Gauging of river if possible. Reports by other engineers.

Cubic feet per second flow.

Cubic feet per second per mile of watershed = say .2 to .3 of total rainfall and $\frac{1}{5}$ available as water-power.

Comparison with other rivers.

Reservoirs.

Possibility of storing water for dry time.

Available Fall.

Location of; accessibility, by what routes.

Can power be used locally, or would it be necessary to transmit it, and if so, where to, and distances? Nature of country over which it would have to be carried.

Volume of water in cubic feet per second.

Horse-Power of River.

Calculated from available fall and volume.

Horse-power for each fall or dam.

Location of dams, dimensions, length, and height, best method of construction, estimated cost.

Backwater; volume, and how far; what interests disturbed by it; benefits, if any.

Compare power with that of similar rivers.

Probable cost of power at dams and transmitted.

Applications Possible.

Near by; at distance, stating when and for what. Note industries applicable to; comparison with other applications.

New Industries Suggested,

and old industries already going to which power is applicable.

Cost to these, and comparison with cost of other forms of power already in use.

Property of the Company.

Land, buildings, water rights, flowage rights, franchises, lines, rights of way. Character of deeds. Probable value.

Comparison with other similar properties.

Other resources.

Liabilities.

Stocks, bonds, floating debt, other.

Earning Capacity.

Probable cost of power per h. p. at power-house.

Probable cost of power per h. p. delivered or transmitted.

Price for which it can be sold at power-house, and price transmitted or delivered.

General Features.

Surrounding country, its characteristics, people, cities, and towns, industries, condition of finances.

Facilities for transportation, water and rail.

Nearness of sources of supplies and sales of products.

Horse-Power of a Waterfall.

The horse-power of a waterfall is expressed in the following formula:

$Q =$ quantity of water in cubic feet flowing over the fall in 1 minute.

$H =$ total head in feet, i.e., the distance between the surface of the water at the top of the fall, and that at its foot. In a water-power the head is the distance between the surface of the water in the head-race, and that of the water in the tail-race.

w = weight of water per cubic foot = 62.36 lbs. at 60° F.

$$\text{Gross horse-power of waterfall} = \frac{Q \times H \times w}{33000} \text{ or } .00189\ QH.$$

Loss of head at the entrance to and exit from a water-wheel, together with the friction of the water passing through, reduces the power that can be developed to about 70 per cent of the gross power of the fall.

Horse-Power of a Running Stream.

The power is calculated by the same formula as for a fall, but in this case H = theoretical head due to the velocity of the water in the stream = $\frac{v^2}{64.4}$ where

v = velocity of water in feet per second.
Q = the cubic feet of water actually impinging against the bucket per minute.

$$\text{Gross horse-power} = .00189\ QH.$$

Wheels for use in the current of a stream realize only about .4 of the gross theoretical power.

Current motors are often developed to operate in strong currents, such as that of the Niagara River opposite Buffalo, but are of little use excepting for small powers. Such a small fraction of the current velocity can be made use of that a current motor is extremely inefficient. In order to realize power from a current it is necessary to reduce its velocity in taking the power, and to get the full power would necessitate the backing up of the whole stream until the actual head equaled the theoretical.

Power of Water Flowing in a Pipe.

$$H \text{ due to velocity} = \frac{v^2}{2g} = \frac{v^2}{64.4} \text{ where } v = \text{velocity in feet per second.}$$

$$H_1 \text{ due to pressure} = \frac{f}{w}, \text{ where } f = \text{pressure in lbs. per square foot.}$$

and w = 62.36 lbs. = weight 1 cubic foot of water.
H_2 distance above datum line in feet.

$$\text{Total } H = \frac{v^2}{2g} + \frac{f}{w} + H_2.$$

In hydraulic transmission the work or energy of a given quantity of water under pressure is the volume in cubic feet × lbs. pressure per square foot.

Q = cubic feet per second.
P = pressure in lbs. per square inch.

$$\text{Horse-power} = \frac{144\ PQ}{550} = .2618\ PQ.$$

Mill-Power.

It has been customary in the past to lease water-power in units larger than the horse-power, and the term *mill-power* has been used to designate the unit. The term has no uniform value, but is different in all localities.

Emerson gives the following values for the seven more important water-power.

Holyoke, Mass. — Each mill-power at the respective falls is declared to have the right during 16 hours in a day to draw 38 cubic feet of water per second at the upper fall when the head there is 20 feet, or a quantity proportionate to the height at the falls. This is equal to 86.2 horse-power as a maximum.

Lowell, Mass. — The right to draw during 15 hours in the day so much water as shall give a power equal to 25 cubic feet a second at the great fall, when the fall there is 30 feet. Equal to 85 h. p. maximum.

Lawrence, Mass. — The right to draw during 16 hours in a day so much water as shall give a horse-power equal to 30 cubic feet per second when the head is 25 feet. Equal to 85 h. p. maximum.

Minneapolis, Minn. — 30 cubic feet of water per second with head of 22 feet. Equal to 74.8 h. p.

Manchester, N. H.—Divide 725 by the number of feet of fall minus 1, and the quotient will be the number of cubic feet per second in that fall. For 20 feet fall this equals 38.1 cubic feet, equal to 86.4 h. p. maximum.

Cohoes, N. Y.—"Mill-power" equivalent to the power given by 6 cubic feet per second, when the fall is 20 feet. Equal to 13.6 h. p. maximum.

Passaic, N. J.—Mill-power: The right to draw 8½ cubic feet of water per second, fall of 22 feet, equal to 21.2 horse-power. Maximum rental, $700 per year for each mill-power = $33.00 per h. p.

The horse-power maximum above given is that due theoretically to the weight of water and the height of the fall, assuming the water-wheel to have perfect efficiency. It should be multiplied by the efficiency of the wheel, say 75 per cent for good turbines, to obtain the h.p. delivered by the wheel.

At Niagara power has in all cases been sold by the horse-power delivered to the wheels if of water, and to the building-line if electrical.

Charges for water in Manchester, Lowell, and Lawrence, are as follows:

Manchester.
About $300 per year per mill-power for original purchases.
$2 per day per mill-power for surplus.

Lowell.
About $300 per year per mill-power for original purchases.
$2 per day per mill-power during "back-water."
$4 per day per mill-power for surplus under 40 per cent.
$10 per day per mill-power for surplus over 40 per cent and under 50 per cent.
$20 per day per mill-power for surplus over 50 per cent.
$75 per day per mill-power for any excess over limitation.

Lawrence.
About $300 per year per mill-power for original purchases.
About $1200 per year per mill-power for new leases at present.
$4 per day per mill-power fur surplus up to 20 per cent.
$8 per day per mill-power for surplus over 20 and under 50 per cent.
$4 per day per mill-power for surplus under 50 per cent.

COMPARISON OF COLUMNS OF WATER IN FEET, Mercury in Inches, and Pressure in Lbs., per Square Inch.

Lbs. Press. Sq. In.	Water. Feet.	Merc'ry Inches.	Water. Feet.	Merc'ry Inches.	Lbs. Press. Sq. In.	Merc'ry Inches.	Water. Feet.	Lbs. Press. Sq. In.
1	2.311	2.046	1	0.8853	0.4327	1	1.1295	0.4887
2	4.622	4.092	2	1.7706	0.8654	2	2.2590	0.9775
3	6.933	6.138	3	2.6560	1.2981	3	3.3885	1.4662
4	9.244	8.184	4	3.5413	1.7308	4	4,5181	1.9550
5	11.555	10.230	5	4.4266	2.1635	5	5.6476	2.4437
6	13.866	12.2276	6	5.3120	2.5962	6	6.7771	2.9325
7	16.177	14.322	7	6.1973	3.0289	7	7.9066	3.4212
8	18.488	16.368	8	7.0826	3.4616	8	9.0361	3.9100
9	20.800	18.414	9	7.9680	3.8942	9	10.165	4.3987
10	23.111	20.462	10	8.8533	4.3273	10	11.295	4.8875
11	25.422	22.508	11	9.7386	4.7600	11	12.424	5.3762
12	27.733	24.554	12	10.624	5.1927	12	13.554	5.8650
13	30.044	26.600	13	11.509	5.6255	13	14.683	6.3537
14	32.355	28.646	14	12.394	6.0582	14	15.813	6.8425
15	34.666	30.692	15	13.280	6.4909	15	16.942	7.3312
16	36.977	32.738	16	14.165	6.9236	16	18.072	7.8200
17	39.288	34.784	17	15.050	7.3563	17	19.201	8.3087
18	41.599	36.830	18	15.936	7.7890	18	20.331	8.7975
19	43.910	38.876	19	16.821	8.2217	19	21.460	9.2862
20	46.221	40.922	20	17.706	8.6544	20	22.590	9.7750
21	48.532	42.968	21	18.591	9.0871	21	23.719	10.264
22	50.843	45.014	22	19.477	9.5198	22	24,849	10.752
23	53.154	47.060	23	20.362	9.9525	23	25.978	11.241
24	55.465	49.106	24	21.247	10.385	24	27.108	11.7300
25	57.776	51.152	25	22.133	10.818	25	28.237	12.219
26	60.087	53.198	26	23.018	11.251	26	29.367	12.707
27	62.398	55.244	27	23.903	11.683	27	30.496	13.196
28	64.709	57.290	28	24.789	12 116	28	31.626	13.685
39	67.020	59.336	29	25.674	12.549	29	32.755	14.174
30	69.331	61.386	30	26.560	12.981	30	33.885	14.662

The following table based on the Lowell mill-power will assist in computing cost of water-power.

SHOWING YEARLY EXPENSE OF WATER-POWER PER H. P. ON WHEEL SHAFT.

Charges for Water.		Attendance, Oil, Supplies, etc.	Fixed Charges on Cost of Plant.						Total Yearly Expense per H. P.					
Per Mill-Power.	Per H.P. per Year		Cost of Plant.						For Plants Costing					
			$50	$60	$70	$80	$90	$100	$50	$60	$70	$80	$90	$100
$300 per year a	$4.62	$0.72	$5.08	$6.10	$7.11	$8.12	$9.13	$10.15	$10.42	$11.44	$12.45	$13.46	$14.47	$15.49
b	12.31								18.11	19.13	20.14	21.15	22.16	23.18
2 per day . .	9.48								15.28	16.30	17.31	18.32	19.33	20.35
4 " " . .	18.96								24.76	25.78	26.79	27.80	28.81	29.83
8 " " . .	37.92								43.72	44.74	45.75	46.76	47.77	48.79
10 " " . .	47.40								53.20	54.22	55.23	56.24	57.25	58.27
20 " " . .	94.80								100.60	101.62	102.63	103.64	104.65	105.67

Explanation of Table.

a, in column "Per H.P. per Year," is the cost, not including interest on the original purchase.

b, in column "Per H. P. per Year," is the cost including interest on original purchase, which amounts to about $7.49 per H.P., or 5 per cent on $10,000 per M. P. per year.

The "Fixed Charges on Cost of Plant" are depreciations at 2.5 per cent average, repairs at 1½ per cent, interest at 5 per cent, taxes at 1½ per cent in ¾ cost, and insurance at .05 per cent on exposed portion.

PRESSURE OF WATER.

The pressure of water in pounds per square inch for every foot in height to 300 feet; and then by intervals to 1000 feet head.

Feet He'd.	Press., Sq. In.	Feet He'd.	Press., Sq. In.	Feet He'd.	Press., Sq. In.	Feet Head.	Press., Sq. In.	Feet Head.	Press., Sq. In.
1	0.43	65	28.15	129	55.88	193	83.60	257	111.32
2	0.86	66	28.58	130	56.31	194	84.03	258	111.76
3	1.30	67	29.02	131	56.74	195	84.47	259	112.19
4	1.73	68	29.45	132	57.18	196	84.90	260	112.62
5	2.16	69	29.88	133	57.61	197	85.33	261	113.06
6	2.59	70	30.32	134	58.04	198	85.76	262	113.49
7	3.03	71	30.75	135	58.48	199	86.20	263	113.92
8	3.46	72	31.18	136	58.91	200	86.63	264	114.36
9	3.89	73	31.62	137	59.34	201	87.07	265	114.79
10	4.33	74	32.05	138	59.77	202	87.50	266	115.22
11	4.76	75	32.48	139	60.21	203	87.93	267	115.66
12	5.20	76	32.92	140	60.64	204	88.36	268	116.09
13	5.63	77	33.35	141	61.07	205	88.80	269	116.52
14	6.06	78	33.78	142	61.51	206	89.23	270	116.96
15	6.49	79	34.21	143	61.94	207	89.66	271	117.39
16	6.93	80	34.65	144	62.37	208	90.10	272	117.82
17	7.36	81	35.08	145	62.81	209	90.53	273	118.26
18	7.79	82	35.52	146	63.24	210	90.96	274	118.69
19	8.22	83	35.95	147	63.67	211	91.39	275	119.12
20	8.66	84	36.39	148	64.10	212	91.83	276	119.56
21	9.09	85	36.82	149	64.54	213	92.26	277	119.99
22	9.53	86	37.25	150	64.97	214	92.69	278	120.42
23	9.96	87	37.68	151	65.40	215	93.13	279	120.85
24	10.39	88	38.12	152	65.84	216	93.56	280	121.29
25	10.82	89	38.55	153	66.27	217	93.99	281	121.72
26	11.26	90	38.98	154	66.70	218	94.43	282	122.15
27	11.69	91	39.42	155	67.14	219	94.86	283	122.59
28	12.12	92	39.85	156	67.57	220	95.30	284	123.02
29	12.55	93	40.28	157	68.00	221	95.73	285	123.45
30	12.99	94	40.72	158	68.43	222	96.16	286	123.89
31	13.42	95	41.15	159	68.87	223	96.60	287	124.32
32	13.86	96	41.58	160	69.31	224	97.03	288	124.75
33	14.29	97	42.01	161	69.74	225	97.46	289	125.18
34	14.72	98	42.45	162	70.17	226	97.90	290	125.62
35	15.16	99	42.88	163	70.61	227	98.33	291	126.05
36	15.59	100	43.31	164	71.04	228	98.76	292	126.48
37	16.02	101	43.75	165	71.47	229	99.20	293	126.92
38	16.45	102	44.18	166	71.91	230	99.63	294	127.35
39	16.89	103	44.61	167	72.34	231	100.06	295	127.78
40	17.32	104	45.05	168	72.77	232	100.49	296	128.22
41	17.75	105	45.48	169	73.20	233	100.93	297	128.65
42	18.19	106	45.91	170	73.64	234	101.36	298	129.08
43	18.62	107	46.34	171	74.07	235	101.79	299	129.51
44	19.05	108	46.78	172	74.50	236	102.23	300	129.95
45	19.49	109	47.21	173	74.94	237	102.66	310	134.28
46	19.92	110	47.64	174	75.37	238	103.09	320	138.62
47	20.35	111	48.98	175	75.80	239	103.53	330	142.95
48	20.79	112	48.51	176	76.23	240	103.90	340	147.28
49	21.22	113	48.94	177	76.67	241	104.39	350	151.61
50	21.65	114	49.38	178	77.10	242	104.83	360	155.94
51	22.09	115	49.81	179	77.53	243	105.26	370	160.27
52	22.52	116	50.24	180	77.97	244	105.69	380	164.61
53	22.95	117	50.68	181	78.40	245	106.13	390	168.94
54	23.39	118	51.11	182	78.84	246	106.56	400	173.27
55	23.82	119	51.54	183	79.27	247	106.99	500	216.58
56	24.26	120	51.98	184	79.70	248	107.43	600	259.90
57	24.69	121	52.41	185	80.14	249	107.86	700	303.22
58	25.12	122	52.84	186	80.57	250	108.29	800	346.54
59	25.55	123	53.28	187	81.00	251	108.73	900	389.86
60	25.99	124	53.71	188	81.43	252	109.16	1000	433.18
61	26.42	125	54.15	189	81.87	253	109.59		
62	26.85	126	54.58	190	82.30	254	110.03		
63	27.29	127	55.01	191	82.73	255	110.46		
64	27.72	128	55.44	192	83.17	256	110.89		

RIVETED STEEL PIPES.

Riveted sheet steel pipe is much used on the Pacific Coast for conveying water for considerable distances under high heads, say as much as 1700 feet. Corrosion of iron and steel pipe has always been an argument against its use, but for about thirty years such pipe has been in use in California; and a life of twenty-five years is not considered the limit, when both inside and outside of the pipe are treated with a coating of asphalt.

The method of covering with asphalt referred to affords perfect protection against corrosion, and so long as the coating is intact, makes it practically indestructible so far as all ordinary wear is concerned. The conditions which interfere with the best service are where the coating is worn off by abrasion in transportation, or where the pipe is subject to severe shock by the presence of air, or by a sudden closing of the gates, or where the service is intermittent, causing contraction and expansion, which opens the joints and breaks the covering. With ordinary care these objections can mostly be overcome. While the primary object of coating pipe in this way is to prevent oxidization, and thus insure its durability, it is incidentally an advantage in providing a smooth surface on the inside, which reduces the friction of water in its passage.

The Coast method of laying pipe is to take the shortest practicable distance that the ground will permit, placing the pipe on the surface and connecting directly from ditch, flume, or other source of supply to the wheel. Avoid short turns or acute angles, as they lessen the head and produce shock.

The ordinary method of jointing is the *slip joint*, made up in much the same way as stove-pipe. Of course this is only adapted to comparatively low heads, special riveted-joint construction being necessary for the higher falls. In laying such pipe where the lengths come together at an angle, a lead joint should be made. This is done by putting on a sleeve, allowing a space, say three-eighths of an inch, for running in lead. With a heavy pressure, and especially on steep grades, the lengths should be wired together, lugs being put on the sections forming the joints for this purpose; and where the grade is very steep, the pipe should be securely anchored with wire cable.

In laying the pipe line it is customary to commence at the wheel, and with slip joint the lower end of each length should be wrapped with cotton drilling or burlaps to prevent leaking; care being taken in driving the joints together not to move the gate and nozzle from their position. Some temporary bracing may be necessary to provide against this.

Where several wheels are to be supplied from one pipe line, a branch from the main in the form of the letter Y is preferable to a right angle outlet. When taken from the main at a right angle, the tap-hole should be nearly as large as the main, reducing by taper joint to the size of pipe attached to the wheel gate.

It is advised where practicable to lay the pipe in a trench, covering it with earth. Even in warm climates, where this is not necessary as protection from frost, it is desirable to prevent contraction and expansion by variations of temperature, as well as to afford security against accident. When laid over a rocky surface a covering of straw or manure will protect it from the sun, and generally prevent freezing; as where kept in motion, water under pressure will stand a great degree of cold without giving trouble in this way. After connections are made, it should be tested before covering to see that the joints are tight.

Care should be taken when the pipes are first filled to see that the air is entirely expelled, the use of air valves being necessary in long lines laid over undulating surfaces. Care should also be taken before starting to see that there are no obstructions in the pipe or connections to wheel, and that there are no leaks to reduce the pressure. Pipe lines of any considerable length should be graduated as to size, being larger near the top and reduced toward the lower end, the thickness of iron for various sizes being determined by the pressure it is to carry. This is a saving in first cost, and facilitates transportation by admitting of length, being run inside of each other.

When used near railroad stations, pipe is generally made in 27 ft. lengths for purpose of economizing freight, this being the length of a car. When transported long distances by wagon, it is usually made in about 20 ft. lengths. For pipe of large diameter, or for transportation over long distances, as also for mule packing, it is made in sections or joints of 24 to 30 inches in length, rolled and punched, with rivets furnished to put together on the ground where laid. Pipe of this character, being cold riveted, is easily put together with the ordinary tools for the purpose. In such case, preparation should be made for coating with asphalt before laying.

In many cases much expense may be saved in pipe by conveying the water in a flume or ditch along the hillside, covering in this way a large part of the distance, then piping it down to the power station by a short line. This is more especially applicable to large plants, where the cost of the pipe is an important item.

DATA FOR FLUMES AND DITCHES.

To give a general idea as to the capacity of flumes and ditches for carrying water, the following data is submitted :

The greatest safe velocity for a wooden flume is about 7 or 8 feet per second For an earth ditch this should not exceed about 2 feet per second. In California it is the general practice to lay a flume on a grade of about $\frac{1}{4}$ inch to the rod, or often 2 inches to the 100 feet, depending on the existing conditions.

Assuming a rectangular flume 3 feet wide, running 18 inches deep, its velocity and capacity would be as shown below : —

Grade.	Vel. in Ft. per Sec.	Quantity Cu. Ft. Min.
$\frac{1}{8}$ inch to rod	2.6	702
$\frac{1}{4}$ " " "	3.7	999
$\frac{1}{2}$ " " "	5.3	1,431

As the velocity of a flume or ditch is dependent largely on its size and character of formation, no more specific data than the above can be given. It is not safe to run either ditch or flume more than about $\frac{3}{4}$ or $\frac{7}{8}$ full.

WOODEN-STAVE PIPE.

Although wooden-stave pipe has been in use for years on old water powers for penstocks, etc., it seems to have been given but little study until late years, when it has been used to some extent on the Pacific Coast for conveying water long distances under heads not much exceeding 200 feet. Although the construction of wooden-stave pipe is quite simple, yet considerable skill and care are necessary to make water-tight work. One of the latest pieces of work employing this type of pipe is the plant of the San Gabriel Los Angeles Transmission, California, — where several miles of wooden-stave pipe, 48 ins. diameter, are used. The pipe is laid uniformly ten feet below hydraulic grade ; and the wood is of such thickness as to be always water-soaked, and will thus outlast almost any other form of construction.

The staves are placed so as to break joints, the flat sides are dressed to a true circle, and the edges to radial planes. The staves are cut off square at the ends, and the ends slotted, a tight-fitting metallic tongue being used to make the joint.

The pipe depends upon steel bands for its strength, and in the case above mentioned they are of round steel rod placed ten inches apart from center to center. Where the pressures vary along the line, bands can be spaced closer or wider apart to make the necessary strength. The preference is given round bands over flat ones, on account of their embedding themselves in the wood better as it swells. They also expose less surface to rust than would flat ones of the same strength. The ends of the bands are secured together through a malleable iron shoe, having an interior shoulder for the head of the bolt, and an exterior shoulder for the nut, the whole band thus being at right angles to the line of the pipe. Where curves are not too sharp, they can easily be made in the wooden pipe ; but for short turns, sections of steel-riveted pipe of somewhat larger internal diameter than that of the wooden pipe are introduced. The joints between wood and steel are made by a bell on the steel pipe that is larger than the outside diameter of the wooden pipe. After partly filling the space between bell and wood with oakum packed hard, for the remainder use neat Portland cement.

Advantages claimed for this type are that it costs less than any other form, and especially so where transportation is over the rugged country where it is most liable to be used ; great length of life, and greater capacity than either cast-iron or steel-riveted. Compared with new riveted pipe, the carrying capacity of stave pipe is said to be from 10 to 40 % more, and this difference increases with age as the wooden pipe gets smoother, while the friction of the metal pipe increases to a considerable degree.

As compared with open flumes, the life is so much greater and repairs so much less as to considerably more than counterbalance the first cost. For detailed information on wooden-stave pipe, see papers by A. L. Adams, September, 1898, Am. Soc. C. E.

TABLE OF RIVETED HYDRAULIC PIPE.

(Pelton Water Wheel Co.)

Showing weight, with safe head for various sizes of double-riveted pipe.

Diam. of pipe in inches.	Area of pipe in inches.	Thickness of iron by wire gauge.	Head in feet the pipe will safely stand.	Cu. ft. water pipe will convey per min. at vel. 3 ft. per sec.	Weight per lineal ft. in lbs.	Diam. of pipe in inches.	Area of pipe in inches.	Thickness of iron by wire gauge.	Head in feet the pipe will safely stand.	Cu. ft. water pipe will convey per min. at vel. 3 ft. per second.	Weight per lineal ft. in lbs.
3	7	18	400	9	2	18	254	16	165	320	16½
4	12	18	350	16	2¼	18	254	14	252	320	20½
4	12	16	525	16	3	18	254	12	385	320	27¼
5	20	18	325	25	3½	18	254	11	424	320	30
5	20	16	500	25	4¼	18	254	10	505	320	34
5	20	14	675	25	5	20	314	16	148	400	18
6	28	18	296	36	4¼	20	314	14	227	400	22½
6	28	16	487	36	5¾	20	314	12	346	400	30
6	28	14	743	36	7½	20	314	11	380	400	32½
7	38	18	254	50	5¼	20	344	10	456	400	36½
7	38	16	419	50	6¾	22	380	16	135	480	20
7	38	14	640	50	8½	22	380	14	206	480	24¾
8	50	16	367	63	7½	22	380	12	316	480	32¾
8	50	14	560	63	9½	22	380	11	347	480	35¾
8	50	12	854	63	13	22	380	10	415	480	40
9	63	16	327	80	8½	24	452	14	188	570	27¼
9	63	14	499	80	10¾	24	452	12	290	570	35½
9	63	12	761	80	14¼	24	452	11	318	570	39
10	78	16	295	100	9¼	24	452	10	379	570	43½
10	78	14	450	100	11¾	24	452	8	466	570	53
10	78	12	687	100	15¾	26	530	14	175	670	29¼
10	78	11	754	100	17½	26	530	12	267	670	38½
10	78	10	900	100	19¼	26	530	11	294	670	42
11	95	16	269	120	9¾	26	530	10	352	670	47
11	95	14	412	120	13	26	530	8	432	670	57¼
11	95	12	626	120	17¼	28	615	14	102	775	31¼
11	95	11	687	120	18¾	28	615	12	247	775	41¼
11	95	10	820	120	21	28	615	11	273	775	45
12	113	16	246	142	11¼	28	615	10	327	775	50¼
12	113	14	377	142	14	28	615	8	400	775	61¼
12	113	12	574	142	18½	30	706	12	231	890	44
12	113	11	630	142	19¾	30	706	11	254	890	48
12	113	10	753	142	22¾	30	706	10	304	890	54
13	132	16	228	170	12	30	706	8	375	890	65
13	132	14	348	170	15	30	706	7	425	890	74
13	132	12	530	170	20	36	1017	11	141	1300	58
13	132	11	583	170	22	36	1017	10	155	1300	67
13	132	10	696	170	24½	36	1017	8	192	1300	78
14	153	16	211	200	13	36	1017	7	210	1300	88
14	153	14	324	200	16	40	1256	10	141	1600	71
14	153	12	494	200	21½	40	1256	8	174	1600	86
14	153	11	543	200	23½	40	1256	7	189	1600	97
14	153	10	648	200	26	40	1256	6	213	1600	108
15	176	16	197	225	13¾	40	1256	4	250	1600	126
15	176	14	302	225	17	42	1385	10	135	1760	74½
15	176	12	460	225	23	42	1385	8	165	1760	91
15	176	11	507	225	24½	42	1385	7	180	1660	102
15	176	10	606	225	28	42	1385	6	210	1760	114
16	201	16	185	255	14½	42	1385	4	240	1760	133
16	201	14	283	255	17¼	42	1385	¼	270	1760	137
16	201	12	432	255	24¼	42	1385	3	300	1760	145
16	201	11	474	255	26½	42	1385	$\frac{5}{16}$	321	1760	177
16	201	10	567	255	29½	42	1385	$\frac{3}{8}$	363	1760	216

Cubic Feet of Water per Minute Discharged Through an Orifice 1 Square Inch in Area.

For any other size of orifice, multiply by its area in square inches.

Heads in Inches.	Cubic Feet Discharged per Minute.	Heads in Inches.	Cubic Feet Discharged per Minute.	Heads in Inches.	Cubic Feet Discharged per Minute.	Heads in Inches.	Cubic Feet Discharged per Minute.	Heads in Inches.	Cubic Feet Discharged per Minute.	Heads in Inches.	Cubic Feet Discharged per Minute.	Heads in Inches.	Cubic Feet Discharged per Minute.
3	1.12	13	2.20	23	2.90	33	3.47	43	3.95	53	4.39	63	4.78
4	1.27	14	2.28	24	2.97	34	3.52	44	4.00	54	4.42	64	4.81
5	1.40	15	2.36	25	3.03	35	3.57	45	4.05	55	4.46	65	4.85
6	1.52	16	2.43	26	3.08	36	3.62	46	4.09	56	4.52	66	4.89
7	1.64	17	2.51	27	3.14	37	3.67	47	4.12	57	4.55	67	4.92
8	1.75	18	2.58	28	3.20	38	3.72	48	4.18	58	4.58	68	4.97
9	1.84	19	2.64	29	3.25	39	3.77	49	4.21	59	4.63	69	5.00
10	1.94	20	2.71	30	3.31	40	3.81	50	4.27	60	4.65	70	5.03
11	2.03	21	2.78	31	3.36	41	3.86	51	4.30	61	4.72	71	5.07
12	2.12	22	2.84	32	3.41	42	3.91	52	4.34	62	4.74	72	5.09

Table Showing the Theoretical Velocity and Discharge in Cubic Feet Through an Orifice of 1 Square Inch Issuing Under Heads Varying from 1 to 100 Feet.

Head in Feet.	Theoretical Discharge in Cu. Ft. per Min.	Theoretical Velocity in Feet per Min.	Head in Feet.	Theoretical Discharge in Cu. Ft. per Min.	Theoretical Velocity in Feet per Min.	Head in Feet.	Theoretical Discharge in Cu. Ft. per Min.	Theoretical Velocity in Feet per Min.
1	3.34	481.2	35	19.77	2847.6	69	27.74	3997.1
2	4.73	680.4	36	20.05	2887.2	70	27.94	4021.1
3	5.79	833.4	37	20.33	2926.8	71	28.14	4054.5
4	6.68	962.4	38	20.60	2966.4	72	28.34	4283.0
5	7.47	1075.8	39	20.87	3004.8	73	28.53	4111.3
6	8.18	1178.4	40	21.13	3043.2	74	28.73	4139.4
7	8.84	1273.2	41	21.38	3081.1	75	28.93	4165.2
8	9.45	1360.8	42	21.64	3118.5	76	29.11	4194.9
9	10.02	1443.6	43	21.90	3156.4	77	29.30	4222.4
10	10.57	1521.6	44	22.15	3191.8	78	29.49	4249.8
11	11.08	1596.0	45	22.40	3227.8	79	29.68	4265.9
12	11.57	1666.8	46	22.65	3263.6	80	29.87	4303.6
13	12.05	1734.6	47	22.89	3298.9	81	30.06	4330.8
14	12.50	1800.6	48	23.14	3333.8	82	30.24	4357.4
15	12.94	1863.6	49	23.38	3368.4	83	30.42	4383.6
16	13.37	1924.8	50	23.61	3402.5	84	30.61	4410.2
17	13.78	1984.2	51	23.85	3436.4	85	30.79	4436.4
18	14.18	2041.8	52	24.08	3469.9	86	30.97	4462.4
19	14.57	2097.6	53	24.31	3503.1	87	31.15	4488.2
20	14.95	2152.2	54	24.54	3536.0	88	31.33	4514.0
21	15.31	2205.0	55	24.76	3568.6	89	31.50	4539.5
22	15.67	2256.6	56	24.99	3600.9	90	31.68	4565.0
23	16.02	2307.6	57	25.21	3632.9	91	31.86	4590.3
24	16.37	2357.4	58	25.43	3664.6	92	32.04	4615.4
25	16.71	2406.0	59	25.65	3696.1	93	32.20	4640.5
26	17.04	2453.4	60	25.87	3727.3	94	32.38	4665.3
27	17.36	2500.2	61	26.08	3758.2	95	32.55	4690.1
28	17.68	2545.8	62	26.29	3788.9	96	32.72	4714.7
29	17.99	2590.8	63	26.51	3819.3	97	32.89	4739.2
30	18.30	2635.8	64	26.72	3849.6	98	33.06	4763.5
31	18.60	2679.0	65	26.92	3879.5	99	33.23	4787.8
32	18.90	2722.2	66	27.13	3909.2	100	33.40	4812.0
33	19.20	2764.2	67	27.33	3938.7			
34	19.49	2806.2	68	27.54	3968.4			

Flow of Water Through an Orifice.

a = area of orifice in square inches.
Q = cubic feet discharged per minute.
h = head in inches.

$$Q = .624\sqrt{h} \times a.$$

The best form of aperture for giving the greatest flow of water is a conical aperture whose greater base is the aperture, the height or length of the section of cone being half the diameter of aperture, and the area of the small opening to the area of the large opening as 10 to 16; there will be no contraction of the vein, and consequently the greatest attainable discharge will be the result.

MEASUREMENT OF FLOW OF WATER IN A STREAM.

The quantity of water flowing in a stream may be roughly estimated as follows:

Find the mean depth of the stream by taking measurements at 10 or 12 or more equal distances across. Multiply this mean depth by the width of the stream, which will give the total cross-section of the prism.

Find the velocity of the flow in feet per minute, by timing a float over a measured distance, several times to get a fair average. Use a thin float, such as a shingle, so that it may not be influenced by the wind.

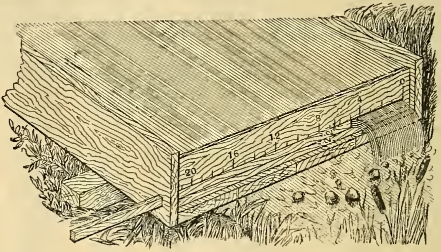


FIG. 13.

The area or cross-section of the prism multiplied by the velocity per minute will give the quantity per minute in cubic feet.

Owing to friction of the bed and banks the actual flow is reduced to about 83 per cent of the calculated flow as above.

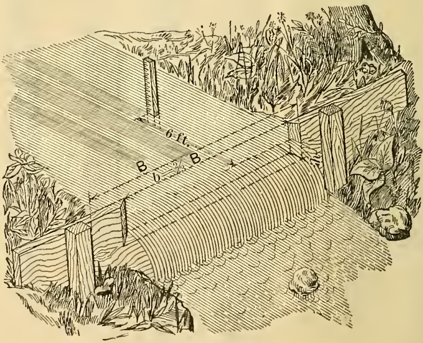


FIG. 14.

Miners' Inch Measurements.

(Pelton Water Wheel Co.)

Miners' inch is a term much in use on the Pacific Coast and in the mining regions, and is described as the amount of water flowing through a hole 1 inch square in a 2-inch plank under a head of 6 inches to the top of the orifice.

Fig. 13 shows the form of measuring-box ordinarily used; and the following table gives the discharge in cubic feet per minute of a miners' inch of water, as measured under the various heads and different lengths and heights of apertures used in California.

Length of Opening in Inches.	Openings 2 Inches High.			Openings 4 Inches High.		
	Head to Center, 5 Ins.	Head to Center, 6 Inches.	Head to Center, 7 Inches.	Head to Center, 5 Inches.	Head to Center, 6 Inches.	Head to Center, 7 Inches.
	Cu.Ft.	Cu. Ft.	Cu. Ft.	Cu. Ft.	Cu. Ft.	Cu. Ft.
4	1.348	1.473	1.589	1.320	1.450	1.570
6	1.355	1.480	1.596	1.336	1.470	1.595
8	1.359	1.484	1.600	1.344	1.481	1.608
10	1.361	1.485	1.602	1.349	1.487	1.615
12	1.363	1.487	1.604	1.352	1.491	1.620
14	1.364	1.488	1.604	1.354	1.494	1.623
16	1.365	1.489	1.605	1.356	1.496	1.626
18	1.365	1.489	1.606	1.357	1.498	1.628
20	1.365	1.490	1.606	1.359	1.499	1.630
22	1.366	1.490	1.607	1.359	1.500	1.631
24	1.366	1.490	1.607	1.360	1.501	1.632
26	1.366	1.490	1.607	1.361	1.502	1.633
28	1.367	1.491	1.607	1.361	1.503	1.634
30	1.367	1.491	1.608	1.362	1.503	1.635
40	1.367	1.492	1.608	1.363	1.505	1.637
50	1.368	1.493	1.609	1.364	1.507	1.639
60	1.368	1.493	1.609	1.365	1.508	1.640
70	1.368	1.493	1.609	1.365	1.508	1.641
80	1.368	1.493	1.609	1.366	1.509	1.641
90	1.369	1.493	1.610	1.366	1.509	1.641
100	1.369	1.494	1.610	1.366	1.509	1.642

NOTE. — *The apertures from which the above measurements were obtained were through material 1¼ inches thick, and the lower edge 2 inches above the bottom of the measuring-box, thus giving full contraction.*

FLOW OF WATER OVER WEIRS.

Weir Dam Measurement.

(Pelton Water Wheel Co.)

Place a board or plank in the stream, as shown in Fig. 14, at some point where a pond will form above. The length of the notch in the dam should be from two to four times its depth for small quantities, and longer for large quantities. The edges of the notch should be beveled toward the intake side as shown. The overfall below the notch should not be less than twice its depth, that is, 12 inches if the notch is 6 inches deep, and so on.

In the pond, about 6 feet above the dam, drive a stake, and then obstruct the water until it rises precisely to the bottom of the notch, and mark the stake at this level. Then complete the dam so as to cause all the water to flow through the notch, and, after time for the water to settle, mark the stake again for this new level. If preferred, the stake can be driven with its top precisely level with the bottom of the notch, and the depth of the water be measured with a rule after the water is flowing free, but the marks are preferable in most cases. The stake can then be withdrawn; and the distance between the marks is the theoretical depth of flow corresponding to the quantities in the table.

Francis's Formulæ for Weirs.

	As given by Francis.	As modified by Smith.
Weirs with both end contractions suppressed	$Q = 3.33lh^{\frac{3}{2}}$	$3.29\left(l + \frac{h}{7}\right)h^{\frac{3}{2}}$
Weirs with one end contraction suppressed	$Q = 3.33(l - .1h)\,h^{\frac{3}{2}}$	$3.29lh^{\frac{3}{2}}$
Weirs with full contraction . .	$Q = 3.33(l - .2h)h^{\frac{3}{2}}$	$3.29\left(l - \frac{h}{10}\right)h^{\frac{3}{2}}$

The greatest variation of the Francis formulæ from the value of c given by Smith amounts to $3\frac{1}{2}$ per cent. The modified Francis formulæ, says Smith, will give results sufficiently exact, when great accuracy is not required, within the limits of h, from .5 feet to 2 feet, l being not less than 3 h.

$Q =$ discharge in cubic feet per second, $l =$ length of weir in feet, $h =$ effective head in feet, measured from the level of the crest to the level of still water above the weir.

If $Q' =$ discharge in cubic feet per *minute*, and l' and h' are taken in inches, the first of the above formulæ reduces to $Q' = 0.4l'h'^{\frac{3}{2}}$. The values are sufficiently accurate for ordinary computations of water-power for weirs without end contraction, that is, for a weir the full width of the channel of approach, and are approximate also for weirs with end contraction when $l =$ at least $10h$, but about 6 per cent in excess of the truth when $l = 4h$.

Weir Table.

Table Showing the Quantity of Water Passing over Weirs in Cubic Feet per Minute.

Depth of Water on Weir in In.	Cubic Ft. per Minute passed for each Ft. of Length of Weir.	Depth of Water on Weir in In.	Cubic Ft. per Minute passed for each Ft. of Length of Weir.	Depth of Water on Weir in In.	Cubic Ft. per Minute passed for each Ft. of Length of Weir.	Depth of Water on Weir in In.	Cubic Ft. per Minute passed for each Ft. of Length of Weir.
1	4.85	$4\frac{3}{4}$	50.20	$8\frac{1}{2}$	120.18	$12\frac{1}{2}$	214.32
$1\frac{1}{8}$	5.78	$4\frac{7}{8}$	52.18	$8\frac{5}{8}$	122.82	$12\frac{3}{4}$	220.76
$1\frac{1}{4}$	6.68	5	54.22	$8\frac{3}{4}$	125.52	13	227.30
$1\frac{3}{8}$	7.80	$5\frac{1}{8}$	56.25	$8\frac{7}{8}$	128.14	$13\frac{1}{4}$	233.92
$1\frac{1}{2}$	8.90	$5\frac{1}{4}$	58.33	9	130.93	$13\frac{1}{2}$	240.54
$1\frac{5}{8}$	10.00	$5\frac{3}{8}$	60.42	$9\frac{1}{8}$	133.65	$13\frac{3}{4}$	247.22
$1\frac{3}{4}$	11.23	$5\frac{1}{2}$	62.55	$9\frac{1}{4}$	136.43	14	254.03
$1\frac{7}{8}$	12.45	$5\frac{5}{8}$	64.68	$9\frac{3}{8}$	139.18	$14\frac{1}{4}$	260.83
2	13.72	$5\frac{3}{4}$	66.86	$9\frac{1}{2}$	141.99	$14\frac{1}{2}$	267.77
$2\frac{1}{8}$	15.02	$5\frac{7}{8}$	68.98	$9\frac{5}{8}$	144.80	$14\frac{3}{4}$	274.70
$2\frac{1}{4}$	16.36	6	71.27	$9\frac{3}{4}$	147.64	15	281.72
$2\frac{3}{8}$	17.75	$6\frac{1}{8}$	73.45	$9\frac{7}{8}$	150.47	$15\frac{1}{4}$	288.82
$2\frac{1}{2}$	19.17	$6\frac{1}{4}$	75.77	10	153.35	$15\frac{1}{2}$	295.93
$2\frac{5}{8}$	20.63	$6\frac{3}{8}$	78.04	$10\frac{1}{8}$	156.20	$15\frac{3}{4}$	303.10
$2\frac{3}{4}$	22.11	$6\frac{1}{2}$	80.36	$10\frac{1}{4}$	159.14	16	310.36
$2\frac{7}{8}$	23.63	$6\frac{5}{8}$	82.63	$10\frac{3}{8}$	162.07	$16\frac{1}{4}$	317.69
3	25.20	$6\frac{3}{4}$	85.04	$10\frac{1}{2}$	164.99	$16\frac{1}{2}$	325.03
$3\frac{1}{8}$	26.78	$6\frac{7}{8}$	87.43	$10\frac{5}{8}$	167.89	$16\frac{3}{4}$	332.42
$3\frac{1}{4}$	28.43	7	89.82	$10\frac{3}{4}$	169.92	17	339.91
$3\frac{3}{8}$	30.06	$7\frac{1}{8}$	92.16	$10\frac{7}{8}$	173.90	$17\frac{1}{4}$	347.45
$3\frac{1}{2}$	31.75	$7\frac{1}{4}$	94.67	11	176.92	$17\frac{1}{2}$	355.02
$3\frac{5}{8}$	33.45	$7\frac{3}{8}$	97.11	$11\frac{1}{8}$	179.94	$17\frac{3}{4}$	362.77
$3\frac{3}{4}$	35.22	$7\frac{1}{2}$	99.50	$11\frac{1}{4}$	182.99	18	370.34
$3\frac{7}{8}$	36.98	$7\frac{5}{8}$	102.10	$11\frac{3}{8}$	186.03	$18\frac{1}{4}$	378.12
4	38.80	$7\frac{3}{4}$	104.63	$11\frac{1}{2}$	189.13	$18\frac{1}{2}$	385.87
$4\frac{1}{8}$	40.63	$7\frac{7}{8}$	107.13	$11\frac{5}{8}$	192.20	$18\frac{3}{4}$	393.66
$4\frac{1}{4}$	42.49	8	109.74	$11\frac{3}{4}$	195.32	19	401.63
$4\frac{3}{8}$	44.39	$8\frac{1}{8}$	112.31	$11\frac{7}{8}$	198.47	$19\frac{1}{4}$	409.58
$4\frac{1}{2}$	46.29	$8\frac{1}{4}$	114.91	12	201.59	$19\frac{1}{2}$	417.48
$4\frac{5}{8}$	48.22	$8\frac{3}{8}$	117.51	$12\frac{1}{4}$	207.94	$19\frac{3}{4}$	425.68

TABLES FOR CALCULATING THE HORSE-POWER OF WATER.

(Pelton Wheel Co.)

Miners' Inch Table.

The following table gives the horse-power of one miners' inch of water under heads from one up to eleven hundred feet. This inch equals 1½ cubic feet per minute.

Heads in Feet.	Horse-Power.	Heads in Feet.	Horse-Power.
1	.0024147	320	.772704
20	.0482294	330	.796851
30	.072441	340	.820998
40	.096588	350	.845145
50	.120735	360	.869292
60	.144882	370	.893439
70	.169029	380	.917586
80	.193176	390	.941733
90	.217323	400	.965880
100	.241470	410	.990027
110	.265617	420	1.014174
120	.289764	430	1.038321
130	.313911	440	1.062468
140	.338058	450	1.086615
150	.362205	460	1.110762
160	.386352	470	1.134909
170	.410499	480	1.159056
180	.434646	490	1.183206
190	.458793	500	1.207350
200	.482940	520	1.255644
210	.507087	540	1.303938
220	.531234	560	1.352232
230	.555381	580	1.400526
240	.579528	600	1.448820
250	.603675	650	1.569555
260	.627822	700	1.690290
270	.651969	750	1.811025
280	.676116	800	1.931760
290	.700263	900	2.173230
300	.724410	1000	2.414700
310	.748557	1100	2.656170

Cubic Feet Table.

The following table gives the horse-power of one cubic foot of water per minute under heads from one up to eleven hundred feet.

Heads in Feet.	Horse-Power.	Heads in Feet.	Horse-Power.
1	.0016098	320	.515136
20	.032196	330	.531234
30	.048294	340	.547332
40	.064392	350	.563430
50	.080490	360	.579528
60	.096588	370	.595626
70	.112686	380	.611724
80	.128784	390	.627822
90	.144892	400	.643920
100	.160980	410	.660018
110	.177078	420	.676116
120	.193176	430	.692214
130	.209274	440	.708312
140	.225372	450	.724410
150	.241470	460	.740508
160	.257568	470	.756606
170	.273666	480	.772704
180	.289764	490	.788802
190	.305862	500	.804900
200	.321960	520	.837096
210	.338058	540	.869292
220	.354156	560	.901488
230	.370254	580	.933684
240	.386352	600	.965880
250	.402450	650	1.046370
260	.418548	700	1.126860
270	.434646	750	1.207350
280	.450744	800	1.287840
290	.466842	900	1.448820
300	.482940	1000	1.609800
310	.499038	1100	1.770780

When the Exact Head is found in Above Table.

EXAMPLE.—Have 100 foot head and 50 inches of water. How many horse-power?

By reference to above table the horse-power of 1 inch under 100 feet head is .241470. The amount multiplied by the number of inches, 50, will give 12.07 horse-power.

When Exact Head is not Found in Table.

Take the horse-power of 1 inch under 1 foot head, and multiply by the number of inches, and then by number of feet head. The product will be the required horse-power.

The above formula will answer for the cubic-feet table, by substituting the equivalents therein for those of miners' inches.

NOTE.— *The above tables are based upon an efficiency of 85 per cent.*

WATER-WHEELS.

Undershot Wheels, in which the water passes under acting by impulse, when constructed in the old-fashioned way with flat boards as floats, have a maximum theoretical efficiency of 50 per cent; but with curved floats, as in Poncelet's wheel, which are arranged so that the water enters without shock and drops from the floats into the tail-race without horizontal velocity, the maximum efficiency is as great as for overshot wheels, and the available efficiency is found to be about 60 per cent. The velocity of the periphery should be about .5 of the theoretical velocity of the water due to the head.

Breast and Overshot Wheels.

The best peripheral velocity is about 6 feet per second, and for the water supplied to it about 12 feet per second, which is the velocity due to a fall of about 2¼ feet; therefore, the point at which the water strikes the wheel should be 2¼ feet below the top-water level. The chief cause of loss in overshot wheels is the velocity which the water possesses at the moment it falls from the float or bucket; overshot wheels are good for falls of 13 feet to 20 feet; below that breast wheels are preferable. The capacity of the buckets should be three times the volume of water held in each. The distance apart of the buckets may be 12 inches in high-breast and overshot wheels, or 18 inches in low-breast wheels, while the opening of buckets may be 6 to 8 inches in high-breast, and 9 inches to 12 inches in low-breast wheels.

TURBINES.

These may be divided into two main classes, viz., pressure and impulse turbines. The former may be again divided into the following: parallel-flow, outward-flow, and inward-flow turbines, according to the direction in which the water flows through the turbine in relation to its axis.

Parallel-flow turbines, sometimes called downward-flow, are best suited for low falls, not exceeding say 30 feet. Fontaine's turbine is of this class, the wheel being placed at the bottom of the water-pipe or flume, just above the level of the tail-race. The water passes through guide blades and strikes the curved floats of the wheel. Jonval's turbine is of similar type, but is arranged to work partly by suction, and may be placed above the level of the tail-race without loss of power, which is often more convenient for working. The efficiency is from 70 to 72 per cent with well-designed wheels of this type.

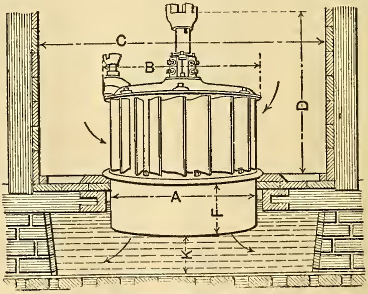


FIG. 15. Victor Wheel set in ordinary Flume.

Outward-flow Turbines have a somewhat higher efficiency than the parallel-flow — as much as 88 per cent has been realized by Boyden's turbine; Fourneyron's has given a maximum of 79 per cent.

Inward-flow Turbines have been designed by Swain and others. Tests made on a Swain turbine by J. B. Francis gave a maximum efficiency of 84 per cent with full supply, and with the gate a quarter open 61 per cent, the circumferential velocity of the wheel ranging from 80 to 60 per cent of the theoretical velocity due to the head of water. In Swain's turbine the edges of the floats are vertical and opposite the guide blades, the edges towards the bottom of the floats being bent into a quadrant form. The Victor turbine is claimed to give 88 per cent under favorable conditions. It receives the water upon the outside, and discharges it downward and outward, the lines of discharge occupying the entire diameter of the lower portion of the wheel, excepting only the space filled by the lower end of the shaft.

Impulse Turbines are suitable for very high falls. The Girard and Pelton are both of this type. It is advised that pressure turbines be used on heads of 80 feet or 100 feet, but above this an impulse turbine is best. A Girard turbine is working under a fall of 650 feet.

Installing Turbines.

Particular attention must be paid to the designing and construction of water-courses. The forebay leading to the flume should be of such size that the velocity of the water never exceeds $1\frac{1}{2}$ feet per second, and should be free from abrupt turns or other defects likely to cause eddies. The tail-race should have similar capacity and sufficient depth below the surface of the stream to allow at least 2 feet of dead water standing when the wheels are not in motion, and with large wheels, 3 feet to 4 feet; after extending several feet beyond the flume, this may be gradually sloped up to the level of the stream. It is not uncommon to see 2 feet or 3 feet of head lost in defective races.

When setting turbines some distance above the tail-race, the mouth of the draft-tube must be 2 inches to 4 inches below the lowest level of the standing tail-water. Theoretically draft-tubes may be 30 feet long; but 20 feet is as long as is desirable on account of the difficulty of keeping air-tight; they should be made as short as possible by placing the turbine at the bottom of the fall.

Particulars of the setting recommended for Victor turbines are given below, as an example.

Table of Dimensions of Victor Turbine.

	A.	B.	C.	D.	E.	F.	K.	
Size of Wheel.	Diameter of Cylinder passing through Floor of Flume.	Diameter of Entire Wheel-Case.	Internal Diameter of Flume.	Length of Shaft from Flange Resting on Floor of Flume to Center of Coupling.	Diameter of Upper Bore of Upper Half of Coupling.	Length of Cylinder passing through Floor of Flume.	Depth of Pit from End of Cylinder to Bottom of Wheel-Pit.	Approximate Weight of Wheel Complete.
In.	In.	In.	Ft.	In.	In.	In.		Lbs.
6	10	$13\frac{1}{2}$	2	12	1	$5\frac{1}{2}$	From 2 to 8 feet deep according to size of wheel and quantity of water discharged. See special instructions on construction of flumes and tail-races.	165
8	$13\frac{1}{2}$	$17\frac{1}{8}$	$2\frac{1}{2}$	$19\frac{11}{16}$	$1\frac{7}{16}$	$6\frac{7}{8}$		260
10	16	$20\frac{1}{4}$	3	$22\frac{3}{4}$	$1\frac{11}{16}$	$7\frac{1}{2}$		350
12	$18\frac{3}{16}$	$23\frac{3}{16}$	$3\frac{1}{2}$	$28\frac{1}{2}$	$1\frac{15}{16}$	$9\frac{5}{8}$		500
15	$23\frac{3}{16}$	$28\frac{3}{16}$	4	$33\frac{3}{4}$	$2\frac{7}{16}$	11		830
$17\frac{1}{2}$	$26\frac{1}{8}$	$31\frac{1}{8}$	5	$35\frac{1}{2}$	$2\frac{11}{16}$	$12\frac{3}{4}$		1125
20	$30\frac{1}{8}$	$35\frac{1}{2}$	6	$37\frac{1}{2}$	$3\frac{3}{16}$	$13\frac{1}{4}$		1475
$22\frac{1}{2}$	$33\frac{1}{8}$	$38\frac{1}{2}$	$6\frac{1}{2}$	42	$3\frac{7}{16}$	$14\frac{1}{2}$		1900
25	$35\frac{1}{8}$	$40\frac{5}{8}$	$6\frac{1}{2}$	$43\frac{5}{8}$	$3\frac{7}{16}$	$15\frac{1}{4}$		2335
$27\frac{1}{2}$	$38\frac{1}{8}$	$43\frac{3}{4}$	$7\frac{1}{2}$	$48\frac{15}{16}$	$3\frac{15}{16}$	$16\frac{1}{4}$		3225
30	$40\frac{1}{8}$	46	8	$50\frac{1}{8}$	$4\frac{3}{8}$	$17\frac{1}{4}$		3540
$32\frac{1}{2}$	$43\frac{1}{8}$	$49\frac{1}{2}$	9	$55\frac{5}{8}$	$4\frac{5}{8}$	$19\frac{1}{2}$		4500
35	$46\frac{1}{8}$	53	9	59	$4\frac{7}{8}$	20		5450
40	$52\frac{1}{4}$	$60\frac{1}{4}$	10	$64\frac{3}{4}$	$5\frac{3}{8}$	22		7500
44	$56\frac{1}{4}$	$65\frac{1}{4}$	11	$67\frac{1}{4}$	$5\frac{7}{8}$	24		9380
48	$60\frac{1}{4}$	$70\frac{1}{4}$	12	$74\frac{5}{8}$	$6\frac{3}{8}$	26		11700
55	68	80	14	$85\frac{1}{4}$	$7\frac{1}{2}$	28		19000
60	$80\frac{1}{4}$	92	16	$96\frac{1}{2}$	$7\frac{7}{8}$	32		

DIMENSIONS OF TURBINES.

Tables of sizes of turbine wheels vary so much under different makers, and are so extensive, as not to permit their insertion here, but through the kindness of Mr. Axel Ekström of the General Electric Company I am permitted to print the following sheets of curves for the McCormick type turbine and the Pelton impulse wheel. From them may be made determinations of dimensions in much shorter time than is necessary by use of tables.

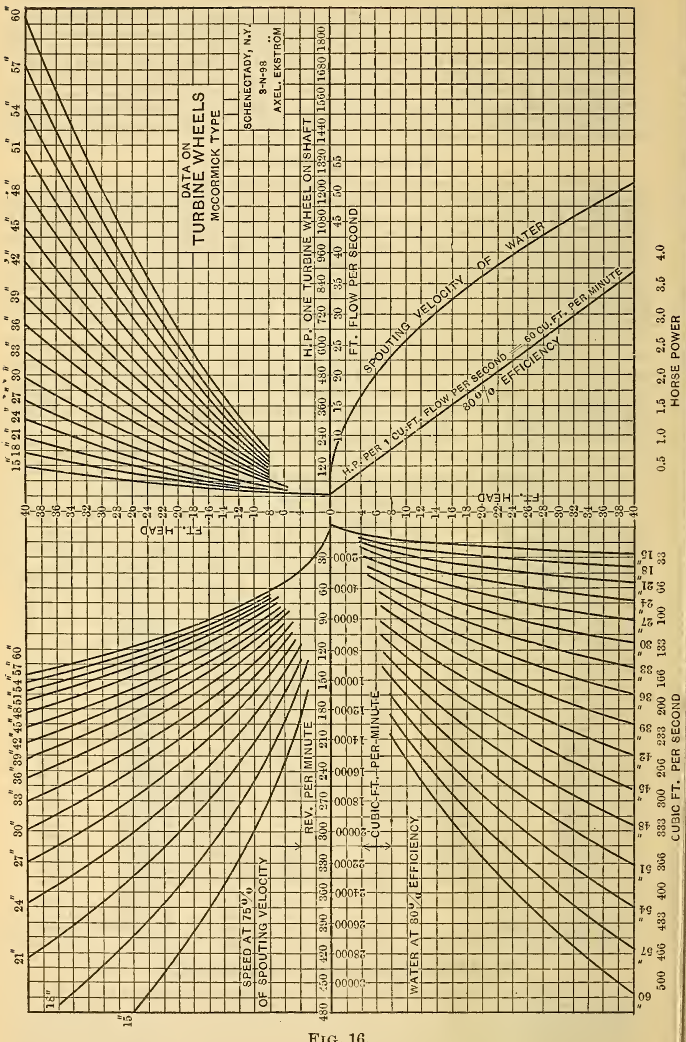

DATA ON
TURBINE WHEELS
McCORMICK TYPE
SCHENECTADY, N.Y.
3-N-98
AXEL. EKSTRÖM
H.P. ONE TURBINE WHEEL ON SHAFT
120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
FT. FLOW PER SECOND
10 15 20 25 30 35 40 45 50 55
SPOUTING VELOCITY OF WATER
H.P. PER 1 CU.FT. FLOW PER SECOND = 60 CU.FT. PER MINUTE
80% EFFICIENCY
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
HORSE POWER
15" 18" 21" 24" 27" 30" 33" 36" 39" 42" 45" 48" 51" 54" 57" 60"
FT. HEAD
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 0
4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
REV. PER MINUTE
30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480
CUBIC-FT.-PER-MINUTE
2000 4000 6000 8000 10000 12000 14000 16000 18000 20000 22000 24000 26000 28000 30000
SPEED AT 75% OF SPOUTING VELOCITY
WATER AT 80% EFFICIENCY
33 66 100 133 166 200 233 266 300 333 366 400 433 466 500
CUBIC FT. PER SECOND

FIG. 16.

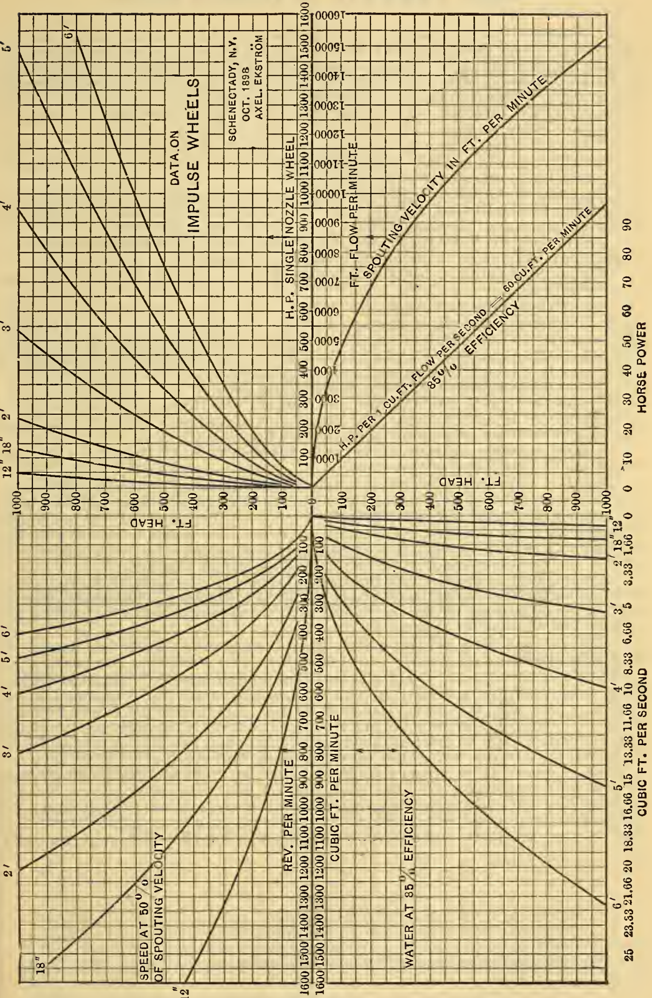

DATA ON
IMPULSE WHEELS
SCHENECTADY, N.Y.
OCT. 1898
AXEL. EKSTRÖM
H.P. SINGLE NOZZLE WHEEL
FT. FLOW PER MINUTE
SPOUTING VELOCITY IN FT. PER MINUTE
H.P. PER 1 CU.FT. FLOW PER SECOND = 60 CU.FT. PER MINUTE
85% EFFICIENCY
HORSE POWER
FT. HEAD
REV. PER MINUTE
CUBIC FT. PER MINUTE
WATER AT 85% EFFICIENCY
SPEED AT 50% OF SPOUTING VELOCITY
CUBIC FT. PER SECOND
12" 18" 2' 3' 4' 5' 6'
0 10 20 30 40 50 60 70 80 90
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600
1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 11000 12000 13000 14000 15000 16000
0 1.66 3.33 5 6.66 8.33 10 11.66 13.33 15 16.66 18.33 20 21.66 23.33 25

FIG. 17.

THE IMPULSE WATER-WHEEL.

Mr. Ross E. Browne states that " The functions of a water-wheel, operated by a jet of water escaping from a nozzle, is to convert the energy of the jet, due to its velocity, into useful work. In order to utilize this energy fully, the wheel bucket, after catching the jet, must bring it to rest before discharging it, without inducing turbulence or agitation of the particles. This cannot be fully effected, and unavoidable difficulties necessitate the loss of a portion of the energy. The principal losses occur as follows:

" First: In sharp or angular diversion of the jet in entering, or in its course through the bucket, causing impact, or the conversion of a portion of the energy into heat instead of useful work.

" Second: In the so-called frictional resistance offered to the motion of the water by the wetted surfaces of the buckets, causing also the conversion of a portion of the energy into heat instead of useful work.

" Third: In the velocity of the water as it leaves the bucket, representing energy which has not been converted into work.

" Hence, in seeking a high efficiency, there are presented the following considerations:

" 1st. The bucket surface at the entrance should be approximately parallel to the relative course of the jet, and the bucket should be curved in such a manner as to avoid sharp angular deflection of the stream. If, for example, a jet strikes a surface at an angle and is sharply deflected, a portion of the water is backed, the smoothness of the stream is disturbed, and there results considerable loss by impact and otherwise.

2d. The number of buckets should be small, and the path of the jet in the bucket short; in other words, the total wetted surface should be small, as the loss by friction will be proportional to this.

" A small number of buckets is made possible by applying the jet tangentially to the periphery of the wheel.

" 3d. The discharge end of the bucket should be as nearly tangential to the wheel-periphery, as compatible with the clearance of the bucket which follows; and great differences of velocity in the parts of the escaping water should be avoided. In order to bring the water to rest at the discharge end of the bucket, it is easily shown mathematically that the velocity of the bucket should be one-half the velocity of the jet.

" An ordinary curved or cup bucket will cause the heaping of more or less dead or turbulent water in the bottom of the bucket. This dead water is subsequently thrown from the wheel with considerable velocity, and represents a large loss of energy.

" The introduction of the wedge in the bucket is an efficient means of avoiding this loss."

Wheels of this type are very efficient under high heads of water, and have been used to a great extent in the extreme western parts of the United States, where the fall is in hundreds of feet. It is difficult to say at what point of head the efficiency becomes such as to induce the use of some other form of wheel; but at 200 feet head the efficiencies of both impulse and turbine will be so much alike that selection must be governed by other factors.

Tests of one of the leading impulse wheels show efficiencies varying from 80 % to 86 % according to head and size of jet. However, many factors besides the efficiency enter into selection of water-wheels, which must be subject to local conditions, and as in most water-power plants, each is a special case by itself, and selection of apparatus best fitted in all ways must govern.

SHAFTING, PULLEYS, BELTING, ROPE-DRIVING.

SHAFTING.

Thurston gives the following formulæ for calculating power and size of shafting.

$H.P.$ = horse-power transmitted.
d = diameter of shaft in inches.
r = revolutions per minute.

For head shafts well supported against springing.	For iron, $H.P. = \frac{d^3r}{125}$; $d = \sqrt[3]{\frac{125\ H.P.}{r}}$
	For cold-r'lled iron $H.P. = \frac{d^3r}{75}$; $d = \sqrt[3]{\frac{75\ H.P.}{r}}$
For line shafting hangers 8 feet apart.	For iron, $H.P. = \frac{d^3r}{90}$; $d = \sqrt[3]{\frac{90\ H.P.}{r}}$
	For cold-r'lld iron, $H.P. = \frac{d^3r}{55}$; $d = \sqrt[3]{\frac{55\ H.P.}{r}}$
For transmission simply, no pulleys.	For iron, $H.P. = \frac{d^3r}{62.5}$; $d = \sqrt[3]{\frac{62.5\ H.P.}{r}}$
	For cold-r'lld iron, $H.P. = \frac{d^3r}{35}$; $d = \sqrt[3]{\frac{35\ H.P.}{r}}$

Jones and Laughlin's use the same formulæ, with the following exceptions:

For line shafts, cold-rolled iron, $H.P. = \frac{d^3r}{50}$; $d = \sqrt[3]{\frac{50\ H.P.}{r}}$.

For transmission and for short-counters,

Turned iron . . . . $H.P. = \frac{d^3r}{50}$; $d = \sqrt[3]{\frac{50\ H.P.}{r}}$.

Cold-rolled iron . . . . $H.P. = \frac{d^3r}{30}$; $d = \sqrt[3]{\frac{30\ H.P.}{r}}$.

Pulleys should be placed as near to bearings as practicable, but care should be taken that oil does not drip from the box into the pulley.

The diameter of a shaft safe to carry the main pulley at the center of a bay may be found by multiplying the fourth power of the diameter obtained by the formulæ above given, by the length of the bay, and dividing the product by the distance between centers of bearings. The fourth root of the quotient will be the required diameter.

The following table is based upon the above rule, and is substantially correct:

Diameter of Shaft given by the Formulæ for Head Shafts.	Diameter of Shaft necessary to carry the Load at the Center of a Bay, which is from Center to Center of Bearings.							
	2½ ft.	3 ft.	3½ ft.	4 ft.	5 ft.	6 ft.	8 ft.	10 ft.
in.	in.	in.	in.	in.	in.	in.	in.	in.
2	2⅛	2¼	2⅜	2½	2⅝	2¾	2⅞	3
2½	2½	2⅝	2¾	2⅞	3	3⅛	3⅜	3⅝
3	3	3⅛	3¼	3⅜	3½	3¾	4	4¼
3½	. . .	3½	3⅝	3¾	4	4¼	4½	4¾
4	. . .	4	4⅛	4¼	4½	4¾	5⅛	5⅜
4½	. . .	. . .	4½	4⅝	4⅞	5⅛	5½	5⅞
5	. . .	. . .	5	5⅛	5⅜	5⅝	6	6½
5½	. . .	. . .	. . .	5½	5¾	6	6½	6⅞
6	. . .	. . .	. . .	6	6⅜	6⅝	7⅛	7½

Should the load be placed near one end of the bay, *multiply* the fourth power of the diameter of shaft necessary to safely carry the load at the center of the bay (see above table) by the product of the two ends of the shaft, and divide this product by the product of the two ends of the shaft where the pulley is placed in the center. The fourth root of this quotient will be the required diameter.

A shaft carrying both receiving and driving pulleys should be figured as a head-shaft.

Deflection of Shafting.

(Pencoyd Iron Works.)

As the deflection of steel and iron is practically alike under similar conditions of dimensions and loads, and as shafting is usually determined by its transverse stiffness rather than its ultimate strength, nearly the same dimensions should be used for steel as for iron.

For continuous line-shafting it is considered good practice to limit the deflection to a maximum of $\frac{1}{100}$ of an inch per foot of length. The weight of bare shafting in pounds $= 2.6\, d^2L = W$, or when as fully loaded with pulleys as is customary in practice, and allowing 40 lbs. per inch of width for the vertical pull of the belts, experience shows the load in pounds to be about $13\, d^2L = W$. Taking the modulus of transverse elasticity at 26,000,000 lbs., we derive from authoritative formulæ the following:

$$L = \sqrt[3]{873\, d^2},\ d = \sqrt{\frac{L^3}{873}},\ \text{for bare shafting;}$$

$$L = \sqrt[3]{175\, d^2},\ d = \sqrt{\frac{L^3}{175}},\ \text{for shafting carrying pulleys, etc.;}$$

L being the maximum distance in feet between bearings for continuous shafting subjected to bending stress alone, d = diam. in inches.

The torsional stress is inversely proportional to the velocity of rotation, while the bending stress will not be reduced in the same ratio. It is therefore impossible to write a formula covering the whole problem and sufficiently simple for practical application, but the following rules are correct within the range of velocities usual in practice.

For continuous shafting so proportioned as to deflect not more than $\frac{1}{100}$ of an inch per foot of length, allowance being made for the weakening effect of key-seats,

$$d = \sqrt[3]{\frac{50\, H.P.}{r}},\ L = \sqrt[3]{700 d^2}\ \text{for bare shafts;}$$

$$d = \sqrt[3]{\frac{70\ H.P.}{r}},\ L = \sqrt[3]{140d^2},\ \text{for shafts carrying pulleys, etc.}$$

$d =$ diam. in inches, $L =$ length in feet, $r =$ revols. per minute.

The following table (by J. B. Francis) gives the greatest admissible distances between the bearings of continuous shafts subject to no transverse strain, except from their own weight.

Diam. of Shaft, in inches	Distance between Bearings in ft. Wrought-iron Shafts.	Steel Shafts.	Diam. of Shaft, in inches.	Distance between Bearings in ft. Wrought-iron Shafts.	Steel Shafts
2	15.46	15.89	6	22.30	22.92
3	17.70	18.19	7	23.48	24.13
4	19.48	20.02	8	24.55	25.23
5	20.99	21.57	9	25.53	26.24

The writer prefers to apply a formula in all cases rather than use tables, as shafting is nearly always one-sixteenth inch less in diameter than the sizes quoted. The following tables are made up from the formulæ first given in this chapter.

Horse-Power Transmitted by Turned Iron Shafting.

As Prime Mover or Head Shaft well Supported by Bearings.

Diam.	Revolutions per Minute.										
	60	80	100	125	150	175	200	225	250	275	300
Ins.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.
1¾	2.6	3.4	4.3	5.4	6.4	7.5	8.6	9.7	10.7	11.8	12.9
2	3.8	5.1	6.4	8	9.6	11.2	12.8	14.4	16	17.6	19.2
2¼	5.4	7.3	8.1	10	12	14	16	18	20	22	24
2½	7.5	10	12.5	15	18	22	25	28	31	34	37
2¾	10	13	16	20	24	28	32	36	40	44	48
3	13	17	20	25	30	35	40	45	50	55	60
3¼	16	22	27	34	40	47	54	61	67	74	81
3½	20	27	34	42	51	59	68	76	85	93	102
3¾	25	33	42	52	63	73	84	94	105	115	126
4	30	41	51	64	76	89	102	115	127	140	153
4½	43	58	72	90	108	126	144	162	180	198	216
5	60	80	100	125	150	175	200	225	250	275	300
5½	80	106	133	166	199	233	266	299	333	366	400

Approximate Centers of Bearings for Wrought Iron Line Shafts Carrying a Fair Proportion of Pulleys.

Shaft, Diameter Inches . .	1½	1¾	2	2¼	2½	2¾	3	3½	4	4½
c. to c. Bearings — Feet . .	7	7½	8	8½	9	9½	10	11	12	13
Shaft, Diameter Inches . .	5	5½	6	6½	7	7½	8	9	10	
c. to c. Bearings — Feet . .	13½	14	15	15½	16	17	18	19	20	

LINE-SHAFTING, BEARINGS 8 FT. APART.

Diam.	Revolutions per Minute.										
	100	125	150	175	200	225	250	275	300	325	350
Ins.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.
1¾	6	7.4	8.9	10.4	11.9	13.4	14.9	16.4	17.9	19.4	20.9
1⅞	7.3	9.1	10.9	12.7	14.5	16.3	18.2	20	21.8	23.6	25.4
2	8.9	11.1	13.3	15.5	17.7	20	22.2	24.4	26.6	28.8	31
2⅛	10.6	13.2	15.9	18.5	21.2	23.8	26.5	29.1	31.8	34.4	37
2¼	12.6	15.8	19	22	25	28	31	35	38	41	44
2⅜	15	18	22	26	29	33	37	41	44	48	52
2½	17	21	26	30	34	39	43	47	52	56	60
2¾	23	29	34	40	46	52	58	64	69	75	81
3	30	37	45	52	60	67	75	82	90	97	105
3¼	38	47	57	66	76	85	95	104	114	123	133
3½	47	59	71	83	95	107	119	131	143	155	167
3¾	58	73	88	102	117	132	146	162	176	190	205
4	71	89	107	125	142	160	178	196	213	231	249

POWER TRANSMISSION ONLY.

Diam.	Revolutions per Minute.										
	100	125	150	175	200	233	267	300	333	367	400
Ins.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.
1½	6.7	8.4	10.1	11.8	13.5	15.7	17.9	20.3	22.5	24.8	27.0
1⅝	8.6	10.7	12.8	15	17.1	20	22.8	25.8	28.6	31.5	34.3
1¾	10.7	13.4	16	18.7	21.5	25	28	32	36	39	43
1⅞	13.2	16.5	19.7	23	26.4	31	35	39	44	48	52
2	16	20	24	28	32	37	42	48	53	58	64
2⅛	19	24	29	33	38	44	51	57	63	70	76
2¼	22	28	34	39	45	52	60	68	75	83	90
2⅜	27	33	40	47	53	62	70	79	88	96	105
2½	31	39	47	54	62	73	83	93	104	114	125
2¾	41	52	62	73	83	97	111	125	139	153	167
3	54	67	81	94	108	126	144	162	180	198	216
3¼	68	86	103	120	137	160	182	205	228	250	273
3½	85	107	128	150	171	200	228	257	285	313	342

Horse-power Transmitted by Cold-rolled Iron Shafting.

AS PRIME MOVER OR HEAD SHAFT WELL SUPPORTED BY BEARINGS.

Diam.	Revolutions per Minute.										
	60	80	100	125	150	175	200	225	250	275	300
Ins.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.
1½	2.7	3.6	4.5	5.6	6.7	7.9	9.0	10	11	12	13
1¾	4.3	5.6	7.1	8.9	10.6	12.4	14.2	16	18	19	21
2	6.4	8.5	10.7	13	16	19	21	24	26	29	32
2¼	9	12	15	19	23	26	30	34	38	42	46
2½	12	17	21	26	31	36	41	47	52	57	62
2¾	16	22	27	35	41	48	55	62	70	76	82
3	21	29	36	45	54	63	72	81	90	98	108
3¼	27	36	45	57	68	80	91	103	114	126	136
3½	34	45	57	71	86	100	114	129	142	157	172
3¾	42	56	70	87	105	123	140	158	174	193	210
4	51	69	85	106	128	149	170	192	212	244	256
4½	73	97	121	151	182	212	243	273	302	333	364

LINE-SHAFTING, BEARINGS 8 FT. APART.

Diam.	Revolutions per Minute.										
	100	125	150	175	200	225	250	275	300	325	350
Ins.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.
1½	6.7	8.4	10.1	11.8	13.5	15.2	16.8	18.5	20.2	21.9	23.6
1⅝	8.6	10.7	12.8	15	17.1	19.3	21.5	23.6	25.7	28.9	31
1¾	10.7	13.4	16	18.7	21.5	24.2	26.8	29.5	32.1	34.8	39
1⅞	13.2	16.5	19.7	23	26.4	29.6	32.9	36.2	39.5	42.8	46
2	16	20	24	28	32	36	40	44	48	52	56
2⅛	19	24	29	33	38	43	48	52	57	62	67
2¼	22	28	34	39	45	50	56	61	68	74	80
2⅜	27	33	40	47	53	60	67	73	80	86	94
2½	31	39	47	54	62	69	78	86	93	101	109
2¾	41	52	62	73	83	93	104	114	125	135	145
3	54	67	81	94	108	121	134	148	162	175	189
3¼	68	86	103	120	137	154	172	188	205	222	240
3½	85	107	128	150	171	192	214	235	257	278	300

POWER TRANSMISSION AND SHORT COUNTERS.

Diam.	Revolutions per Minute.										
	100	125	150	175	200	233	267	300	333	367	400
Ins.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.
1¼	6.5	8.1	9.7	11.3	13	15.2	17.4	19.5	21.7	23.9	26
1⅜	8.5	10.7	12.8	15	17	19.8	22.7	25.5	28.4	31	34
1½	11.2	14	16.8	19.6	22.5	26	30	33	37	41	45
1⅝	14.2	17.7	21.2	24.8	28.4	33	38	42	47	52	57
1¾	18	22	27	31	35	41	47	53	59	65	71
1⅞	22	27	33	38	44	51	58	65	72	79	87
2	26	33	40	46	53	62	71	80	88	97	106
2⅛	32	40	47	55	63	73	84	95	105	116	127
2¼	38	47	57	66	76	89	101	114	127	139	152
2⅜	44	55	66	77	88	103	118	133	148	163	178
2½	52	65	78	91	104	121	138	155	172	190	207
2¾	69	84	99	113	138	161	184	207	231	254	277
3	90	112	135	157	180	210	240	270	300	330	360

Hollow Shafts.

Let d be the diameter of a solid shaft, and $d_1 d_2$ the external and internal diameters of a hollow shaft of the same material. Then the shafts will be of equal torsional strength when $d^3 = \frac{d_1^4 - d_2^4}{d_1}$. A 10-inch hollow shaft with internal diameter of 4 inches will weigh 16 % less than a solid 10-inch shaft, but its strength will be only 2.56 % less. If the hole were increased to 5 inches diameter the weight would be 25 % less than that of the solid shaft, and the strength 4.25 % less.

Table for Laying Out Shafting.

The table on the following page is used by Wm. Sellers & Co. for the laying out of shafting.

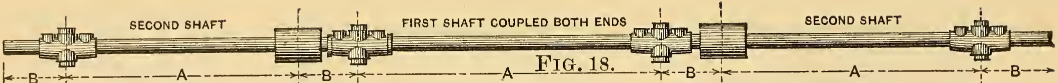


FIG. 18.

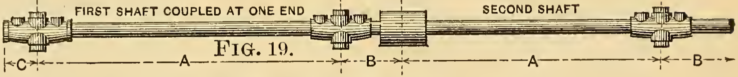


FIG. 19.

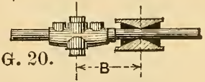


FIG. 20.

Table for Laying Out Shafting.

Length of Collared End for Fast Coll. ins.	Nominal Size of 2d Shaft. / Nominal Size of 1st Shaft, ins.	1½″	1¾″	2″	2¼″	2½″	2¾″	3″	3¼″	3½″	4″	4½″	5″	5½″	6″	6½″	7″	7½″	8″	Length of Bearing or Box, ins.	Double Cone-Vise Coupl'g. Length, Inches.	Double Cone-Vise Coupl'g. Diameter Inches.
		Distance from Center of Bearing to End of Shaft for Coupling. See *B*, Figs. 18, 19, and 20.																				
3½	1½	8½																		6	5½	3¾
4	1¾	9	9½																	7	6½	4⅝
4½	2	9½	10½	11																8	7⅝	5⅜
5	2¼		11	11½	12															9	8¼	5⅞
5⅝	2½		11½	12	12½	13														10	9½	6 9/16
6¼	2¾		12	12½	13	13½	14													11	10	7
6¾	3			13	13½	14	14½	15												12	11	7¾
7¼	3¼			13½	14	14½	15	15½	15½											13	12	8¼
7⅞	3½			14	14½	15	15½	16	16	16½										14	13	9 1/16
8 15/16	4			15	15½	16	16½	17	17	17½	18									16	14½	10
10	4½				16½	17	17½	18	18	18½	19½	20								18	16	11⅜
11⅛	5					18½	18½	19	19½	20	20½	21½	22							20	18	12 9/16
12 3/16	5½						20	20½	21	21	22	22½	23½	24						22	19	13½
13¼	6						21½	21½	22	22½	23	24	24½	25	26					24	21	14½
14⅜	6½							23	23½	24	24½	25	26	26½	27½	28½				26	25	17⅜
15½	7								25	25	26	26½	27½	28	29	30	30½			28	25	17⅜
16½	7½									26½	27	28	28½	29½	30	31	31½	32		30	28⅜	19 5/16
17¾	8										28½	29½	30	31	31½	32½	33	34	32½	32	28⅜	19 5/16

USE OF TABLE.—Look for size of first shaft in left-hand column, under the head of size of first shaft, and in the top line of table marked size of second shaft, find the size of the shaft to be coupled to it. The intersection gives the length *B*; this added to the length *A*, or distance from center to center of bearing, and in cases similar to Fig. 19, to the length *C*, gives the length of the first shaft, thus: as in Fig. 18, $B + A + B =$ length; Fig. 19, $C + A + B =$ length.

Make bearings at equal distances from each other when practicable; always put 2 bearings on first, which is collared shaft. See Figs. 18 & 19.

In coupling shafts of different sizes either reduce the end of the large shaft in diameter and use a small coupling, or use a coupling to suit the larger shaft, with 1 cone bored for smaller nominal shaft.

PULLEYS.

Unwin says the number of arms is arbitrary, and gives the following values:

$a =$ Number of arms $=$ for a single set $= 3 + \frac{b\,d}{150}$.
$d =$ diameter pulley.
$t =$ thickness of edge of rim of pulley $= .75$ inches $+ .005d$.
$T =$ thickness of middle of rim of pulley $= 2t + c$.
$b =$ breadth of rim of pulley $= \frac{9}{8}(B + 0.4)$.
$B =$ breadth of belt.

$$h = \text{breadth of arm at hub} \begin{cases} \text{for single belt} = .6337\sqrt[3]{\dfrac{b\,d}{a}} \\ \text{for double belt} = .798\sqrt[3]{\dfrac{b\,d}{a}} \end{cases}$$

$h_1 =$ breadth of arm at rim $= \frac{2}{3}h$.
$e =$ thickness of arm at hub $= 0.4\,h$.
$e_1 =$ thickness of arm at rim $= 0.4\,h_1$.
$c =$ crowning $= \frac{1}{24}b$.
$L =$ length of hub $=$ about $\frac{2}{3}b$.

Reuleaux says pulleys of more than one set of arms may be considered as separate pulleys, except proportions of arms may be 0.8 to 0.7 that of single-arm pulleys.

To Find Size of Pulley.

$D =$ diameter of driver, or No. teeth in gear.
$d =$ diameter of driven, or No. teeth in pinion.
$Rev =$ revolutions per minute of driver.
$rev =$ revolutions per minute of driven.

$$D = \frac{d \times rev}{Rev}. \qquad Rev = \frac{d \times rev}{D}.$$

$$d = \frac{D \times Rev}{rev}. \qquad rev = \frac{D \times Rev}{d}.$$

BELTING.

The coefficient of friction of belts on pulleys varies greatly, and it is therefore customary to use some arbitrary formula that has proved safe in practice.

$d =$ diameter pulley in inches.
$\pi d =$ circumference.
$v =$ velocity of belt (or pulley face) in feet per minute.
$a =$ angle of arc of contact, commonly assumed as 180°.
$l =$ length of arc of contact in feet $= \frac{\pi\,d\,a}{4320}$.
$F =$ tractive force per square inch cross-section of belt.
$w =$ width of belt in inches.
$t =$ thickness of belt in inches.
$S =$ tractive force per inch of width $= \frac{F}{t}$.
$rpm =$ revolutions per minute.

$$v = \frac{\pi\,d}{12} \times rpm.$$

$$H.\,P. = \frac{v\,w\,S}{33000} = \frac{d\,w\,S \times rpm}{126050}.$$

A rule in common use for approximate determination of the H.P. of belts is, that a single belt 1 inch wide, traveling 1000 feet per minute, will transmit 1 horse-power. This corresponds to a strain on the belt of 33 lbs. per inch of width.

Authorities say single belts can be safely worked at 45 lbs. strain per square inch, and on this basis

$$H.P. = \frac{v\,w}{733} = \frac{d\,w \times rpm}{2800}.$$

Double belts are said to be able to transmit power in the ratio of 10 to 7 for single belts.

$$\text{H. P. of double belts} = \frac{v\,w}{513} = \frac{d\,w \times rpm}{1960}.$$

If the double belt is twice the thickness of the single belt, then it is fair to assume that it will transmit twice the power, and

$$\text{H. P. of double belt} = \frac{v\,w}{366} = \frac{d\,w \times rpm}{1400}.$$

A. F. Nagle (Trans. A. S. M. E., vol. ii. 1881) gives the following formula

$$\text{H. P.} = CVtw\left(\frac{F - 0.012\,V^2}{550}\right).$$

$$\text{Where } C = 1 - 10^{-.00758fa}.$$
$$f = \text{coefficient of friction.}$$

Horse-Power of a Belt one Inch Wide, Arc of Contact 180°.

Comparison of Different Formulæ.

Velocity in Feet per Second.	Velocity in Feet per Minute.	Square Ft. of Belt per Minute.	Form. 1 H.P. = $\frac{wv}{550}$.	Form. 2 H.P. = $\frac{wv}{1100}$.	Form. 3 H.P. = $\frac{wv}{1000}$.	Form. 4 H.P. = $\frac{wv}{733}$.	Form. 5 Double. Belt H.P. = $\frac{wv}{513}$.	Nagle's Form. $\frac{7}{32}''$ single Belt.	
								Laced.	Riveted.
10	600	50	1.09	.55	.60	.82	1.17	.73	1.14
20	1200	100	2.18	1.09	1.20	1.64	2.34	1.54	2.24
30	1800	150	3.27	1.64	1.80	2.46	3.51	2.25	3.31
40	2400	200	4.36	2.18	2.40	3.27	4.68	2.90	4.33
50	3000	250	5.45	2.73	3.00	4.09	5.85	3.48	5.26
60	3600	300	6.55	3.27	3.60	4.91	7.02	3.95	6.09
70	4200	350	7.63	3.82	4.20	5.73	8.19	4.29	6.78
80	4800	400	8.73	4.36	4.80	6.55	9.36	4.50	7.36
90	5400	450	9.82	4.91	5.40	7.37	10.53	4.55	7.74
100	6000	500	10.91	5.45	6.00	8.18	11.70	4.41	7.96
110	6600	550	. . .	. . .	. . .	. . .	. . .	4.05	7.97
120	7200	600	. . .	. . .	. . .	. . .	. . .	3.49	7.75

Width of Belt for a given Horse-Power.

The width of belt required for any given horse-power may be obtained by transposing the formulæ for horse-power so as to give the value of w. Thus:

$$\text{From formula (1), } w = \frac{550\text{ H. P.}}{v} = \frac{9.17\text{ H. P.}}{V} = \frac{2101\text{ H. P.}}{d \times rpm} = \frac{275\text{ H. P.}}{L \times rpm}.$$

$$\text{From formula (2), } w = \frac{1100\text{ H. P.}}{v} = \frac{18.33\text{ H. P.}}{V} = \frac{4202\text{ H. P.}}{d \times rpm} = \frac{530\text{ H. P.}}{L \times rpm}.$$

$$\text{From formula (3), } w = \frac{1000\text{ H. P.}}{v} = \frac{16.67\text{ H. P.}}{V} = \frac{38.20\text{ H. P.}}{d \times rpm} = \frac{500\text{ H. P.}}{L \times rpm}.$$

$$\text{From formula (4), } w = \frac{733\text{ H. P.}}{v} = \frac{12.22\text{ H. P.}}{V} = \frac{2800\text{ H. P.}}{d \times rpm} = \frac{360\text{ H. P.}}{L \times rpm}.$$

$$\text{From formula (5),* } w = \frac{513\text{ H. P.}}{v} = \frac{8.56\text{ H. P.}}{V} = \frac{1960\text{ H. P.}}{d \times rpm} = \frac{257\text{ H. P.}}{L \times rpm}.$$

* *For double belts.*

Length of Belt.

Approximate rule; two pulleys $\left[\left(\frac{Dia_1+Dia_2}{2}\right)\times 3.1416\right]+[2\times$ distance between centers] = length of belt.

Length of Belt in Roll.

Outside diameter roll in inches + diameter hole × number turns × .1309 = length of belt in inches for double belt.

Weight of Belt (*approximate*).

$\frac{\text{Length in feet}\times\text{width in inches}}{13}$ = weight of single belt. Divide by 8 for double belts.

Horse-Power Transmitted by Light, Double Endless Leather Belting.

(Buckley.)

	Width, Inches.	4	6	8	10	12	14	16	18	20	22	24
Speed in feet per min.	2000	14	22	29	36	43	50	58	65	72	80	87
	2400	17	26	35	44	52	60	70	78	88	96	105
	2800	20	30	40	51	61	71	81	91	102	112	122
	3000	22	33	44	54	65	76	87	98	108	120	131
	3500	25	38	50	63	76	89	101	114	127	140	153
	4000	29	43	58	73	87	101	116	131	145	160	174
	4500	32	49	65	82	98	114	131	147	163	180	196
	5000	36	55	73	91	109	127	145	163	182	200	218
	5500	40	60	80	100	120	140	160	180	200	220	240
	6000	44	65	87	109	130	153	175	200	218	240	260

(Speed × width ÷ 550 = horse-power, light, double.)
(Horse-power × 550 ÷ speed = width, light, double.)

Horse-Power Transmitted by Heavy, Double Endless Leather Belting.

	Width, Inches.	4	6	8	10	12	14	16	18	20	22	24
Speed in feet per min.	2000	18	27	36	43	51	60	70	80	86	96	104
	2400	21	31	42	53	62	72	83	94	105	115	120
	2800	24	36	48	61	73	85	96	109	122	135	146
	3000	27	40	53	65	78	90	104	118	129	144	157
	3500	30	45	60	75	91	106	121	137	152	168	184
	4000	35	52	70	88	104	121	139	157	174	192	209
	4500	38	59	78	98	118	137	157	176	196	216	235
	5000	43	66	87	110	130	152	174	196	218	240	262
	5500	48	72	96	120	144	168	192	216	240	264	288
	6000	52	78	104	122	153	183	210	240	262	288	312

(Speed × width ÷ 460 = horse-power, heavy, double.)
(Horse-power × 460 ÷ speed = width, heavy, double.)

ROPE DRIVING.

$C =$ Circumference of rope in inches.
$D =$ Diameter of pulley in feet.
$R =$ Revolutions per minute.

Horse-power of Rope: $\frac{C \times D \times R}{200} =$ H.P.

or, Half the diameter of rope multiplied by the hundreds of feet per minute traveled. (L. I. Seymour.)

Breaking strength of manila rope in pounds $= C^2 \times$ coefficient. The coefficient varies from 900 for ½-inch to 700 for 2-inch diameter rope. The following is a reliable table prepared by T. Spencer Miller, M.E. (See *Engineering News*, December 6, 1890.)

Diameter.	Circumference.	Ultimate Strength.	Coefficient.
½	1½	2,000	900
⅝	2	3,250	845
¾	2¼	4,000	820
⅞	2¾	6,000	790
1	3	7,000	780
1⅛	3½	9,350	765
1¼	3¾	10,000	760
1⅜	4¼	13,500	745
1½	4½	15,000	735
1⅝	5	18,200	725
1¾	5½	21,750	712
2	6	25,000	700

This table was compiled by averaging and graduating results of tests at the Watertown Arsenal and Laboratory of Riehle Brothers, in Philadelphia.

Weight of manila rope in pounds per foot $= .032$ (Circumference in inches)^2. (C. W. Hunt.)
or, diameter of rope in inches squared = weight in pounds per yard approximately.

The coefficient of friction on a rope working on a cast-iron pulley $= 0.28$; when working in an ungreased groove it is increased about three times, or from 0.57 to 0.84. If the pulleys are greased, the coefficient is reduced about one-half. It has been found by experiment that a rope 6 inches circumference in a grooved pulley possesses four times the adhesive resistance to slipping, exhibited by a half-worn, ungreased 4-inch single belt.

The length of splice should be 72 times the diameter of rope. The strength of a rope containing a properly made "long splice" was found to be 7,000 pounds per square inch of section.

A mixture of molasses and plumbago makes an excellent dope for transmitting ropes. Grease and oils of all kinds should be kept from transmission ropes, since, as a rule, they are injurious.

Following is another formula for horse-power of manila rope:

$$H.P. = \frac{(T_0 - C)V}{33000},$$

in which h.p. is the horse-power transmitted by one rope, V the velocity in feet per minute, T_0 the maximum working stress, and C the centrifugal tension, so that $(T - C)$ is the *net* tension available for the transmission of power. Taking the total maximum stress at $200d^2$ and allow 20 % of this for slack side tension, we have $T_0 = 160d^2$, so that H.P. $= \frac{(160\,d^2 - C)\,V}{33{,}000}$.

A table has been calculated by this rule, giving the horse-power per rope, transmitted at various speeds.

C = CENTRIFUGAL TENSION IN MANILA ROPES — POUNDS.

Velocity of Rope in ft. per Min.	Nominal Diameter of Rope in Inches.											
	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	2
1000	0.7	1.1	1.5	2.1	2.7	3.4	4.3	5.1	6.2	7.2	8.3	11
1500	1.5	2.4	3.4	4.7	6.2	7.6	9.7	11	13	16	18	25
2000	2.7	4.3	6.1	8.2	11	13	17	20	24	28	33	44
2500	4.3	6.7	9.6	13	17	21	27	32	38	45	52	69
3000	6.2	9.7	13	18	24	30	39	45	55	64	74	100
3500	8.4	13	19	25	34	42	53	63	75	89	102	136
4000	11	17	24	33	44	54	69	82	98	116	133	177
4500	14	22	31	42	55	69	87	103	125	146	168	223
5000	17	27	39	52	69	86	109	129	156	183	210	275
5500	21	33	47	63	83	104	132	156	189	221	254	332
6000	24	39	56	75	99	125	157	188	225	257	303	396
6500	39	45	65	88	116	145	183	217	261	307	353	462

Horse-Power of Manila Ropes.

Velocity of Rope. Ft. per Min.	Nominal Diameter of Rope in Inches.											
	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	2
2000	2.25	3.51	5.14	6.84	9.08	11.5	14.0	17.0	20.3	23.8	27.5	36.1
2100	2.35	3.67	5.27	7.15	9.40	11.8	14.7	17.8	21.1	24.8	28.8	37.6
2200	2.45	3.82	5.48	7.45	9.80	12.3	15.3	18.5	22.0	25.9	30.0	39.2
2300	2.55	3.98	5.71	7.75	10.2	12.8	15.9	19.3	22.9	26.9	31.2	40.8
2400	2.62	4.10	5.89	7.98	10.5	13.2	16.4	19.8	23.6	27.7	32.2	42.0
2500	2.70	4.21	6.05	8.21	10.8	13.6	16.8	20.4	24.3	28.5	33.1	43.2
2600	2.78	4.33	6.21	8.43	11.1	14.0	17.3	21.0	25.0	29.3	34.0	44.4
2700	2.85	4.45	6.39	8.67	11.4	14.4	17.8	21.5	25.6	30.5	35.0	45.6
2800	2.94	4.59	6.59	8.93	11.75	14.8	18.3	22.2	26.4	31.0	36.0	47.0
2900	3.00	4.68	6.73	9.13	12.0	15.1	18.7	22.7	27.0	31.6	36.8	48.0
3000	3.06	4.78	6.87	9.32	12.3	15.4	19.1	23.2	27.6	32.3	37.6	49.1
3100	3.12	4.87	7.01	9.50	12.5	15.7	19.5	23.6	28.2	33.0	38.3	50.0
3200	3.18	4.97	7.14	9.70	12.7	16.0	19.9	24.0	28.7	33.7	39.0	51.0
3300	3.25	5.07	7.27	9.89	13.0	16.3	20.3	24.5	29.2	34.3	39.8	52.0
3400	3.30	5.15	7.39	10.0	13.2	16.6	20.6	25.0	29.7	34.8	40.4	52.8
3500	3.35	5.22	7.50	10.2	13.4	16.9	20.9	25.3	30.1	35.4	41.0	53.6
3600	3.40	5.30	7.61	10.3	13.6	17.1	21.2	25.7	30.6	35.9	41.6	54.4
3700	3.44	5.36	7.70	10.4	13.7	17.3	21.5	26.0	30.0	36.3	42.1	55.0
3800	3.46	5.40	7.76	10.5	13.8	17.4	21.6	26.2	31.1	36.6	42.4	55.4
3900	3.49	5.45	7.81	10.6	13.9	17.6	21.8	26.4	31.4	36.9	42.7	55.8
4000	3.51	5.49	7.86	10.6	14.0	17.7	21.9	26.5	31.6	37.1	43.0	56.1
4100	3.53	5.52	7.92	10.7	14.1	17.8	22.0	26.7	31.8	37.3	43.2	56.4
4200	3.55	5.54	7.95	10.8	14.2	17.9	22.1	26.8	31.9	37.5	43.4	56.8
4300	3.56	5.55	7.98	10.8	14.2	17.9	22.2	26.9	32.0	37.6	43.6	56.9
4400	3.57	5.56	7.99	10.8	14.2	18.0	22.2	27.0	32.1	37.6	43.6	57.0
4500	3.56	5.55	7.96	10.8	14.2	17.9	22.2	26.9	32.0	37.6	43.5	56.9
4600	3.55	5.54	7·95	10.8	14.2	17.9	22.1	26.8	31.9	37.5	43.4	56.8
4700	3.53	5.50	7.90	10.7	14.1	17.8	22.0	26.6	31.7	37.2	43.1	56.4
4800	3.51	5.48	7.86	10.7	14.0	17.7	21.9	26.5	31.6	37.1	43.0	56.2
4900	3.49	5.45	7.81	10.6	13.9	17.6	21.8	26.4	31.4	36.9	42.7	55.8
5000	3.45	5.38	7.73	10.5	13.8	17.4	21.5	26.1	31.0	36.4	42.2	55.2
5100	3.43	5.35	7.67	10.4	13.7	17.2	21.3	25.9	30.8	36.2	41.9	54.8
5200	3.38	5.26	7.56	10.2	13.5	17.0	21.0	25.5	30.4	35.6	41.3	54.0
5300	3.34	5.20	7.47	10.1	13.3	16.8	20.8	25.2	30.0	35.2	40.8	53.4
5400	3.28	5.11	7.34	9.95	13.1	16.5	20.4	24.8	29.4	34.6	40.1	52.5
5500	3.21	5.00	7.20	9.75	12.8	16.2	20.0	24.2	28.9	33.9	39.3	51.4
6000	2.78	4.33	6.21	8.43	11.1	14.0	17.3	21.0	25.0	29.3	34.0	44.4
6500	2.17	3.38	4.85	6.60	8.6	10.9	13.5	16.4	19.5	22.9	26.5	34.7

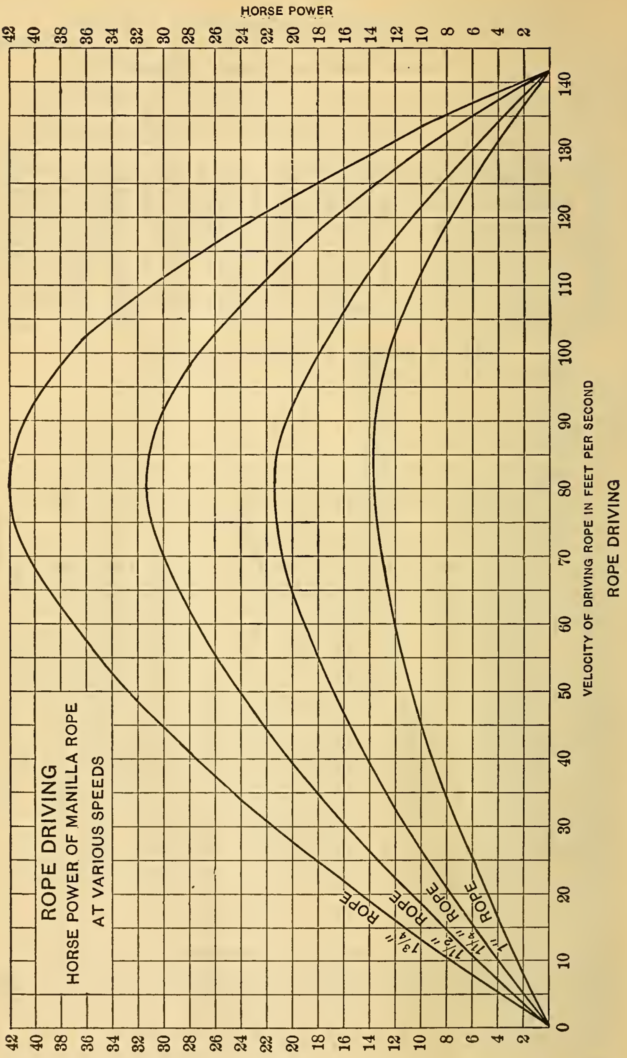

HORSE POWER
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
VELOCITY OF DRIVING ROPE IN FEET PER SECOND
ROPE DRIVING
ROPE DRIVING
HORSE POWER OF MANILLA ROPE
AT VARIOUS SPEEDS
1¾" ROPE
1½" ROPE
1¼" ROPE
1" ROPE

FIG. 21.

Horse-Power of "Stevedore" Transmission Rope at Various Speeds.

In this table the effect of the centrifugal force has been taken into consideration, and the strain on the fibers of the rope is the same at all speeds when transmitting the horse-power given in the table. When more than one rope is used, multiply the tabular number by the number of the ropes. At a speed of 8,400 per minute the centrifugal force absorbs all the allowable tension the rope should bear, and no power will be transmitted.

Table of the Horse-Power of Transmission Rope.

(Hunt's Formula.)

Diameter of Rope.	Speed of the Rope in Feet per Minute.											Smallest Diam. Pulleys.
	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	6,000	7,000	8,400	
½	1.45	1.9	2.3	2.7	3.	3.2	3.4	3.4	3.1	2.2	.0	.20
⅝	2.3	3.2	3.6	4.2	4.6	5.0	5.3	5.3	4.9	3.4	.0	.25
¾	3.3	4.3	5.2	5.8	6.7	7.2	7.7	7.7	7.1	4.9	.0	.30
⅞	4.5	5.9	7.0	8.2	9.1	9.8	10.8	10.7	9.3	6.9	.0	.36
1	5.8	7.7	9.2	10.7	11.9	12.8	13.6	13.7	12.5	8.8	.0	.42
1¼	9.2	12.1	14.3	16.8	18.6	20.0	21.2	21.4	19.5	13.8	.0	.54
1½	13.1	17.4	20.7	23.1	26.8	28.8	30.6	30.8	28.2	19.8	.0	.60
1¾	18.	23.7	28.2	32.8	36.4	39.2	41.5	41.8	37.4	27.6	.0	.72
2	23.2	30.8	36.8	42.8	47.6	51.2	54.4	54.8	50.	35.2	.0	.84

For a temporary installation when the rope is not to be long in use, it might be advisable to increase the work to double that given in the tables.

Slip of Ropes and Belts.

(W. W. Christie.)

Some French trials, with constant resistance, the power expended and slip in several modes of transmission was as follows:

Ropes,	158.54	gross h.p.,	Slip,	0.33	per cent.
Cotton belt,	159.67	"	"	0.78	"
Leather "	158.84	"	"	0.96	"
" "	160.23	"	"	0.78	"

Stated in percentage value, the results were:

Ropes,	100.00	gross power,	Slip,	0.100.
Cotton belt,	100.87	"	"	0.237.
Leather "	100.37	"	"	0.292.
" "	101.07	"	"	0.237,

Manila Cordage.					Tarred Hemp.
Size, Circumfer'ce. Inches.	Size, Diameter. Inches.	Weight of 100 Fathoms.	Feet in one Pound.	Breaking Strain of New Ropes. Pounds.	Weight of 100 Fathoms.
1¼	⅜	31	20	For Ropes in use deduct ⅓ from these figures, for chafing, etc.	40
1½	½	44	14		55
1¾	$\frac{9}{16}$	60	10		75
2	⅝	79	7½	3000	100
2¼	¾	99	6	4000	125
2½	$\frac{13}{16}$	122	5	5000	155
2¾	⅞	146	4	6000	190
3	1	176	3⅜	7000	225
3¼	$1\frac{1}{16}$	207	3	8500	265
3½	1⅛	240	2½	9500	300
3¾	1¼	275	2⅙	11000	355
4	$1\frac{5}{16}$	305	2	12500	405
4¼	1⅜	355	$1\frac{8}{12}$	14000	455
4½	1½	395	1½	16000	500
5	1⅝	490	1¼	20000	630
5½	1¾	595	1	24000	750
6	2	705	10 in.	27000	910
6½	2⅛	825	8½	31500	1050
7	2¼	960	7½	37000	1235
7½	2½	1100	6½	42500	1400
8	2⅝	1255	5½	48500	1600
8½	2⅞	1415	5	54500	1820
9	3	1585	4½	61500	2050

Hawser laid will weigh ⅙ less.

Notes on the Uses of Wire Rope.

(Roebling.)

Two kinds of wire rope are manufactured. The most pliable variety contains 19 wires in the strand, and is generally used for hoisting and running rope.

For safe working load allow ⅕ or ⅐ of the ultimate strength, according to speed, so as to get good wear from the rope. Wire rope is as pliable as new hemp rope of the same strength; but the greater the diameter of the sheaves the longer wire rope will last.

Experience has proved that the wear increases with the speed. It is, therefore, better to increase the load than the speed. Wire rope must not be coiled or uncoiled like hemp or manila — all untwisting or kinking must be avoided.

In no case should galvanized rope be used for running. One day's use scrapes off the zinc coating.

Table of Strains Produced by Loads on Inclined Planes.

Elevation in 100 Ft.	Strain in Lbs. on Rope from a Load of 1 Ton.	Elevation in 100 Ft.	Strain in Lbs. on Rope from a Load of 1 Ton.
Ft. Deg.		Ft. Deg.	
10 = 5½	212	90 = 42	1347
20 = 11⅕	404	100 = 45	1419
30 = 16¾	586	110 = 47¾	1487
40 = 21⅚	754	120 = 50¼	1544
50 = 26⅓	905	130 = 52½	1592
60 = 31	1040	140 = 54½	1633
70 = 35	1156	150 = 56¼	1671
80 = 38⅔	1260	160 = 58	1703

Table of Transmission of Power by Wire Ropes.

Showing necessary size and speed of wheels and rope to obtain any desired amount of power.

(Roebling.)

Diam. of Wheel in Ft.	No. of Revolutions.	Diam. of Rope.	Horse-Power.	Diam. of Wheel in Ft.	No. of Revolutions.	Diam. of Rope.	Horse-Power.
4	80	$\frac{3}{8}$	3.3	10	80	$\frac{11}{16}$	58.4
	100	$\frac{3}{8}$	4.1		100	$\frac{11}{16}$	73.
	120	$\frac{3}{8}$	5.		120	$\frac{11}{16}$	87.6
	140	$\frac{3}{8}$	5.8		140	$\frac{11}{16}$	102.2
5	80	$\frac{7}{16}$	6.9	11	80	$\frac{11}{16}$	75.5
	100	$\frac{7}{16}$	8.6		100	$\frac{11}{16}$	94.4
	120	$\frac{7}{16}$	10.3		120	$\frac{11}{16}$	113.3
	140	$\frac{7}{16}$	12.1		140	$\frac{11}{16}$	132.1
6	80	$\frac{1}{2}$	10.7	12	80	$\frac{3}{4}$	99.3
	100	$\frac{1}{2}$	13.4		100	$\frac{3}{4}$	124.1
	120	$\frac{1}{2}$	16.1		120	$\frac{3}{4}$	148.9
	140	$\frac{1}{2}$	18.7		140	$\frac{3}{4}$	173.7
7	80	$\frac{9}{16}$	16.9	13	80	$\frac{3}{4}$	122.6
	100	$\frac{9}{16}$	21.1		100	$\frac{3}{4}$	153.2
	120	$\frac{9}{16}$	25.3		120	$\frac{3}{4}$	183.9
8	80	$\frac{5}{8}$	22.	14	80	$\frac{7}{8}$	148.
	100	$\frac{5}{8}$	27.5		100	$\frac{7}{8}$	185.
	120	$\frac{5}{8}$	33.		120	$\frac{7}{8}$	222.
9	80	$\frac{5}{8}$	41.5	15	80	$\frac{7}{8}$	217.
	100	$\frac{5}{8}$	51.9		100	$\frac{7}{8}$	259.
	120	$\frac{5}{8}$	62.2		120	$\frac{7}{8}$	300.

Hoisting Ropes (19 Wires to the Strand).

(Trenton Iron Company's List.)

Iron.								Crucible Steel.			
Trade Number.	Diameter in Ins.	Circumference in Ins.	Weight per ft., in Lbs., with Hemp Center.	Break'g Stress, in Tons of 2000 Lbs.	Proper Working Load in Tons of 2000 Lbs.	Circumference of Hemp Rope of Equal Strength.	Min. Size of Drum or Sheave, in Ft.	Break'g Stress, in Tons of 2000 Lbs.	Proper Work'g Load, in Tons of 2000 Lbs.	Circumference of Hemp Rope of Equal Strength.	Min. Size of Drum or Sheave in Ft.
1	$2\frac{1}{4}$	7	8.	74	15	$15\frac{1}{2}$	8	164.69	32.9	. . .	9
2	2	$6\frac{1}{4}$	6.3	65	13	$14\frac{1}{2}$	7	132.37	26.5	. . .	8
3	$1\frac{3}{4}$	$5\frac{1}{2}$	5.25	54	11	13	$6\frac{1}{2}$	108.13	21.63	. . .	$7\frac{1}{2}$
4	$1\frac{5}{8}$	5	4.1	44	9	12	5	97.17	19.44	. . .	6
5	$1\frac{1}{2}$	$4\frac{3}{4}$	3.65	39	8	$11\frac{1}{2}$	$4\frac{3}{4}$	86.38	17.3	$16\frac{1}{2}$	$5\frac{1}{2}$
$5\frac{1}{2}$	$1\frac{3}{8}$	$4\frac{1}{4}$	3.	33	6.5	$10\frac{1}{4}$	$4\frac{1}{2}$	61.00	12.2	15	5
6	$1\frac{1}{4}$	4	2.5	27	5.5	$9\frac{1}{2}$	4	50.17	10.	$12\frac{1}{4}$	5
7	$1\frac{1}{8}$	$3\frac{1}{2}$	2.	20	4	8	$3\frac{1}{2}$	38.00	7.7	11	$4\frac{1}{2}$
8	1	$3\frac{1}{8}$	1.58	16	3	7	3	29.2	5.8	9	4
9	$\frac{7}{8}$	$2\frac{3}{4}$	1.2	11.5	2.5	6	$2\frac{3}{4}$	21.55	4.	8	$3\frac{3}{4}$
10	$\frac{3}{4}$	$2\frac{3}{8}$	.88	8.64	1.75	5	$2\frac{1}{2}$	14.99	3.	$6\frac{1}{2}$	$3\frac{1}{2}$
$10\frac{1}{4}$	$\frac{5}{8}$	2	.7	5.13	1.25	$4\frac{1}{2}$	2	12.53	2.5	$5\frac{3}{4}$	3
$10\frac{1}{2}$	$\frac{9}{16}$	$1\frac{3}{4}$	.44	4.27	.75	4	$1\frac{3}{4}$	8.81	1.75	$5\frac{1}{4}$	$2\frac{3}{4}$
$10\frac{3}{4}$	$\frac{1}{2}$	$1\frac{1}{2}$	.35	3.48	.5	$3\frac{1}{2}$	$1\frac{1}{2}$	7.52	1.5	$4\frac{3}{4}$	2

The drums and sheaves should be made as large as possible. The minimum size of drum is given in a column in table.

It is better to increase the load than the speed.

Wire rope is manufactured either with a wire or a hemp center. The latter is more pliable than the former, and will wear better where there is short bending. The weight of rope with wire center is about 10 per cent more than with hemp center.

Power Transmission and Standing Ropes (7 Wires to the Strand).

(Trenton Iron Company's List.)

Iron.							Crucible Steel.		
Trade Number.	Diameter in Ins.	Circumference in Ins.	Weight per Foot, in Lbs., with Hemp Center.	Breaking Stress, in Tons of 2000 Lbs.	Proper Working Load, in Tons of 2000 Lbs.	Circumference of Hemp Rope of Equal Strength.	Breaking Stress, in Tons of 2000 Lbs.	Proper Working Load, in Tons of 2000 Lbs.	Circumference of Hemp Rope of Equal Strength.
11	$1\frac{1}{2}$	$4\frac{3}{4}$	3.37	36	9	$10\frac{3}{4}$	88.38	22	$16\frac{1}{2}$
12	$1\frac{3}{8}$	$4\frac{1}{4}$	2.77	30	$7\frac{1}{2}$	10	67.2	16.8	$15\frac{1}{2}$
13	$1\frac{1}{4}$	4	2.28	25	$6\frac{1}{4}$	$9\frac{1}{4}$	60.67	15.2	15
14	$1\frac{1}{8}$	$3\frac{1}{2}$	1.82	20	5	8	39.84	10.	11
15	1	$3\frac{1}{8}$	1.5	16	4	7	31.82	8.	$9\frac{1}{2}$
16	$\frac{7}{8}$	$2\frac{3}{4}$	1.12	12.3	3	$6\frac{1}{4}$	24.7	6.2	$8\frac{1}{2}$
17	$\frac{3}{4}$	$2\frac{3}{8}$	.88	8.8	$2\frac{1}{4}$	$5\frac{1}{4}$	18.48	4.6	$7\frac{3}{4}$
18	$\frac{11}{16}$	$2\frac{1}{8}$	.7	7.6	2	5	16.32	4.	$7\frac{1}{4}$
19	$\frac{5}{8}$	2	.57	5.8	$1\frac{1}{2}$	$4\frac{3}{4}$	12.44	3.1	6
20	$\frac{9}{16}$	$1\frac{3}{4}$	.41	4.1	1	4	9.33	2.3	$5\frac{1}{4}$
21	$\frac{1}{2}$	$1\frac{1}{2}$	.31	2.83	$\frac{3}{4}$	$3\frac{1}{4}$	6.89	1.7	$4\frac{1}{2}$
22	$\frac{7}{16}$	$1\frac{3}{8}$	.23	2.13	$\frac{1}{2}$	$2\frac{3}{4}$	5.23	1.3	$3\frac{1}{2}$
23	$\frac{3}{8}$	$1\frac{1}{8}$	.19	1.65	. . .	$2\frac{1}{2}$	3.93	1.	$3\frac{1}{8}$
24	$\frac{5}{16}$	1	.16	1.38	. . .	$2\frac{1}{4}$	3.25	.81	3
25	$\frac{9}{32}$	$\frac{7}{8}$	.125	1.03	. . .	2	2.96	.75	$2\frac{3}{4}$

Wire Rope.

Tons breaking weight = (diameter in quarter inches)^2.

MISCELLANEOUS TABLES.

WEIGHTS AND MEASURES.

Measure of Capacity.

Gallon. — The standard gallon measures 231 cubic inches, and contains 8.3388822 pounds avoirdupois = 58372.1757 grains Troy, of distilled water, at its maximum density 39.83° Fahrenheit, and 30 inches barometer height.

Bushel. — The standard bushel measures 2150.42 cubic inches = 77.627413 pounds avoirdupois of distilled water at 39.83° Fahrenheit, barometer 30 inches. Its dimensions are 18½ inches inside diameter, 19½ inches outside, and 8 inches deep; and when heaped, the cone must not be less than 6 inches high, equal 2747.70 cubic inches for a true cone.

Pound. — The standard pound avoirdupois is the weight of 27.7015 cubic inches of distilled water, at 39.83° Fahrenheit, barometer 30 inches, and weighed in the air.

Measure of Length.

Miles.	Furlongs.	Chains.	Rods.	Yards.	Feet.	Inches.
1	8	80	320	1760	5280	63360
0.125	**1**	10	40	220	660	7920
0.0125	0.1	**1**	4	22	66	792
0.003125	0.025	0.25	**1**	5.5	16.5	198
0.00056818	0.0045454	0.045454	0.181818	**1**	3	36
0.00018939	0.00151515	0.01515151	0.0606060	0.33333	**1**	12
0.000015783	0.000126262	0.001262626	0.00505050	0.0277777	0.083333	**1**

Measure of Surface.

Sq. Miles.	Acres.	S. Chains	Sq. Rods.	Sq. Yards	Sq. Feet.	Sq. Inches
1	640	6400	102400	3097600	27878400	4014489600
0·001562	**1**	10	160	4840	43560	6272640
0.0001562	0.1	**1**	16	484	4356	627264
0.000009764	0.00625	0.0625	**1**	30.25	272.25	39204
0.000000323	0.0002066	0.002066	0.0330	**1**	9	1296
0.0000000358	0.00002296	0.0002296	0.00367	0.1111111	**1**	144
0.00000000025	0.000000159	0.00000159	0.00002552	0.0007716	0.006944	**1**

Measure of Capacity.

Cub. Yard.	Bushel.	Cub. Feet.	Pecks.	Gallons.	Cub. Inch.
1	21.6962	27	100.987	201.974	46656
0.03961	**1**	1.24445	4	9.30918	2150.42
0.037037	0.803564	**1**	3.21425	7.4805	1728
0.009259	0.25	0.31114	**1**	2.32729	537.605
——	0.107421	0.133681	0.429684	**1**	231
——	——	0.000547	0.001860	0.004329	**1**

Measure of Liquids.

Gallon.	Quarts.	Pints.	Gills.	Cub. Inch.
1	4	8	32	231
0.25	**1**	2	8	57.75
0.125	0.5	**1**	4	28.875
0.03125	0.125	0.25	**1**	7.21875
0.004329	0.17315	0.03463	0.13858	**1**

Measures of Weights.

AVOIRDUPOIS.

Ton.	Cwt.	Pounds.	Ounces.	Drams.
1	20	2240	35840	573440
0.05	**1**	112	1792	28672
0.00044642	0.0089285	**1**	16	256
0.00002790	0.000558	0.0625	**1**	16
0.00000174	0.0000348	0.0016	0.0625	**1**

TROY.

Pounds.	Ounces.	Dwt.	Grains.	Pound Avoir.
1	12	240	5760	0.822861
0.083333	**1**	20	480	0.068571
0.004166	0.05000	**1**	24	0.0034285
0.0001736	0.002083333	0.0416666	**1**	0.00014285
1.215275	14.58333	291.6666	7000	**1**

APOTHECARIES.

Pounds.	Ounces.	Drams.	Scruples.	Grains.
1	12	96	288	5760
0.08333	**1**	8	24	480
0.01041666	0.125	**1**	3	60
0.0034722	0.0416666	0.3333	**1**	20
0.00017361	0.0020833	0.016666	0.05	**1**

Equivalents of Lineal Measures—Metrical and English.

	Meters.	English Measures.			
		Inches.	Feet.	Yards.	Miles.
Microne	.0001	.003937	.000328	.000109	. . . . .
Millimeter . . mm	.001	.039371	.003281	.001094	. . . . .
Centimeter . cm	.01	.393708	.032809	.010936	. . . . .
Decimeter . . .	.1	3.937079	.328089	.109363	. . . . .
Meter	**1.**	**39.370790**	**3.280899**	**1.093633**	**.000621**
Decameter . .	10.	. . . . .	32.80899	10.93633	.006214
Hectometer . .	100.	. . . . .	328.0899	109.3633	.062138
Kilometer . . .	1,000.	. . . . .	3280.899	1093.633	.621382
Miriameter . .	10,000.	. . . . .	. . . . . .	. . . . . .	6.213824

Equivalents of Lineal Measures — Met. and Eng. — *Continued.*

English Measures.	Meters.	Reciprocals.
1 inch	.02539954	39.37079
12 inches = 1 foot	.3047945	3.280899
3 feet = 1 yard	.9143835	1.093633
5½ yards = 16½ feet = 1 rod or pole	5.029109	.1988424
4 poles = 66 feet = 22 yards = 1 chain (Gunter's)	20.11644	.0497106
80 chains = 320 poles = 5280 ft. = 1760 yds. = 1 mile	1609.3149	.00062138

A Gunter's chain has 100 links. Each link = 7.92 inches = 0.2017 meter.

Equivalents of Superficial Measures — Metrical and Eng.

(METRICAL AND ENGLISH MEASURES.)

	Square meters.	English Measures.				
		Square inches.	Square feet.	Square yards.	Acres.	Square miles.
Milliare . . .	.1	155.01	1.076	.119	. . . .	. . .
Centiare = sq. met	1.	1550.06	10.764	1.196	. . . .	. . .
Deciare . . .	10.	15500.59	107.64	11.960	. . . .	. . .
Are	**100.**	**155005.9**	**1076.4**	**119.6033**	. . . .	. . .
Decare (not used)	1000.	. . . .	10764.3	1196.033	. . . .	. . .
Hectare . . .	10000.	. . . .	107643.	11960.33	2.4711431	. . .
Square kilometer	1000000.	. . . .	. . . .	. . . .	247.11431	.386126

English Measures.	Metrical Measures.	Reciprocals.
1 square inch	6.451367 sq. cent.	.1550059
144 square inches = 1 square foot .	.09289968 sq. mt.	10.7642996
9 square feet = 1 square yard . .	.8360972 “ “	1.196033
30¼ sq. yds. } = 1 perch = 1 square rod 272¼ sq. ft. } or pole	25.29194 “ “	.0395383
160 perches = } 10 sq. chains } = 1 acre	4046.711 “ “	.00024711
640 acres = 1 square mile	2589894.5 “ “	.00000038612

Equivalents of Weights — Metrical and English.

	Grammes	English Weights.				
		Oz. avoir.	Lbs. avoir.	Tons 2000 lbs.	Tons 2240 lbs.	Troy weight.
Milligramme .	.001	. . . .	. . . .	. . .	. . .	.015 Grs.
Centigramme .	.01	. . . .	. . . .	. . .	. . .	.15 “
Decigramme .	.1	. . . .	. . . .	. . .	. . .	1.543 “
Gramme . . .	**1.**	**.0353**	**.0022**	. . .	. . .	**15.43235“**
Decagramme .	10.	.3527	.02205	. . .	. . .	. . . . .
Hectogramme .	100.	3.5274	.22046	. . .	. . .	. . . . oz.
Kilogramme .	1000.	35.2739	2.2046	.001102	.000984	32.150727“
Myriagramme .	10000.	352.7394	22.0462	.011023	.009842	321.507266“
Quintal . . .	100000.	3527.3943	220.4261	.110231	.098421	3215.07266 “
Millier or Tonne	1000000	. . . .	2204.6215	1.102311	.984206	32150.72655“

English Weights — “ Avoirdupois.”	Grammes.	Reciprocals.
1 grain	.06479895	15.43234875
24.34375 grains = 1 dram	1.771836	.564383
16 drams = 1 ounce = 437.5 grains . . .	28.349375	.0352739
16 ounces = 1 pound = 7000 grains . . .	453.592652	.00220462
100 lbs. = 1 cwt. (American)	45359.265	.000022046
112 lbs. = 1 cwt. (English)	50802.376	.00001968
20 cwt. = 1 ton (Am.) in kilos	907.18524	.001102311
20 cwt. = 1 ton (Eng.) in kilos	1016.04753	.000984206
English Weights — “ Troy.”		
1 grain	.06479895	15.43234875
24 grains = 1 dwt.	1.555175	.6430146
20 dwt = 1 oz.	31.103496	.3215073
12 oz. = 1 lb.	373.241954	.00267923

Equivalents of Cubic Measures — Metrical and English.

(LIQUID AND DRY MEASURES.)

Liquid.	Dry.		Metrical Measures.		English Measures.					
			Litres.	Cub. Met.	Cub. Inches.	Cub. Feet.	U.S. Gallons. 231 cub. in.	Gallons. 277.27 cu.in.	Bushels. 2150.4 cu.in.	Cub. Yds.
Millilitre . .	. . . .	Cub. Cent.	.001	. . . .	.061	. . . .	.00026	.00022	. . . . .	. . .
Centilitre . .	. . . .	. . . . .	.01	. . . .	.61	. . . .	.00264	.0022	. . . . .	. . .
Decilitre . .	. . . .	. . . . .	.1	. . . .	6.10	. . . .	.02642	.022	.0027	. . .
Litre	**Millistere . .**	**Cub. Decim**	**1.**	**.001**	**61.027**	**.0353**	**.26418**	**.2201**	**.0275**	. . .
Decalitre . .	Centistere .	. . . . .	10.	.01	610.271	.3532	2.64179	2.201	.27512	. . .
Hectolitre .	Decistere . .	. . . . .	100.	.1	6102.706	3.5317	26.4179	22.00967	2.7512	.1308
Kilolitre . .	Stere	Cub. Met.	1000.	1.	. . . .	35.317	264.179	220.0967	27.5121	1.308
Myriolitre .	Decastere .	. . . . .	10000.	10.	. . . .	353.1658	. . . . .	. . . . .	275.1209	13.0802
. . . .	Hectostere .	. . . . .	. . . .	100.	. . . .	. . . .	. . . . .	. . . . .	. . . . .	130.8022

English Measures.	Metrical Measures.	Reciprocals.
1 cubic inch	16.38618 cub. cent.	.061027
1728 cubic inches = 1 cubic foot	.02831531 cub. met.	35.316582
27 cubic feet = 1 cubic yard	.7645134 " "	1.30802
1 pint (imperial or dry measure)	.56793 litres	1.760773
2 pints = 1 quart (dry measure)	1.13586 "	.880387
4 quarts = 1 gallon (imperial) = 277.274 cubic inches	4.543457 "	.220097
1 wine gallon of 231 cubic inches	3.78521 "	.264179
8 gallons (imperial) = 1 bushel (2150.4 cubic inches)	36.34766 " .036348 cub. met.	.027512 27.51209
8 bushels = 1 quarter (English)	290.7813 litres.	.003439

Metrical Measures Equivalent to English Measures.

Meters.	Inches.	Feet.
$1^{m}/_{m}$	0.039	0.0033
2	0.079	0.0066
3	0.118	0.0098
4	0.157	0.0131
5	0.197	0.0164
6	0.236	0.0197
7	0.276	0.0230
8	0.315	0.0262
9	0.354	0.0295
$10^{m}/_{m} = 1^{c}/_{m}$	0.394	0.033
2	0.787	0.066
3	1.181	0.098
4	1.575	0.131
5	1.969	0.164
6	2.362	0.197
7	2.756	0.230
8	3.150	0.262
9	3.543	0.295
$10_{c}/_{m} = .1^{m}$	3.937	0.328
.2	7.874	0.656
.3	11.811	0.984
.4	15.748	1.312
.5	19.685	1.640
.6	23.622	1.969
.7	27.560	2.297
.8	31.497	2.625
.9	35.434	2.953
$1^{m}0$	39.371	3.281

Table for the Conversion of Mils. (1-1000 Inches) into Centimeters.

Mils.	Centimeters.	Mils.	Centimeters.	Mils.	Centimeters.	Mils.	Centimeters.
1	.00254	18	.04571	35	.08888	52	.1321
2	.00508	19	.04825	36	.09142	53	.1346
3	.00762	20	.05079	37	.09396	54	.1372
4	.01016	21	.05333	38	.09650	55	.1397
5	.01270	22	.05587	39	.09904	56	.1422
6	.01524	23	.05841	40	.1016	57	.1448
7	.01778	24	.06095	41	.1041	58	.1473
8	.02032	25	.06348	42	.1067	59	.1499
9	.02286	26	.06602	43	.1092	60	.1524
10	.02540	27	.06856	44	.1118	61	.1549
11	.02793	28	.07110	45	.1143	62	.1575
12	.03047	29	.07364	46	.1168	63	.1600
13	.03301	30	.07618	47	.1194	64	.1626
14	.03555	31	.07872	48	.1219	65	.1651
15	.03809	32	.08126	49	.1245	66	.1676
16	.04063	33	.08380	50	.1270	67	.1702
17	.04317	34	.08634	51	.1295	68	.1727

Table for the Conversion of Mils. — *Continued.*

Mils.	Centimeters.	Mils.	Centimeters.	Mils.	Centimeters.	Mils.	Centimeters.
69	.1752	77	.1956	85	.2159	93	.2362
70	.1778	78	.1981	86	.2184	94	.2387
71	.1803	79	.2006	87	.2209	95	.2413
72	.1829	80	.2032	88	.2235	96	.2438
73	.1854	81	.2057	89	.2260	97	.2465
74	.1879	82	.2083	90	.2286	98	.2489
75	.1905	83	.2108	91	.2311	99	.2514
76	.1930	84	.2133	92	.2336	100	.2540

English Measures Equivalent to Metrical Measures.

Inches.	Milimeters.	Inches.	Meters.	Feet.	Meters.	Feet.	Meters.
$\frac{1}{32}$	0.794	1	0.0254	0.01	.003	10	3.048
$\frac{1}{16}$	1.588	2	.0508	0.02	.006	20	6.096
$\frac{3}{32}$	2.381	3	.0762	0.03	.009	30	9.144
$\frac{1}{8}$	3.175	4	.1016	0.04	.012	40	12.192
$\frac{5}{32}$	3.969	5	.1270	0.05	.015	50	15.240
$\frac{3}{16}$	4.762	6	.1524	0.06	.018	60	18.288
$\frac{7}{32}$	5.556	7	.1778	0.07	.021	70	21.336
$\frac{1}{4}$	6.350	8	.2032	0.08	.024	80	24.384
$\frac{9}{32}$	7.144	9	.2286	0.09	.027	90	27.431
$\frac{5}{16}$	7.937	10	.2540	.1	.030	100	30.479
$\frac{11}{32}$	8.731	11	.2794	.2	.061	200	60.959
$\frac{3}{8}$	9.525	12	.3048	.3	.091	300	91.438
$\frac{13}{32}$	10.319			.4	.122	400	121.918
$\frac{7}{16}$	11.112			.5	.152	500	152.397
$\frac{15}{32}$	11.906			.6	.183	600	182.877
$\frac{1}{2}$	12.700			.7	.213	700	213.356
$\frac{17}{32}$	13.494			.8	.244	800	243.836
$\frac{9}{16}$	14.287			.9	.274	900	274.315
$\frac{19}{32}$	15.081			1.0	.305	1000	304.794
$\frac{5}{8}$	15.875			2	.610		
$\frac{21}{32}$	16.668			3	.914		
$\frac{11}{16}$	17.462			4	1.219		
$\frac{23}{32}$	18.256			5	1.524		
$\frac{3}{4}$	19.050			6	1.829		
$\frac{25}{32}$	19.843			7	2.134		
$\frac{13}{16}$	20.637			8	2.438		
$\frac{27}{32}$	21.430			9	2.743		
$\frac{7}{8}$	22.224			10	3.048		
$\frac{29}{32}$	23.018						
$\frac{15}{16}$	23.812						
$\frac{31}{32}$	24.606						
1	25.400						

Conversion of Inches and Eighths into Decimals of a Foot.

Inches.	Fractions of an Inch.							
	0	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$
0	.0000	.01041	.02083	.03125	.04166	.05208	.0625	.07291
1	.08333	.09375	.10416	.11458	.125	.13541	.14588	.15639
2	.16666	.17707	.1875	.19792	.20832	.21873	.22914	.23965
3	.25	.26041	.270	.28125	.29166	.30208	.3125	.32291
4	.33333	.34375	.35416	.364	.375	.38541	.39588	.40639
5	.41666	.42707	.437	.44792	.45832	.46873	.47914	.48965
6	.5	.51041	.520	.53125	.54166	.55208	.5625	.57291
7	.58333	.59375	.60416	.614	.625	.63541	.64588	.65639
8	.66666	.67707	.685	.69792	.70832	.71773	.72914	.73965
9	.75	.76041	.770	.78125	.79169	.80208	.8425	.82291
10	.83333	.84375	.85416	.864	.875	.88541	.89588	.90639
11	.91666	.92707	.937	.94792	.95832	.96873	.97914	.98965
12	1 foot.	foot.	foot.	foot.	foot.	foot.	foot.	foot.

$\frac{1}{16}$ in. = 0.005208 ft ; $\frac{1}{32}$ in. = 0.00265 ft. ; $\frac{1}{64}$ in. = 0.001375 ft.

GREEK LETTERS.

Α	α	Alpha.	Ν	ν	Nu.
Β	β	Beta.	Ξ	ξ	Xi.
Γ	γ	Gamma.	Ο	ο	Omicron.
Δ	δ	Delta.	Π	π	Pi.
Ε	ϵ	Epsīlon.	Ρ	ρ	Rho.
Ζ	ζ	Zeta.	Σ	σ ς	Sigma.
Η	η	Eta.	Τ	τ	Tau.
Θ	θ	Theta.	Υ	υ	Upsīlon.
Ι	ι	Iota.	Φ	ϕ	Phi.
Κ	κ	Kappa.	Χ	χ	Chi.
Λ	λ	Lambda.	Ψ	ψ	Psi.
Μ	μ	Mu.	Ω	ω	Omĕga.

CENTRIFUGAL FORCE.

F = centrifugal force in pounds.
W = weight in pounds.
v = velocity in feet per second.
r = radius of circle in feet.
n = revolutions per minute.

Then

$$F = \frac{W r n^2}{2933}.$$

ANGULAR VELOCITY.

The number of degrees per second through which a body revolves about a center.

$$w = 2\pi n$$

where

w = angular velocity.
n = revolutions per second.

FRICTION.

The following laws of friction are only approximate, the first not being true where pressures are very great, and the third beyond a velocity of 150 feet per minute.

1. *Friction varies directly as the pressure on the surfaces in contact.*
2. *Friction is independent of the extent of the surface in contact.*
3. *Friction is independent of the velocity, when the surfaces are in motion.*
4. *Rolling friction varies directly as the pressure, and inversely as the diameter of the rolling bodies, where the cylinders or balls are of the same substances, and are pulled or pushed, as in a car or wagon.*

   Where the load is propelled by a crank fixed on the axle, the law is reversed.

TEMPERATURE, or INTENSITY OF HEAT.

Standard Points—		Fahrenheit.	Centigrade.	Réaumur.
Boiling point of water under one atmosphere	=	212°	100°	80°
Melting point of ice		32°	0°	0°
(Absolute zero; known by theory only	=	about—461°.2	— 274°	— 219°.2)

9° Fahrenheit = 5° Centigrade = 4° Réaumur.

$$\text{Temp Fah.} = \frac{9}{5}\ \text{Temp. Cent.} + 32° = \frac{9}{4}\ \text{Temp. Réau.} + 32°$$

$$\text{Temp. Cent.} = \frac{5}{9}\ (\text{Temp. Fah.} - 32°) = \frac{5}{4}\ \text{Temp. Réau.}$$

$$\text{Temp. Réau.} = \frac{4}{9}\ (\text{Temp. Fah.} - 32°) = \frac{4}{5}\ \text{Temp. Cent.}$$

Table of Comparison of Different Thermometers.

Fah.	Réau.	Cent.	Fah.	Réau.	Cent.	Fah.	Réau.	Cent.
212	80.0	100.0	180	65.7	82.2	148	51.5	64.4
211	79.5	99.4	179	65.3	81.6	147	51.1	63.8
210	79.1	98.8	178	64.8	81.1	146	50.6	63.3
209	78.6	98.3	177	64.4	80.5	145	50.2	62.7
208	78.2	97.7	176	64.0	80.0	144	49.7	62.2
207	77.7	97.2	175	63.5	79.4	143	49.3	61.6
206	77.3	96.6	174	63.1	78.8	142	48.8	61.1
205	76.8	96.1	173	62.6	78.3	141	48.4	60.5
204	76.4	95.5	172	62.2	77.7	140	48.0	60.0
203	76.0	95.0	171	61.7	77.2	139	47.5	59.4
202	75.5	94.4	170	61.3	76.6	138	47.1	58.8
201	75.1	93.8	169	60.8	76.1	137	46.6	58.3
200	74.6	93.3	168	60.4	75.5	136	46.2	57.7
199	74.2	92.7	167	60.0	75.0	135	45.7	57.2
198	73.7	92.2	166	59.5	74.4	134	45.3	56.6
197	73.3	91.6	165	59.1	73.8	133	44.8	56.1
196	72.8	91.1	164	58.6	73.3	132	44.4	55.5
195	72.4	90.5	163	58.2	72.7	131	44.0	55.0
194	72.0	90.0	162	57.7	72.2	130	43.5	54.4
193	71.5	89.4	161	57.3	71.6	129	43.1	53.8
192	71.1	88.8	160	56.8	71.1	128	42.6	53.3
191	70.6	88.3	159	56.4	70.5	127	42.2	52.7
190	70.2	87.7	158	56.0	70.0	126	41.7	52.2
189	69.7	87.2	157	55.5	69.4	125	41.3	51.6
188	69.3	86.6	156	55.1	68.8	124	40.8	51.1
187	68.8	86.1	155	54.6	68.3	123	40.4	50.5
186	68.4	85.5	154	54.2	67.7	122	40.0	50.0
185	68.0	85.0	153	53.7	67.2	121	39.5	49.4
184	67.5	84.4	152	53.3	66.6	120	39.1	48.8
183	67.1	83.8	151	52.8	66.1	119	38.6	48.3
182	66.6	83.3	150	52.4	65.5	118	38.2	47.7
181	66.2	82.7	149	52.0	65.0	117	37.7	47.2

Table of Comparison of Different Thermometers — *Continued.*

Fah.	Réau.	Cent.	Fah.	Réau.	Cent.	Fah.	Réau.	Cent.
116	37.3	46.6	70	16.8	21.1	24	—3.5	—4.4
115	36.8	46.1	69	16.4	20.5	23	—4.0	—5.0
114	36.4	45.5	68	16.0	20.0	22	—4.4	—5.5
113	36.0	45.0	67	15.5	19.4	21	—4.8	—6.1
112	35.5	44.4	66	15.1	18.8	20	—5.3	—6.6
111	35.1	43.8	65	14.6	18.3	19	—5.7	—7.2
110	34.6	43.3	64	14.2	17.7	18	—6.2	—7.7
109	34.2	42.7	63	13.7	17.2	17	—6.6	—8.3
108	33.7	42.2	62	13.3	16.6	16	—7.1	—8.8
107	33.3	41.6	61	12.8	16.1	15	—7.5	—9.5
106	32.8	41.1	60	12.4	15.5	14	—8.0	—10.0
105	32.4	40.5	59	12.0	15.0	13	—8.4	—10.5
104	32.0	40.0	58	11.5	14.4	12	—8.8	—11.1
103	31.5	39.4	57	11.1	13.8	11	—9.3	—11.6
102	31.1	38.8	56	10.6	13.3	10	—9.7	—12.2
101	30.6	38.3	55	10.2	12.7	9	—10.2	—12.7
100	30.2	37.7	54	9.7	12.2	8	—10.6	—13.3
99	29.7	37.2	53	9.3	11.6	7	—11.1	—13.8
98	29.3	36.6	52	8.8	11.1	6	—11.5	—14.4
97	28.8	36.1	51	8.4	10.5	5	—12.0	—15.0
96	28.4	35.5	50	8.0	10.0	4	—12.4	—15.5
95	28.0	35.0	49	7.5	9.4	3	—12.8	—16.1
94	27.5	34.4	48	7.1	8.8	2	—13.3	—16.6
93	27.1	33.8	47	6.6	8.3	1	—13.7	—17.2
92	26.6	33.3	46	6.2	7.7	0	—14.2	—17.7
91	26.2	32.7	45	5.7	7.2	—1	—14.6	—18.3
90	25.7	32.2	44	5.3	6.6	—2	—15.1	—18.8
89	25.3	31.6	43	4.8	6.1	—3	—15.5	—19.4
88	24.8	31.1	42	4.4	5.5	—4	—16.0	—20.0
87	24.4	30.5	41	4.0	5.0	—5	—16.4	—20.5
86	24.0	30.0	40	3.5	4.4	—6	—16.8	—21.1
85	23.5	29.4	39	3.1	3.8	—7	—17.3	—21.6
84	23.1	28.8	38	2.6	3.3	—8	—17.7	—22.2
83	22.6	28.3	37	2.2	2.7	—9	—18.2	—22.7
82	22.2	27.7	36	1.7	2.2	—10	—18.6	—23.3
81	21.7	27.2	35	1.3	1.6	—11	—19.1	—23.8
80	21.3	26.6	34	0.8	1.1	—12	—19.5	—24.4
79	20.8	26.1	33	0.4	0.5	—13	—20.0	—25.0
78	20.4	25.5	32	0.0	0.0	—14	—20.4	—25.5
77	20.0	25.0	31	—0.4	—0.5	—15	—20.8	—26.1
76	19.5	24.4	30	—0.8	—1.1	—16	—21.3	—26.6
75	19.1	23.8	29	—1.3	—1.6	—17	—21.7	—27.2
74	18.6	23.3	28	—1.7	—2.2	—18	—22.2	—27.7
73	18.2	22.7	27	—2.2	—2.7	—19	—22.6	—28.3
72	17.7	22.2	26	—2.6	—3.3	—20	—23.1	—28.8
71	17.3	21.6	25	—3.1	—3.8			

Number of Degrees Cent. = Number of Degrees Fah.

Degrees Cent.	Tenths of a Degree — Centigrade Scale.									
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.
0	0.00	0.18	0.36	0.54	0.72	0.90	1.08	1.26	1.44	1.62
1	1.80	1.98	2.16	2.34	2.55	2.70	2.88	3.06	3.24	3.42
2	3.60	3.78	3.96	4.14	4.32	4.50	4.68	4.86	5.04	5.22
3	5.40	5.58	5.76	5.94	6.12	6.30	6.48	6.66	6.84	7.02

Number of Degrees Cent. = Number of Degrees Fah. — (*Continued.*)

Degrees Cent.	Tenths of a Degree — Centigrade Scale.									
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.
4	7.20	7.38	7.56	7.74	7.92	8.10	8.28	8.46	8.64	8.82
5	9.00	9.18	9.36	9.54	9.72	9.90	10.08	10.26	10.44	10.62
6	10.80	10.98	11.16	11.34	11.52	11.70	11.88	12.06	12.24	12.42
7	12.60	12.78	12.96	13.14	13.32	13.50	13.68	13.86	14.04	14.22
8	14.40	14.58	14.76	14.94	15.12	15.30	15.48	15.66	15.84	16.02
9	16.20	16.38	16.56	16.74	16.92	17.10	17.28	17.46	17.64	17.82

Number of Degrees Fah. = Number of Degrees Cent.

Degrees Fah.	Tenths of a Degree — Fahrenheit Scale.									
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	Cent.	Cent.	Cent.	Cent.	Cent.	Cent.	Cent.	Cent.	Cent.	Cent.
0	0.00	0.06	0.11	0.17	0.22	0.28	0.33	0.39	0.44	0.50
1	0.56	0.61	0.67	0.72	0.78	0.83	0.89	0.94	1.00	1.06
2	1.11	1.17	1.22	1.28	1.33	1.39	1.44	1.50	1.56	1.61
3	1.67	1.72	1.78	1.83	1.89	1.94	2.00	2.06	2.11	2.17
4	2.22	2.28	2.33	2.39	2.44	2.50	2.56	2.61	2.67	2.72
5	2.78	2.83	2.89	2.94	3.00	3.06	3.11	3.17	3.22	3.28
6	3.33	3.39	3.44	3.50	3.56	3.61	3.67	3.72	3.78	3.83
7	3.89	3.94	4.00	4.06	4.11	4.17	4.22	4.28	4.33	4.39
8	4.44	4.50	4.56	4.61	4.67	4.72	4.78	4.83	4.89	4.94
9	5.00	5.06	5.11	5.17	5.22	5.28	5.33	5.39	5.44	5.50

Coefficients of Expansion at Ordinary Temperatures.

(Solids.)

Material.		Coefficient of Expansion.	
		°F.	°C.
Aluminum		.0000114	.0000206
Brass		.0000104	.0000187
Brick		.00000306	.00000551
Bronze		.0000100	.0000180
Cement and Concrete	from	.0000055	.000010
	to	.0000078	.000014
Copper		.00000961	.0000173
Glass	from	.00000399	.00000719
	to	.00000521	.00000938
Gold		.00000841	.0000151
Granite		.0000046	.0000083
Iron, cast		.00000587	.0000106
Iron, wrought		.00000677	.0000122

Coefficients of Expansion — (*Continued.*)

Material.	Coefficient of Expansion.	
	°F.	°C.
Lead	.0000158	.0000284
Marble (average)	.000004	.000007
Masonry from	.0000026	.0000047
to	.0000049	.0000088
Platinum	.00000494	.00000890
Porcelain	.0000020	.0000036
Sandstone from	.0000040	.0000070
to	.0000067	.000012
Silver	.0000108	.0000194
Slate	.0000056	.0000102
Steel, untempered	.00000611	.0000110
Steel, tempered	.00000689	.0000124
Tin	.0000116	.0000209
Wood (pine)	.00000276	.00000496
Zinc	.0000163	.0000293

HEAT.

Specific Heat of Substances.

The *specific heat* of a body at any temperature is the ratio of the quantity of heat required to raise the temperature of the body one degree to the quantity of heat required to raise an equal mass of water at or near to its temperature of maximum density (4°C. or 39.2°F.) through one degree.

Specific Heats of Metals.

(Tomlinson.)

Metal.	Specific Heat at		
	0°C. or 32°F.	50°C.or 122°F.	100°C or 212°F
Aluminum	0.2070	0.2185	0.2300
Copper	0.0901	0.0923	0.0966
German Silver	0.0941	0.0947	0.0952
Iron	0.1060	0.1130	0.1200
Lead	0.0300	0.0315	0.0331
Platinum	0.0320	0.0326	0.0333
Platinum Silver	0.0473	0.0487	0.0501
Silver	0.0547	0.0569	0.0591
Tin	0.0523	0.0568	0.0595
Zinc	0.0901	0.0938	0.0976

Mean Specific Heat of Platinum.

(Pouillet.)

Between 0°C. (32°F.) and 100°C. (212°F.)	0.0335
" " " " 300°C. (572°F.)	0.0343
" " " " 500°C. (932°F.)	0.0352
" " " " 700°C. (1292°F.)	0.0360
" " " " 1000°C. (1832°F.)	0.0373
" " " " 1200°C. (2192°F.)	0.0382

Mean Specific Heat of Water.

(Regnault.)

Between 0°C. (32°F.) and 40°C. (104°F.)	1.0013
“ “ “ “ 80°C. (176°F.)	1.0035
“ “ “ “ 120°C. (248°F.)	1.0067
“ “ “ “ 160°C. (320°F.)	1.0109
“ “ “ “ 200°C. (392°F.)	1.0160
“ “ “ “ 230°C. (446°F.)	1.0204

Mean Specific Heat of Glass (Kohlrausch) 0.19

Specific Heat of Gases and Vapors at Constant Pressure.

Substance.	Specific Heat for Equal.		Observer.
	Volumes.	Weights.	
Air	0.2375	0.2375	Regnault
Carbon monoxide	0.2370	0.2450	Regnault
Carbon dioxide	0.2985	0.1952	Wiedermann
Hydrogen	0.2359	3.4090	Regnault
Nitrogen	0.2368	0.2438	Regnault
Oxygen	0.2405	0.2175	Regnault
Steam	0.2989	0.4805	Regnault

Total Heat of Steam.

British Thermal Unit: (B. T. U.) is the quantity of heat which will raise the temperature of one pound of water one degree Fah. at or near its temperature of maximum density 39.1°.

French Calorie: is the quantity of heat that will raise the temperature of one kilogramme of pure water 1°C. at or near 4°C.

Pound Calorie: is the quantity of heat that will raise the temperature of one pound of water 1°C.

1 B. T. U. = .252 Calories.
1 Calorie = 3.968 B. T. U.
1 lb. Calorie = 2.2046 B. T. U.
1 pound Calorie = $\frac{5}{9}$ Calorie.

The Mechanical Equivalent of Heat.

Joule gives	1 B. T. U. = 772 ft. lbs.
Professor Rowland,	1 B. T. U. = 778 ft. lbs.

$$1 \text{ ft. lb.} = \frac{1}{778} = .001285 \text{ B. T. U.}$$

$$1 \text{ H. P.} = 42.416 \text{ B. T. U.}$$

(See Table of Energy Equivalents on p. 684.)

Heat Unit Table. (A. E. Hunt.)

Name.	Molecular Symbol.	Atomic Weight.	Molecular Weight.	Products of Combustion.	Specific Gravity Hydrogen = 2.	Specific Gravity Air = 1.	Weight of 1 Liter in Grams.	Weight of 1 Cu. Ft. in Grains.	Weight of 1 Cu. Ft. in Pounds.	Calories C-K.	Heat-Value Carbon = 1.	Volume-Calorie Hydrogen = 1.
Hydrogen	H_2	1	2.	H_2O	2.0000	0.06925	0.08955	39.1263	.00559	34217.5	4.23	1.00
Marsh Gas	CH_4	...	15.97	H_2O-CO_2	15.974	0.55300	0.71506	312.445	.04464	13244.	1.63	3.09
Carbon Monoxid	CO	...	27.93	CO_2	27.937	0.96715	1.25058	546.4397	.07806	2441.7	0.302	1.00
Acetylene	C_2H_2	...	25.94	H_2O-CO_2	25.947	0.89829	1.16148	507.5338	.07255	11923.	1.48	4.53
Aethylene	C_2H_4	...	27.94	H_2O-CO_2	27.947	0.96749	1.25103	546.6318	.07809	11884.	1.47	4.86
Aethane	C_2H_6	...	29.94	H_2O-CO_2	29.947	1.03675	1.34058	585.7637	.08368	12347.	1.53	5.41
Propylene	C_3H_6	...	41.91	H_2O-CO_2	41.921	1.45124	1.87654	819.9506	.11713	11731.	1.45	7.21
Butylene	C_4H_8	...	55.89	H_2O-CO_2	55.894	1.93488	2.50190	1093.2072	.15617	11619.	1.44	9.51
Allylene	C_3H_4	...	39.92	H_2O-CO_2	39.921	1.38194	1.78692	780.7961	.11154	11690.	1.45	6.83
Benzole	C_6H_6	...	77.82	H_2O-CO_2	77.822	2.69463	3.48429	1522.4659	.21749	10102.	1.25	11.51
Naphthalene	$C_{10}H_8$	...	127.7	H_2O-CO_2	127.722	4.39880	5.68783	2485.322	.35505	9618.7	1.19	17.98
Sulphureted Hydrogen	H_2S	...	33.98	SO_2-H_2O	33.981	1.17664	1.52147	664.802	.09497	3488.	0.43	1.73
Carbon Bi-Sulphid	CS_2	...	75.93	CO_2-SO_2	75.931	2.62580	3.39980	1483.577	.21194	3404.	0.421	3.79
Water Gas		* See analysis below.			15.562	0.53883	0.69678	304.438	.04349	4839.7	0.5989	0.936
Coal Gas		* See analysis below.			11.332	0.39236	0.50739	186.620	.02666	13817.	1.710	1.924
Ammonia	NH_3	...	17.01	H_2O-N_2	17.010	0.58901	0.76163	332.790	.47543	5332.	0.659	1.33
Air	...	...	...	.....	14.444	1.00000	1.29306	565.000	.08071	...	...	...
Nitrogen	N_2	14.01	28.02	.....	28.021	0.97026	1.25461	548.197	.07831	...	...	...
Oxygen	O_2	15.96	31.92	.....	31.920	1.10531	1.42923	624.500	.08921	...	...	...
Carbon Dioxid	CO_2	...	43.89	.....	43.892	1.51980	1.96519	858.687	.12267	...	...	...
Carbon from Wood	C_2	11.97	23.94	CO_2	...	...	...	...	...	8080.	1.000	...
Anthracite—Penna.	...	...	...	CO_2-H_2O	...	...	...	...	...	7844.4	0.971	...
Bituminous Coal	...	...	...	CO_2-H_2O	...	...	...	...	...	8391.7	1.038	...
Cannel Coal	...	...	...	CO_2-H_2O	...	...	...	...	...	6365.5	0.788	...
Furnace Coke	...	...	...	CO_2-H_2O	...	...	...	...	...	7019.4	0.868	...
Gas House Coke	...	...	...	CO_2-H_2O	...	...	...	...	...	7000.	0.866	...
Coal Tar	...	...	...	CO_2-H_2O	...	...	...	...	...	8667.	1.073	...
Crude Petroleum	...	...	...	CO_2-H_2O	...	...	...	...	...	11094.1	1.373	...

* NOTE.	Water Gas. (Uncarbureted.)	Coal Gas.		Water Gas. (Uncarbureted.)	Coal Gas.
Hydrogen	49.2 %	50.28 %	Carbon monoxid	43.8 %	4.37 %
Marsh gas	0.3 %	36.95 %	Carbon dioxid	2.7 %	None.
Illuminants	Trace.	6.34 %	Nitrogen	4.0 %	Trace.

Specific Gravity.

Names of Substances.	Specific gravity	Weight per Cub. in.
Woods.		
Cedar, Indian	1.315	.0476
“ American	.561	.0203
Citron	.726	.0263
Cocoa-wood	1.040	.0376
Cherry-tree	.715	.0259
Cork	.240	.0087
Cypress, Spanish	.644	.0233
Ebony, American	1.331	.0481
“ Indian	1.209	.0437
Elder-tree	.695	.0252
Elm, trunk of	.671	.0243
Filbert-tree	.600	.0217
Fir, male	.550	.0199
“ female	.498	.0180
Hazel	.600	.0217
Jasmine, Spanish	.770	.0279
Juniper-tree	.556	.0201
Lemon-tree	.703	.0254
Lignum-vitæ	1.333	.0482
Linden-tree	.604	.0219
Logwood	.913	.0331
Mastic-tree	.849	.0307
Mahogany	1.063	.0385
Maple	.750	.0271
Medlar	.944	.0342
Mulberry	.897	.0324
Oak, heart of, 60 old	1.170	.0423
Orange-tree	.705	.0255
Pear-tree	.661	.0239
Pomegranate-tree	1.354	.0490
Poplar	.383	.0138
“ white Spanish	.529	.0191
Plum-tree	.785	.0284
Quince-tree	.705	.0255
Sassafras	.482	.0174
Spruce	.500	.0181
“ old	.460	.0166
Pine, yellow	.660	.0239
“ white	.554	.0200
Vine	1.327	.0480
Walnut	.671	.0243
Yew, Dutch	.788	.0285
“ Spanish	.807	.0292
Liquids.		
Acid, Acetic	1.062	.0384
“ Nitric	1.217	.0440
“ Sulphuric	1.841	.0666
“ Muriatic	1.200	.0434
“ Fluoric	1.500	.0542
“ Phosphoric	1.558	.0563
Alcohol, commer.	.833	.0301
“ pure	.792	.0287
Ammoniac, liquid	.897	.0324
Beer, lager	1.034	.0374
Champagne	.997	.0360
Cider	1.018	.0361
Ether, sulphuric	.739	.0267
Naptha	.848	
Egg	1.090	.0394
Honey	1·450	.0524
Human blood	1.054	.0381
Milk	1.032	.0373
Oil, Linseed	.940	.0340
“ Olive	.915	.0331
“ Turpentine	.870	.0314
“ Whale	.932	.0337
Proof Spirit	.925	.0334
Vinegar	1.080	.0390
Water, distilled	1.000	.0361
“ sea	1.030	.0371
“ Dead Sea	1.240	.0448
Wine	.992	.0359
“ Port	.997	.0361
Miscellaneous.		
Ebonite	1.8	
Pitch	1.6	
Asphaltum	.905 1.650	.0327 .0597
Beeswax	.965	.0349
Butter	.942	.0341
Camphor	.988	.0357
India rubber	.933	.0338
Fat of Beef	.923	.0334
“ Hogs	.936	.0338
“ Mutton	.923	.0334
Gamboge	1.222	.0442
Gunpowder, loose	.900	.0325
“ shaken	1.000	.0361
“ solid	1.550 1.800	.0561 .0650
Gum Arabic	1.452	.0525
Indigo	1.009	.0365
Lard	.947	.0343
Mastic	1.074	.0388
Spermaceti	.943	.0341
Sugar	1.605	.0580
Tallow, sheep	.924	.0334
“ calf	.934	.0338
“ ox	.923	.0334
Atmospheric air	.0012	.000043
Gases. Vapors.		W'g't cu.ft. gr'ns.
Atmospheric air	1.000	527.0
Ammoniacal gas	.500	263.7
Carbonic acid	1.527	805.3
Carbonic oxid	.972	512.7
Carbureted hydrogen	.972	512.7
Chlorine	2.500	1316
Chlorocarbonous acid	3.472	1828
Chloroprussic acid	2.152	1134
Fluoboric acid	2 371	1250
Hydriodic acid	4.346	2290
Hydrogen	.069	36.33
Oxygen	1.104	581.8
Sulphuretted hydrogen	1.777	9370
Nitrogen	.972	512.0
Vapor of alcohol	1.613	851.0
“ turpentine spirits	5.013	2642
“ water	.623	328.0
Smoke of bituminous coal	.102	53.80
“ wood	.90	474.0
Steam at 212°	.488	257.3

TABLE OF SPECIFIC GRAVITY AND UNIT WEIGHTS.

Water at 39.1° Fahrenheit = 4° Centigrade ; 62.425 pounds to the cubic foot (authority, Kent, Haswell, and D. K. Clark).

	Specific Gravity.	Authority.	Lbs. per Cubic Foot.	Lbs. per Cubic Inch.	Kilos per Cubic Decm.
Aluminum, pure cast	2.56	P. R. C.	159.63	.0924	2.56
“ “ rolled	2.68	“	167.11	.0967	2.68
“ “ anne'ld	2.66	“	165.86	.0960	2.66
“ nickel alloy, cast	2.85	“	178.10	.1031	2.85
“ “ “ rolled	2.76	“	172.10	.0996	2.76
“ “ “ ann'ld	2.74	“	170.85	.0989	2.74
Aluminum Bronze, 10%	7.70	Riche.	480.13	.2779	7.70
“ “ 5%	8.26	“	515.63	.2984	8.26
Brass, cu. 67, zn. 33 cast	8.32	Haswell.	519.36	.3006	8.32
“ cu. 60, zn. 40 “	8.405	Thurston.	524.68	.3036	8.405
Cobalt	8.50	R.-A.	530.61	.3071	8.50
Brass, plates high yellow	8.586	P. R. C.	535.38	.3098	8.586
Bronze composition cu. 90, tin 10	8.669	Thurston.	541.17	.3132	8.669
Bronze composition cu. 84, tin 16	8.832	Haswell.	551.34	.3191	8.832
Lithium	0.57	R.-A.	36.83	.0213	.57
Potassium	0.87	“	54.31	.0314	.87
Sodium	0.97	“	60.55	.0350	.97
Rubidium	1.52	“	94.89	.0549	1.52
Calcium	1.57	“	98.01	.0567	1.57
Magnesium	1.74	“	108.62	.0629	1.74
Caesium	1.88	“	117.36	.0679	1.88
Boron	2.00	Haswell.	124.85	.0723	2.00
Glucinum	2.07	R.-A.	129.22	.0748	2.07
Strontium	2.54	“	158.56	.0918	2.54
Barium	3.75	“	234.09	.1355	3.75
Zirconium	4.15	“	259.06	.1499	4.15
Selenium	4.50	Haswell.	280.91	.1626	4.50
Titanium	5.30	“	330.85	.1915	5.30
Vanadium	5.50	R.-A.	343.34	.1987	5.50
Arsenic	5.67	“	353.95	.2048	5.67
Columbium	6.00	Haswell.	374.55	.2168	6.00
Lanthanum	6.20	“	387.03	.2240	6.20
Niobium	6.27	R.-A.	391.40	.2265	6.27
Didymium	6.54	“	408.26	.2363	6.54
Cerium	6.68	“	417.00	.2413	6.68
Antimony	6.71	“	418.86	.2424	6.71
Chromium	6.80	“	429.49	.2457	6.80
Zinc, cast	6.861	Haswell.	428.30	.2479	6.861
“ pure	7.15	R.-A.	446.43	.2583	7.15
“ rolled	7.191	Haswell.	448.90	.2598	7.191
Wolfram	7.119	“	444.40	.2572	7.119
Tin, pure	7.29	R.-A.	455.08	.2634	7.29
Indium	7.42	“	463.19	.2681	7.42
Iron, cast	7.218	Kent.	450.08	.2605	7.218
“ wrought	7.70	“	480.13	.2779	7.70
“ wire	7.774	Haswell.	485.29	.2808	7.774
Steel, Bessemer	7.852	“	479.00	.2837	7.852
“ soft	7.854	Kent.	489.74	.2834	7.854
Iron, pure	7.86	R.-A.	490.66	.2840	7.86

TABLE OF SPECIFIC GRAVITY.—*Continued.*

	Specific Gravity.	Authority.	Lbs. per Cubic Foot.	Lbs. per Cubic Inch.	Kilos per Cubic Decm.
Manganese	8.00	R.-A.	499.40	.2890	8.00
Cinnabar	8.809	Haswell.	505.52	.2925	8.098
Cadmium	8.60	R.-A.	536.85	.3107	8.60
Molybdenum . . .	8.60	“	536.85	.3107	8.60
Gun Bronze	8.750	Haswell.	546.22	.3161	8.750
Tobin Bronze . . .	8.379	A. C. Co.	523.06	.3021	8.379
Nickel	8.80	R.-A.	549.34	.3179	8.80
Copper, pure . . .	8.82	“	550.59	.3186	8.82
Copperplates and sheet	8.93	A. of C. M.	556.83	.3222	8.93
Bismuth	9.80	R.-A.	611.76	.3540	9.80
Silver	10.53	“	657.33	.3805	10.53
Tantalum	10.80	“	674.19	.3902	10.80
Thorium	11.10	“	692.93	.4010	11.10
Lead	11.37	“	709.77	.4108	11.37
Palladium	11.50	“	717.88	.4154	11.50
Thalium	11.85	“	739.73	.4281	11.85
Rhodium	12.10	“	755.34	.4371	12.10
Ruthenium	12.26	“	765.33	.4429	12.26
Mercury	13.59	“	848.35	.4909	13.59
Uranium	18.70	“	1167.45	.6755	18.70
Tungsten	19.10	“	1192.31	.6900	19.10
Gold	19.32	“	1206.05	.6979	19.32
Platinum	21.50	“	1342.13	.7767	21.50
Iridium	22.42	“	1399.57	.8099	22.42
Osmium	22.48	“	1403.31	.8121	22.48

Anthorities — R.-A. — Professor Roberts-Austen.
Haswell — Haswell's Engineer's Pocket Book.
P. R. C. — Pittsburg Reduction Co.'s tests.
Kent — Kent's Mechanical Engineer's Pocket Book.
Thurston — Report of Committee on Metallic Alloys of U. S. Board appointed to test iron, steel, and other metals. Thurston's Materials of Engineering.
Riche — Quoted by Thurston.
A. C. Co. — Ansonia Brass and Copper Co.
A. of C. M. — Association of Copper Manufacturers.

SPECIFIC GRAVITY AT 62° FAHRENHEIT OF ALUMINUM AND ALUMINUM ALLOYS.

Aluminum Commercially Pure, Cast	2.56
Nickel Aluminum Alloy Ingots for rolling	2.72
“ “ Casting Alloy	2.85
Special Casting Alloy, Cast	3.00
Aluminum Commercially Pure, as rolled, sheets and wire	2.68
“ “ “ Annealed	2.66
Nickel Aluminum Alloy, as rolled, sheets and wire	2.76
“ “ “ Sheets Annealed	2.74

Weight.

Using these specific gravities, assuming water at 62 degrees Fahrenheit, and at Standard Barometric Height, as 62.355 lbs. per cubic foot (authority, Kent and D. K. Clark).

Sheet of cast aluminum, 12 inches square and 1 inch thick, weighs 13.3024 lbs.
Sheet of rolled aluminum, 12 inches square and 1 inch thick, weighs 13.9259 lbs.
Bar of cast aluminum, 1 inch square and 12 inches long, weighs 1.1085 lbs.
Bar of rolled aluminum, 1 inch square and 12 inches long, weighs 1.1605 lbs.
Bar of aluminum, cast, 1 inch round and 12 inches long, weighs .8706 lbs.
Bar of rolled aluminum, 1 inch round and 12 inches long, weighs .9114 lbs.

INDEX.

[*Follow matter.*

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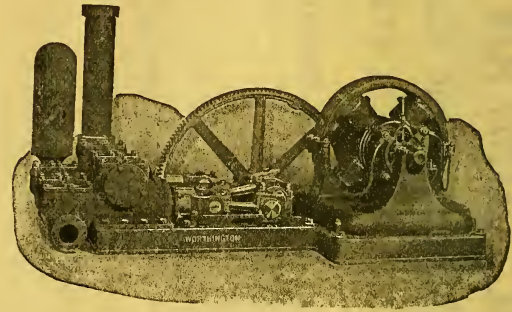

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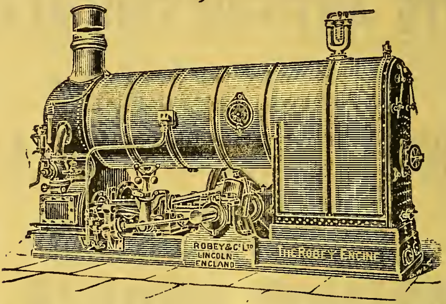

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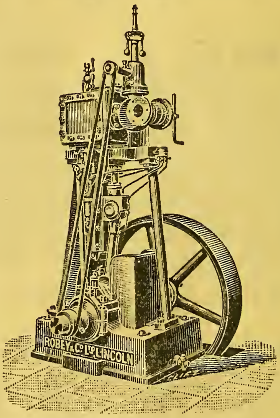

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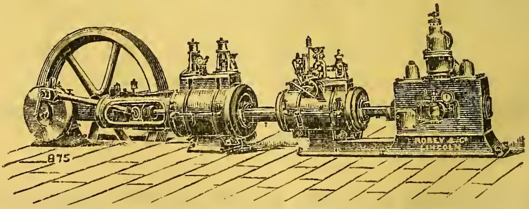

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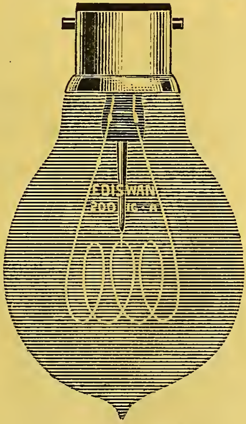

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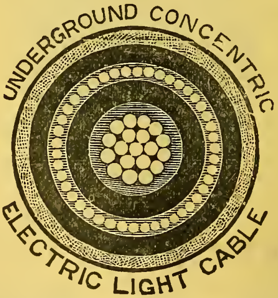

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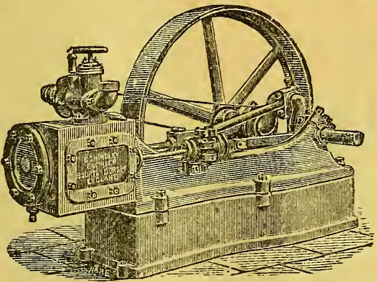

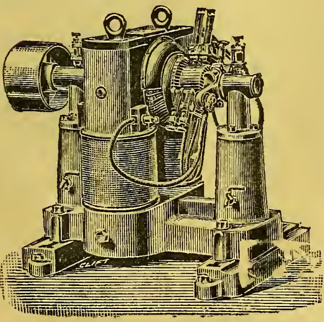

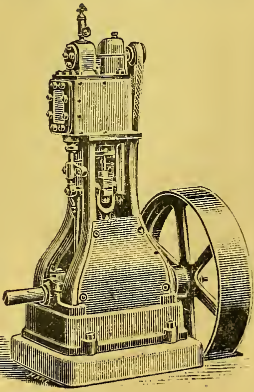

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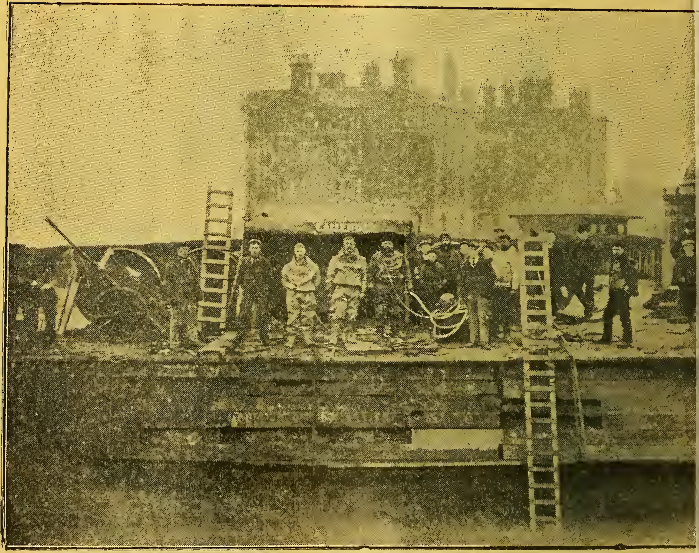

Laying Callender Mains across

LOWESTOFT HARBOUR.

[*Face Title.*