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EDWIN R. KELLER,
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PREFACE TO THE FIRST EDITION.

IT is quite customary for persons to write books on the steam-engine, and then offer as an apology for so doing, that they have discovered that there is no practical treatise on the same subject in the market, which shows either a lack of modesty on their part, and a want of appreciation of what has already been written, or an unwillingness to do justice to those who have previously treated the same subject. There is no want of literature on the steam-engine; in fact, it would be difficult for the most experienced engineer or talented author to add anything original. The steam-engine of the present day is probably as perfect as it ever will be; in fact, there has not been any important improvement made in any class of steam-engines for several years, except in the quality of the materials employed in their construction and refinement of workmanship; consequently, the work of those who treat on the steam-engine, for the present, must be confined simply to abbreviating, simplifying, correcting, and explaining what has already been written, as well as noting the results of the experiments which are tried to test the efficiency of different designs of steam-engines. Whoever will apply himself to this object in the future, will be performing what has long been needed. Of course, we may discover a new engine that will be radically different from any in use at the present day, which would involve the necessity of a new order of literature and new theories, but such an innovation is highly improbable, and casts only a dim shadow in the future.

This book was not written for the purpose of instructing engineers *how to design or proportion* steam-engines or boilers, but rat
to inform them how to take care of and manage them intellige

as well as to furnish to those intending to qualify themselves for th United States Navy, Revenue Service, Mercantile Marine, or to take charge of the better class of stationary steam-engines, with a plain, practical treatise. In order to enhance its value to young engineers, as well as those of limited education, none but the plainest language has been used. This has not been done for the purpose of encouraging the engineer to dispense with the use of mathematics, or discard theories, as all our great triumphs in mechanical science have been based on theories and demonstrated by practice.

In the discussion of the different subjects brevity has been adhered to, because the spirit of the age demands it, even in the discussion of the most important subjects. There can be no reason why the reader should be compelled to wade through chapters of matter to obtain information which may be condensed into a few terse and intelligent paragraphs, nor to deal with the dead past when the living present is before him. The mathematical formula employed have been abbreviated, since it is immaterial how a problem is worked, providing the result is correct and susceptible of easy explanation. Up to the present time, the knowledge to intelligently apply the steam-engine indicator has been confined to a few persons in every country styling themselves experts. This partly arose from the fact that authors who have heretofore treated on this subject were men of literary ability and well versed in mathematics, who found it more agreeable to elucidate their subject in their own peculiar style than in any other.

The writer's experience of over thirty-five years, and his association with all classes of engineers, enable him to understand fully the kind of information most needed by the average engineer. Consequently, he has undertaken the task of furnishing it, and how well he has succeeded in the accomplishment of his object, he cheerfully leaves to the reader to decide. If it should appear that he has suc-'ed in imparting useful and important information to the mem-' a profession to which he himself belongs, he will feel amply d for his efforts. S. R.

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. A body at rest will remain at rest, or if in motion will continue to move uniformly in a straight line till acted upon by some force.

. If a body be acted upon by several forces, it will obey each as if the others did not exist, and this whether the body be at rest or in motion.

If a force act to change the state of a body with re
rest or motion, the body will offer a resistance

THE ENGINEER'S HANDY-BOOK.

PART I.

POWER, TRANSMISSION, AND MEASUREMENT.

CHAPTER I.

MECHANICS.

All machinery, when analyzed, will be found to consist of a combination of six simple machines, commonly called *mechanical elements.* The six elements are respectively the *lever*, the *pulley*, the *wheel and axle*, the *inclined plane*, the *wedge*, and the *screw.* Though they are not powers, or, in other words, sources of power or force, yet they transmit and diffuse or concentrate forces. The essential idea of machinery is that it renders force available for effecting practical ends. Machines prepare, as it were, the raw material of force supplied to us from natural sources. It is transmitted and modified by certain combinations of the elements of machinery, and is given off, at last, in a condition suitable for producing the desired mechanical effect. We do not create force; the object of machinery is to transmit it, and diffuse or concentrate it in one or more points of action. The various diffused or concentrated forces, then, being added together, will amount exactly to the original available force.

Machines.—Machines are instruments employed to regulate motion, so as to save either time or force. The maximum effect of machines is the *greatest effect* which can be produced by them. *In all machines that work* with a uniform motion there are a boring particles. Such molecular forces may be either attractive or repellant, or both. In most cases both forces are acting. If the attractive forces preponderate, the body will be in a solid state; if the forces are equal, in a liquid state; while if the repellant forces are stronger than the attractive, the body will be in the gaseous condition.

The Unit of Force employed by American and English engineers is the pound avoirdupois.

Inertia is that property of matter by virtue of which it resists any attempt to change its condition. Thus if a body is at rest, a force must be applied in order to set it in motion. If it is in motion, a force must be applied to bring it to rest. The heavier the body the greater the force necessary to overcome its inertia.

Motion.—Motion, in mechanics, is a change of place, or it is that property inherent in matter by which it passes from one point of space to another. Absolute motion is the absolute change of place in a moving body, independent of any other motion whatever; in which general sense, however, it never falls under our observation. All those motions, which we consider as absolute, are in fact only relative, being referred to the earth, which is itself in motion. By absolute motion, therefore, we must only understand that which is so with regard to some fixed point upon the earth, this being the sense in which it is interpreted by writers on this subject. Accelerated motion is that which is continually receiving constant accessions of velocity. Angular motion is the motion of a body as referred to a centre, about which it revolves. Compound motion is that which is produced by two or more powers acting in different directions. Natural motion is that which is natural to bodies, or that which arises from the action of gravity. Parallel Motions.—Contrivances of this kind are required for the conversion of rotary and alter-
angular motion into rectilineal motion, and the converse;
solute necessity there is of guiding the path of a piston
ngine, has called forth more attention to the principles
nism of parallel motions than would otherwise, in a

probability, have been awarded to the subject. Relative motion is the relative change of place in one or more moving bodies. Retarded motion is that which suffers continual diminution of velocity, the laws of which are the reverse of those of accelerated motion. Rotary motion, turning as a wheel on its axis, pertaining to or resembling the motion of a wheel. Rotary motions were favorite ones with ancient philosophers. They considered a circle as the most perfect of all figures, and erroneously concluded that a body in motion would naturally revolve in one.

To the substitution of circular for straight motions, and of continuous for alternating ones, may be attributed nearly all the conveniences and elegancies of civilized life. It is not too much to assert, that the present advanced state of science and the arts is due to revolving mechanism. From the earliest times it had been an object to convert, whenever practicable, the rectilinear and reciprocating movements of machines into circular and continuous ones. Old mechanics seem to have been led to this result by that tact or natural sagacity, that is more or less common to all times and people. Thus the dragging of heavy loads on the ground led to the adoption of wheels and rollers,—hence carts and carriages. The rotary movements of the drill superseded the alternating one of the punch and gouge, in making perforations; the whetstone gave way to the revolving grindstone; the turning-lathe produced round forms infinitely more accurate and more expeditiously than the uncertain and irregular carving or cutting with the knife.

Laws of Motion.—Newton's:

1st. A body at rest will remain at rest, or if in motion will continue to move uniformly in a straight line till acted upon by some force.

2d. If a body be acted upon by several forces, it will obey each as if the others did not exist, and this whether the body *be at rest or in motion.*

3d. If a force act to change the state of a body with respect to *rest or motion, the* body will offer a resistance equal and directly opposed to the force. Or to every action there is opposed an equal and opposite reaction.

Perpetual Motion.—In mechanics, a machine which, when set in motion, would continue to move forever, or, at least, until destroyed by the friction of its parts, without the aid of any exterior cause, would constitute perpetual motion. The discovery of perpetual motion has always been a celebrated problem in mechanics, on which many ingenious, though in general ill-instructed, persons have spent their time; but all the labor bestowed on it has proved abortive. In fact, the impossibility of its existence has been fully demonstrated from the known laws of matter. In speaking of perpetual motion, it is to be understood that, from among the forces by which motion may be produced, we are to exclude not only air and water, but other natural agents, as heat, atmospheric changes, etc. The only admissible agents are the inertia of matter, and its attractive forces, which may all be considered of the same kind as gravitation. It is an admitted principle in philosophy, that action and reaction are equal, and that, when motion is communicated from one body to another, the first loses just as much as is gained by the second. But every moving body is continually retarded by two passive forces,—the resistance of the air and friction. In order, therefore, that motion may be continued without diminution, one of two things is necessary—either that it be maintained by an exterior force, (in which case it would cease to be what we understand by a perpetual motion,) or that the resistance of the air and friction be annihilated, which is practically impossible.

The motion cannot be perpetuated, till these retarding forces are compensated, and they can only be compensated by an exterior force, as the force, communicated to any body, cannot be greater than the generating force, which is only sufficient to continue the same quantity of motion, when there is no resistance. The error, *of confounding mere* pressure with energy available to produce *ower, is the main origin* of the majority of attempts at perpetual *otion, and even* sometimes causes, among confused minds, ex aggerated expectations about the effects to be obtained from mechanical contrivances. A wound-up spring is exactly equivalent to a weight. It may exert a certain pressure, great in proportion to its size and strength; but, unless it is allowed to unwind it, it cannot produce motion or power. It is the same with compressed air or gases; they are, in fact, nothing but wound-up springs, with this difference, however, that, in place of needing mechanical power to wind them up, we may use either heat, chemical agencies, or electricity.

Velocity or Speed is the rate of motion—that is, the space travelled over by a moving body divided by the time required. Thus, if a railroad train requires two hours to cover the distance of ninety miles between Philadelphia and New York, its velocity is ninety divided by two, or 45 miles per hour. The same velocity might be otherwise expressed as three-quarters of a mile per minute, or 240 rods per minute, or 4 rods per second, or 66 feet per second.

Velocity is uniform if equal spaces are passed over in equal times.

Acceleration is the rate at which velocity changes, or it is the gain or loss in velocity in one second. For instance, a falling body in the first second passes over 16.1 feet, in the next second 48.3 feet, and so on. Its average velocity in the first second is 16.1 feet per second, and in the next second is 48.3 feet per second; the gain in velocity is 32.2 feet each second, and therefore we say the body has an acceleration of 32.2 feet per second.

Falling Bodies are subject to two forces, that of gravitation and that of the resistance of the air. The latter is for ordinary shapes so small as to be neglected, and the relations existing are covered by the following simple formulæ:

Let v = velocity of falling body expressed in feet per second.
g = acceleration due to gravity, found by measurement to be about 32.2 feet.
t = time in seconds, reckoned from moment of starting to fall.
h = distance passed over in t seconds.

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[illegible] by experiment.

[illegible] examples will show how these formulæ are [illegible]

[illegible] starts from rest and falls freely, what will be its [illegible] at the end of the fifth second?

[illegible] substituting the actual values of g and t, we [illegible]

[illegible] $= 161$. or velocity at end of fifth second [illegible] feet per second.

[illegible] starts to fall freely from a height of 50 feet, what will [illegible] when it reaches the earth?

Taking [illegible] $= \sqrt{64.4\,h}$ and substituting for h its value 50 feet, we [illegible] $= \sqrt{64.4 \times 50} = \sqrt{3220}$. Looking in the table of squares we find that the square root of 3220 is between 56.7 and 56.8, and nearer to 56.8. The velocity when it reaches earth will be 56.8 feet per second.

3d. If a body be allowed to fall, what distance will it have passed through at the end of the tenth second?

Taking $h = \frac{gt^2}{2}$ and substituting, we have $h = \frac{32.2 \times 10 \times 10}{2}$, or

reducing, $h = \frac{3220}{2} = 1660$ feet.

The following table is convenient for use in such problems:

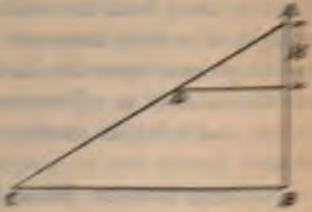
t - seconds	1st	2d	3d	4th	5th	6th	7th	8th	9th	10th
v - velocity at end of t seconds $= 32.2 \times$	1	2	3	4	5	6	7	8	9	10
[illegible]led in each sec. $= \frac{32.2}{2} \times$	1	3	5	7	9	11	13	15	17	1
[illegible] t seconds $= \frac{32.2}{2} \times$	1	4	9	16	25	36	49	64	81	100

[illegible]ty at the end of the fifth second is $32.2 \times 5 = 1$

[illegible]ance passed over in the sixth second is

$\frac{32.2 \times 11}{2} = 177.1$ feet. The total distance passed over in four seconds is $\frac{32.2 \times 16}{2} = 257.6$ feet, and in ten seconds is $\frac{32.2 \times 100}{2}$ $= 1610$ feet.

Motion Down an Inclined Plane.—Neglecting friction, the preceding formulæ may be used for the motion of bodies down inclined planes. In this case H is the vertical height through which the body descends. The distance D measured down the slope may be found by proportion.



Example.—Suppose a hill, whose vertical height $A\,B = 1000$ feet, is covered with snow and a smooth icy crust is formed, as is frequently the case in New England. The distance $A\,C$ is known to be 2000 feet. A sled starts at A and descends. Friction neglected, the preceding table gives us H = vertical height = at end of first second 16.2 feet, second second = 64.4 feet, third second = 144.9 feet, fourth second = 257.6 feet. At the end of the fourth second the distance $A\,D$ is the same fraction of $A\,C$ as 257.6 is of 1000. Therefore at end of the fourth second the sled will have travelled along $A\,C$ a distance $A\,D = 2000 \times \frac{257.6}{1000} = 515.2$ feet. The velocity in the direction $A\,B$ at the end of the fourth second is, from the table, 32.2×4 $= 128.8$ feet per second. As the sled has moved in 4 seconds 515.2 feet along $A\,C$ while descending vertically 257.6 feet, the velocity along $A\,C$ at the end of the fourth second will be $\frac{515.2}{257.6}$ × the velocity in the direction of $A\,B$. In fact, at any instant the velocity along $A\,C$ will be $\frac{515.2}{257.6}$ times as great as the velocity in the direction $A\,B$. Notice that $\frac{515.2}{257.6}=2$, and that the $\frac{\text{distance } A\,C}{\text{distance } A\,B}=2$ also. In general, the velocity along $A\,C=$ velocity along $A\,B\times\frac{\text{distance } A\,C}{\text{distance } A\,B}$.

Mass.—The mass of a body is defined to be its weight in pounds divided by the value of g at the place where it is weighed. This value of g, the acceleration imparted by gravity to a falling body, differs somewhat in value at different places on the earth's surface owing to the fact that the earth is not a perfect sphere. As we go up a mountain g diminishes, because we are getting farther away from the earth and its pull on a body is less. The weight of a body measured by a spring balance also diminishes as we go away from the earth's centre in just the same proportion as the value of g. Therefore the quotient of weight $\div\, g$ is a constant, and it is this quotient which we agree to call the mass of a body.

Relation between Mass, Force, and Acceleration.—If a force of F pounds be applied to a mass M, the mass will be put in motion and will be given an acceleration of a feet per second. That is, in the form of the usual equation $F=M\,a$. If we know any two of these three quantities, we can by simple arithmetic find the third. For example, What force must be applied to a certain body at rest to give it in one second a velocity of 20 feet per second. Recollecting that acceleration is the change in velocity in one second, the value of a is 20. Weigh the body, and suppose we find its weight to be 64.4 pounds. Its mass M is then $\frac{\text{weight in pounds}}{g}=\frac{64.4}{32.2}=2$. Substituting in the formula, we have $F=2\times 20=40$ pounds, the necessary force.

Another example: Suppose a cart weighing 100 pounds be dragged at a velocity of 20 feet per second by a man on a tricycle, and suppose that the cart is attached to the cycle through pring balance. The needle of the balance will read a cer at, and this reading gives the force in pounds necessary to ome the friction of the cart, and the resistance of the air. se it to be 10 pounds. Now suppose the cyclist speeds up, sing his velocity to 22 feet per second. There is a gain of ty or an acceleration of 2 feet per second. To produce this ration there must be an additional force exerted by the t, and this increase will be shown on the balance, whose g will be increased. The increase will be due to two : 1st, the extra pounds pull needed to overcome the in- d air resistance at the higher speed, which will be some- near 2 pounds; 2d, the force needed to accelerate the cart per second. This force is $F = Ma = \frac{100 \times 2}{32.2}$, or 6.2 pounds. at during the second in which the speed is being raised the e will read about 18 pounds. If after reaching the speed feet per second, the cyclist continues at that speed, the g of the balance will drop to about 12 pounds.

ow the cyclist slows up, changing in one second from a of 22 to 20 feet per second, the reverse action will take and during this second the balance-reading will drop from an amount, 6.2 pounds, which is needed to retard the cart y 2 pounds more, which is the difference in pull between s necessary to maintain the cart at 22 feet and that needed p it at 20 feet per second.

Momentum of a body is defined as the product of its times its velocity. For instance, a body weighing 100 s and moving 50 feet per second has a momentum of $\frac{t \times \text{velocity}}{g}$, or $\frac{100 \times 50}{32.2} = 155.28$.

s equal in numbers to the force which will start the body est and accelerate it till at the end of one second it has the velocity. Thus, suppose a force of 155.28 pounds be ap- o a weight of 100 pounds, what velocity will it have at the *the first second?*

$$F = Ma = \frac{\text{weight} \times \text{acceleration}}{g}.$$

$$155.28 = \frac{100 \times a}{32.2}, \quad \text{or} \quad a = \frac{155.28 \times 32.2}{100} = 50 \text{ feet per second.}$$

If the acceleration is 50 feet per second, since by definition the acceleration is the gain in velocity in one second, the velocity of the body one second after the application of the force of 155.28 pounds must be 50 feet per second. It is also evident that if 155.28 pounds will in one second impart to a body previously at rest a velocity of 50 feet per second, it will also bring to rest in one second a body weighing 100 pounds which is moving at a velocity of 50 feet per second. The momentum of a moving body is therefore equal to the force which must be used to bring it to rest in one second.

Energy or Work in mechanics involves two things—force and space. If only one be present, no work is done. For instance, a weight resting on a table is doing no work, for while it exerts a pressure or force on the table it does not move. If it be allowed to fall, say, for example, being attached to a cord passing over a drum, it can be made to do work.

The unit of work among American and English engineers is the foot-pound—*i. e.*, the work done in raising one pound through a distance of one foot. The same work would be done in raising 2 pounds to a height of 6 inches or 12 pounds to a height of 1 inch. The number of foot-pounds of work done is, then, always equal to the force in pounds multiplied by the distance in feet over which it is exerted. For example, a man lifts 100 pounds to a table 4 feet high. He does 400 foot-pounds of work. He may lift it slowly or quickly—it makes no difference in the amount of work done. He may lift it up one foot and place it on a block, rest a while, then raise on to another block two feet high, and so on. The number of foot-pounds of work performed by him remains the same.

The work which the man has done is stored up in the 100 *pound weight, and will* remain there till the weight is allowed to fall. If the weight be allowed to fall one foot, it can be made to do 100×1, or 100 foot-pounds of useful work, if, as suggested above, we attach it to a rope passing over a drum, or it can be allowed to fall suddenly a distance of one foot and give up its stored energy in the form of heat, which heat may or may not be usefully employed. If allowed to fall another foot, it gives up another 100 foot-pounds, and so on till it reaches its original level, when it will have given up the 400 foot-pounds stored in it by virtue of its having been raised four feet. The case of a tower clock is an excellent example of the storing the work of a man by a raised weight and afterward employing it usefully by letting the weight fall slowly. A similar storage of work occurs in winding a watch or spring clock. In the case of a steam engine taking steam the entire stroke, exhausting into a vacuum and with a pressure of 100 pounds to the square inch, diameter 8 inches, length of stroke 10 inches, the number of foot-pounds work done on the forward stroke is

$$100 \times \text{area of piston} \times \frac{10}{12} = \frac{100 \times 25.1328 \times 10}{12} = 2094.4 \text{ foot-pounds.}$$

Energy, strictly speaking, is stored work, or the capacity for doing work. The word is often employed in the place of work. Energy existing in a body at rest is called *potential* energy. Such is a raised weight, a coiled spring, or water pumped to a height. The number of foot-pounds stored up is equal to the number of pounds raised multiplied by the height. Energy existing in a moving body is called *kinetic*. The number of foot-pounds stored in a body of weight W and velocity V is equal to the work done in starting it from rest and accelerating it till its velocity is V, and this number of foot-pounds is $\frac{1}{2} M V^2$ or $\frac{W V^2}{g \times 2}$. Thus a cannon-ball weighing 10 pounds and moving 1000 feet per second has $\frac{10 \times 1000 \times 1000}{32.2 \times 2}$ or 153726 foot-pounds of energy stored up in it. The explosion of the powder produced this energy. When the cannon-ball strikes it gives this amount up in the form of heat, less, of course, that which has been lost in overcoming the fricti of the air.

Forms of Energy:

Potential.—Stresses—either compression, extension, or torsion.
Gravitational, between two separated bodies.
Chemical, between two separated atoms.
Electrical, between two separated charged bodies.
Magnetic, between two separated magnetized bodie

Kinetic.—Rectilinear or rotary motion.
Vibration, such as sound.
Wave-motions, such as light.
Heat—molecular motion.
Electric current flow.

Source of Energy.—The rays of the sun are the primary sour of all energy which man employs. They cause the growth o plants, which furnish food and fuel to man. Our vast coal d posits, which now are drawn on to furnish most of the world' power, are only the energy of the sun's rays stored up in plants in bygone ages. It is the sun which now raises water from the sea-level to the mountain-top, thus giving it potential energy which is used to turn water-wheels and made to do useful work.

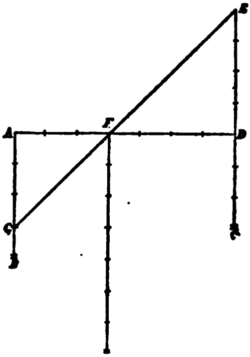
Conservation of Energy.—The amount of energy in the universe cannot be changed by man. He can transmit it or change the form in which it appears, but he can in no wise create it or destroy it. A bushel of coal has a certain number of foot-pounds of energy stored in it. This energy is chemical in form, consisting in the attraction which the oxygen of the air has for the carbon of the coal. If the coal is burned, an exactly equal number of foot-pounds is liberated in the form of heat. If burned in a boiler, the potential chemical energy of the coal is changed into kinetic energy of heat; this is used in raising the temperature and pressure of steam, and the confined steam has an equal number of foot-pounds less what escaped as heat up the boiler-stack. The steam taken into the engine is allowed to expand, and gives up a part of its potential energy to the piston, the work escaping, s heat into the exhaust. The energy of the piston is made to urn the crankshaft, and this may again give up its energy (except that lost as heat in friction in the engine) to a dynamo, which changes the rotary mechanical energy into electric energy (less some lost as heat). This electrical energy may be transmitted over wires and run into motors, changing electrical into mechanical energy again, or into lamps, changing from electrical to light and heat energy, or may even be run into a chemical solution, and by decomposing this into its elements, change the electrical energy into the original form of chemical energy. The sum of this chemical energy plus that wasted in heat at the different transformations will exactly equal the energy originally in the bushel of coal. Nothing can be done by any combination of machines or processes to increase the energy in the coal. All that can be done is to make the desired transformations as efficient as possible, wasting as little as possible in the form of heat. This is by no means easy, for all forms of energy tend to assume the form of heat, and in the chain of transformations mentioned above not one-twentieth of the energy in the coal would be found in the form of chemical energy at the end, the remainder having been changed into the form of heat at different stages of the process.

Power is the rate at which work is done. If a man lifts 100 pounds 4 feet twice per minute, or 120 times per hour, his rate of working is 4 × 100 × 120, or 48,000 foot-pounds per hour.

Horse-Power.—James Watt, experimenting on the ability of draught horses to do work for a short time, found that they could do work at the rate of about 550 foot-pounds per second, or 33,000 foot-pounds per minute, and this rate is adopted as the horse-power. The man above would be doing work at the rate of $\frac{48,000}{33,000}$, or 1.4555+ horse-power.

The power is equal to work divided by time. Thus if a man does *55 pounds 100 times in 15* minutes, he does $\frac{5500}{15}$ foot-pounds point of application of the resultant force may be found as follows:

Let *A B* and *CD* represent the two parallel forces of 4 and 3 pounds respectively. Continue *C D* to *E*, making distance *D E* = *A B*, make *A G* equal to *CD* and draw *E G*. Then *F* is the point of application of the resultant of the two forces, and



the value of this resultant would be 7 pounds. The distance *A F* is to *F D* as 3 is to 4. A force of 7 pounds upward applied at *F* would just balance the two forces *A B* and *C D*.

Moment, or Statical Moment.—In order to handle easily the subject of levers and tendency to rotation it is best to treat them by means of moments so called. The moment of a force about a point is equal to the intensity of the force in pounds multiplied by the length of the line drawn perpendicularly from the point to the line of direction of the force. Thus in the figure the moment of the force *A B* about the point *F* is $4 \times 3 = 12$, and the moment of the force *C D* about the point *F* is $3 \times 4 = 12$.

If a rod *A D* having a weight of 4 pounds at *A* and 3 pounds at *B* were supported on a knife-edge at *F*, it would just balance. *The downward force* of 7 pounds acting at *F* is just balanced by *the upward reaction of* the knife-edge.

If weight were added at A, the end A would tip down, the rod tending to rotate about F as a centre. Notice that the moment of the force $A\,B$ is now greater than that of $C\,D$. Whenever the moments of two forces about a point are equal and the forces tend to turn the body around that point in opposite directions, the body has no tendency to rotate. Any unbalanced moment causes rotation.

Mechanical Elements.—As before stated, all machinery can be analyzed into six elements, which are—*the lever*, *the wheel and axle*, *the inclined plane*, *the wedge*, *the pulley*, and *the screw*. These elements in no sense can create force; they only allow us to direct it and to use it to advantage.

Levers.—Levers are classified into three different kinds or orders. When the fulcrum is between the force and the weight, the lever is called a lever of the first order; when the weight is between the force and the fulcrum, the lever is of the second order; when the force is between the weight and the fulcrum, the lever is of the third order. The levers of safety-valves for steam-boilers belong to this last class.

The lever is an inflexible bar, by the application of which one force may balance or overcome another. These forces are termed, respectively, the *power* and the *resistance* or *weight*, not from any difference in the action of the forces, but with reference merely to the intention with which the machine is used; and, indeed, the same terms are used about all the other mechanical elements. In applying the rod to operate upon any resistance, it must rest upon a centre prop, or fulcrum, somewhere along its length, upon which it turns in the performance of its work. Thus, there are three points in every lever to be regarded in examining its action—namely, the points of application of the power, the weight, and the point resting on the fulcrum. * There is a certain relation to be observed between the magnitudes of the opposing force and the distances from the fulcrum—namely, that in every case the

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* Note that the *power above is really* a force of so many pounds, and not *mechanical power as previously* defined.

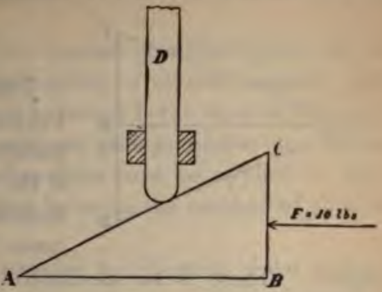
power *multiplied* by its distance from the fulcrum is equal to the weight *multiplied* by its distance from the same point. This is another statement of the principle of moments. Make the moment of the one force about the fulcrum equal to the moment of the other force, and solve for the quantity which is unknown.

Examples.—If with a crowbar pivoted on a stone we are trying to raise up a large stone weighing, say, 1000 pounds. From the point of the crowbar to the pivot or fulcrum is 1 foot. From the fulcrum to where the handle is grasped is, say, 4 feet. What force must be exerted to lift up the stone? Call this force f for shortness. Taking moments about the fulcrum, we have $f \times 4 = 1000 \times 1$, or $4f = 1000$ pounds. Therefore, dividing both sides of our equation by 4, we have f the force to be exerted is 250 pounds. If, instead of 1 foot, the distance from point to fulcrum were 1 inch, the force f would be only one-twelfth of 250 pounds, or 20 pounds 13 ounces and a trifle over. By the aid of levers enormous weights can thus be moved by the application of comparatively small forces. No power is gained, for while the force to be applied in the second case is 12 times as small, the hand applying it moves through a distance 12 times as great as in the first case.

The Wheel and Axle.—The wheel and axle may be considered as a perpetual lever, from the constant renewal of the points of suspension and resistance. The fulcrum is the centre of the axis, the longer arm is the radius of the wheel, and the shorter arm the radius of the axis. As the diameters of different circles bear the same proportion to each other that their respective circumferences do, the power is also to the weight as the diameter of the wheel is to the diameter of the axle. If one wheel move another of equal circumference, no power will be gained, as they will both move equally fast. But if one wheel move another of different diameter, whether larger or smaller, the velocities with which they move will be inversely as their diameters, circumferences, or number of teeth.

The Inclined Plane in its action of a small force balancing large one may best be understood by considering it from the standpoint of work or energy. The inclined plane $A\ B\ C$ is pushed against the column D by a force of 10 pounds. The side $A\ B$ is, say, 12 inches and $B\ C$ 4 inches. How great a weight on the column D, which moves between guides, can be raised neglecting losses in friction. Suppose we start with the point A just entering and apply the 10-pound force till the point C is just touching the column. The force of 10 pounds has been exerted over a distance of 12 inches. The work done is 10×12 inch-pounds. The weight of the column D has been raised 4 inches, or one-third of one foot. The work done = weight times distance = $W \times 4$ inch-pounds. Assuming no friction losses, the work done by the force 10 pounds must equal the work done on the column, therefore $4 \times W = 10 \times 12$, or $\frac{W}{10} = \frac{12}{4}$—*i. e.*, in general, the weight raised is to the force applied as the length of the horizontal side is to the length of the vertical side. Making the inclined plane less abrupt increases the gain in force. The general equation $\frac{W}{F} = \frac{\text{length } A\ B}{\text{length } B\ C}$ allows any one of the four quantities, W, F, $A\ B$, or $B\ C$, to be calculated if the other three are known. For instance, suppose it was desired to raise a weight of 2000 pounds and the greatest force that could be applied was 200 pounds, what should be the relation between the two perpendicular sides of the wedge? Here $W = 2000$ and $F = 200$. By the equation

$$\frac{W}{F} = \frac{A\ B}{B\ C}, \text{ or } \frac{A\ B}{B\ C} = \frac{2000}{200} = \frac{10}{1}; \text{ therefore } A\ B = 10 \times B\ C.$$



The Wedge *is a double inclined* plane, and is hence governed power multiplied by its distance from the fulcrum is eq weight multiplied by its distance from the same point. another statement of the principle of moments. Make the of the one force about the fulcrum equal to the mome other force, and solve for the quantity which is unkn

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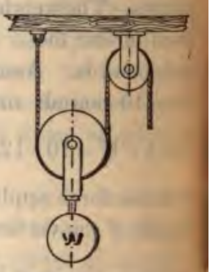
The Inclined Plane is

by exactly the same principles. The form of the equation becomes

$$\frac{W}{F}=\frac{AB}{CD}.$$

The Pulley.—Pulleys are of two kinds, *fixed* and *movable.* The fixed pulley turns only upon its axis, and if the applied force is downward the weight is lifted through the same distance through which the force is applied. There is no mechanical advantage in this form, it merely serving to reverse the direction of a force.

The movable pulley turns on its axis and also rises and falls. The figure shows such a pulley in combination with a fixed pulley. The advantage gained by a movable pulley can best be seen by considering it from the standpoint of work done. Assume that there is no loss in friction of bearings and stiffness of rope, and recollect that the fixed pulley has no effect except to change the direction of the applied force. We may then consider that one end of the rope is fixed and a force of F pounds is applied at the other end, and that this force is pulling upward and trying to raise the weight W pounds. What is the relation between the values of F and W? Suppose F acts long enough so that the rope end moves two feet. The work done by the force F is $2F$ foot-pounds. The weight W will evidently be raised only one-half of two feet, or one foot, and the work done on W will be $W\times 1$, or W foot-pounds. These two amounts of work must be equal, since there is assumed to be no loss in friction; therefore $2F=W$, or $F=\frac{1}{2}W$. That is, by the use of one movable pulley we can raise a weight of 100 pounds by applying a force of *50 pounds. It takes,* however, just twice as long to do it as if we *ised the weight* without using the pulley.

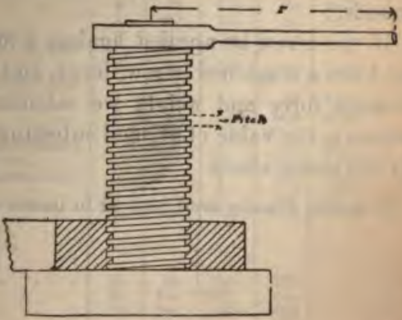


If we had two movable pulleys, 25 pounds would raise 100 pounds; with four movable pulleys 12½ pounds would raise 100 pounds, and so on.

The ordinary block and tackle consists of a fixed pulley of one or more sheaves, and a movable pulley of several sheaves. The action of the movable pulley of 2 sheaves is the same as two movable pulleys, with 3 sheaves as three pulleys, and so on. Hence to find with a certain tackle what force must be applied to lift a certain weight, divide the weight by twice the number of sheaves in the movable pulley.

The Screw.—The screw is another modification of the inclined plane, and it may be said to remove the same kind of practical inconveniences incidental to the use of the latter that the pulley does in reference to the simple lever. The lever is very limited in the extent of its action and so is the inclined plane. But the pulley multiplies the extent of the action of the lever, by presenting, in effect, a series of levers acting in regular succession; and just such a purpose is effected by the screw. It multiplies the extent of the action of the inclined plane by presenting, in effect, a continued series of planes.

The *screw*, in principle, is that of an inclined plane wound round a cylinder, which generates a spiral of uniform inclination, each revolution producing a rise or traverse motion equal to the pitch of the screw—that is, the distance between two consecutive threads.



As in cases of other elements, the relation between applied force and weight *raised is easily obtained* by looking at it from the standpoint *of work*.

In the figure a force F is applied at the end of a lever. The distance from the point of application of F to the centre of the screw is r inches. Suppose F is applied through one revolution of the screw raising a weight W attached to its end a distance P inches equal to the pitch of the screw.

The force F does work to the amount of $2 \times 3.1416 \times r \times F$, for $2 \times 3 \times 3.1416 \times r$ is the distance through which F acts. Work is done on the weight W to an amount $W \times P$.

$$\text{Therefore } 2 \times 3.1416\, r\, F = W P, \quad \text{or} \quad F = \frac{W P}{6.2832\, r}.$$

Example.—What force must be applied at the end of the lever of a jackscrew to raise a weight of 2000 pounds, if the lever arm is 2 feet and the pitch of the screw ½ inch.

$$F = \frac{2000 \times \frac{1}{2}}{6.2832 \times 2 \times 12} = 6.63 \text{ pounds.}$$

Example.—If a force of 10 pounds be applied at the end of the lever, what weight will it lift?

$$W = \frac{6.2832\, r\, F}{P} = \frac{6.2832 \times 2 \times 12 \times 10}{\frac{1}{2}} = 3016 \text{ pounds.}$$

Example.—If the lever be 4 feet long, what will be the weight lifted? *Ans.* By doubling the length of lever the same force of 10 pounds, applied at its end, will lift double the weight, or 6032 pounds.

If the screw be applied against a toothed wheel as in a winch, we have a combined screw, lever, and axle. To get the relation between force and weight we calculate separately for the wheel and axle the value of W, and substitute this value in the equation for the screw above.

Note that P and r must both be in inches or feet.

CHAPTER II.

GENERATION AND TRANSMISSION OF POWER.

Sources of Power.—While, as explained under "Conservation of Energy," the ultimate or fundamental source of energy is in the sun's rays, these are not used directly by man. The principal secondary sources of power are the tides operating some form of tide-mill, the wind, waterfalls, carbon in its different forms, such as coal, petroleum, or gas, and various chemicals used in electrical batteries. Of these, water-power and carbon power are the two most important. We may further say that while there are many hot-air or gas engines in use, yet practically all the carbon power is derived by means of the steam boiler and steam engine.

AMOUNTS OF POWER USED IN VARIOUS OPERATIONS.

Description of Works.	Work-hrs. per day	Force. F	Veloc'y V	Ft.-lbs. per sec.	Horses. H
A man can raise a weight by a single fixed pulley,	6	50	0.8	40	0.072
A man working a crank,	8	20	2.5	50	0.090
A man on a tread-wheel (horizontal),	8	144	0.5	72	0.130
A man in a tread-wheel (axis 24° from vertical),	8	30	2.3	69	0.125
A man draws or pushes in a horizontal direction,	8	30	2	60	0.109
A man pulls up or down,	8	12	3.7	44.4	0.080
A man can bear on his back,	7	95	2.5	237.5	. . .
A horse in a horse-mill, walking moderately,	8	106	3	318	0.577
A horse in a horse-mill, running fast,	5	72	9	648	1.178
An ox in a horse-mill, walking moderately,	8	154	2	308	0.558
A mule " " "	8	71	3	213	0.308
An ass " " "	8	33	2.65	87.4	0.160
On bad Foot-roads.					
A man can bear,	10	50	3.5	175	
Llama of Peru can bear,	10	100	3.5	350	
Donkey can bear,	10	200	3.5	700	
Mule can bear,	10	400	5	2000	

ANIMAL POWER.

Work of a Man against Known Resistances. (Rankine.)

Kind of Exertion.	R, lbs.	V, ft. per sec.	$\frac{T''}{3600}$ (hours per day).	RV, ft.-lbs. per sec.	RVT, ft.-lbs. per day.
1 Raising his own weight up stair or ladder	143	0.5	8	72.5	2,088,000
2. Hauling up weights with rope, and lowering the rope unloaded	40	0.75	6	30	648,000
3. Lifting weights by hand	44	0.55	6	24.2	522,720
4 Carrying weights up-stairs and returning unloaded	143	0.13	6	18.5	399,600
5 Shovelling up earth to a height of 5 ft. 3 in	6	1.3	10	7.8	280,800
6. Wheeling earth in barrow up slope of 1 in 12, ½ horiz. veloc. 0.9 ft. per sec. and returning unloaded	132	0 075	10	9.9	356,400
7 Pushing or pulling horizontally (capstan or oar)	26.5	2.0	8	53	1,526,400
8. Turning a crank or winch . .	12.5 18.0 20.0	5 0 2.5 14 4	? 8 2 min.	62.5 45 288	.... 1,296,000 ....
9. Working pump..	13.2	2 5	10	33	1,188,000
10. Hammering	15	?	8?	?	480,000

EXPLANATION.—R, resistance; V, effective velocity = distance through which R is overcome ÷ total time occupied, including the time of moving unloaded, if any; T'', time of working, in seconds per day; $T'' \div 3600$, same time, in hours per day; RV, effective power, in foot-pounds per second; RVT, daily work.

Performance of a Man in Transporting Loads Horizontally. (Rankine.)

Kind of Exertion.	L, lbs.	V, ft.-sec.	$\frac{T}{3600}$ (hours per day).	LV, lbs. conveyed 1 foot.	LVT, lbs. conveyed 1 foot.
11. Walking unloaded, transporting his own weight	140	5	10	700	25,200,000
12. Wheeling load L in 2-whld. barrow, return unloaded ..	224	1⅔	10	373	13,428,000
13. Ditto in 1-wh. barrow, ditto..	132	1⅔	10	220	7,920,000
14. Travelling with burden.....	90	2½	7	225	5,670,000
15. Carrying burden, returning unloaded	140	1⅔	6	233	5,032,800
16. Carrying burden, for 30 seconds only	252 126 0	0 11 7 23.1	... ...	0 1474.2 0	....

EXPLANATION.—L, load; V, effective velocity, computed as before; T'', *time of working, in seconds per day*; $T'' \div 3600$, same time in hours per day; LV, *transport per second*, in lbs. conveyed one foot; LVT, daily transport.

Work of a Horse against a Known Resistance. (Rankine.)

Kind of Exertion.	*R.*	*V.*	$\frac{T.}{3600}$	*RV.*	*RVT.*
1. Cantering and trotting, drawing a light railway carriage (thoroughbred)...........	min. 22½ mean 30½ max. 50	14⅔	4	447½	6,444,000
2. Horse drawing cart or boat, walking (draught-horse).....	120	3.6	8	432	12,441,600
3. Horse drawing a gin or mill, walking	100	3 0	8	300	8,640,000
4. Ditto, trotting	66	6.5	4½	429	6,950,000

EXPLANATION.—*R*, resistance, in lbs.; *V*, velocity, in feet per second; *T*" ÷ 3600, hours work per day; *RV*, work per second; *RVT*, work per day.

The average power of a draught-horse, as given in line 2 of the above table, being 432 foot-pounds per second, is 432/550 = 0.785 of the conventional value assigned by Watt to the ordinary unit of the rate of work of prime movers. It is the mean of several results of experiments, and may be considered the average of ordinary performance under favorable circumstances.

Performance of a Horse in Transporting Loads Horizontally. (Rankine.)

Kind of Exertion.	*L.*	*V.*	*T.*	*LV.*	*LVT.*
5. Walking with cart, always loaded....	1500	3.6	10	5400	194,400,000
6. Trotting, ditto....	750	7.2	4½	5400	87,480,000
7. Walking with cart, going loaded, returning empty; *V*, mean velocity...............	1500	2.0	10	3000	108,000,000
8. Carrying burden, walking....	270	3.6	10	972	34,992,000
9. Ditto, trotting	180	7.2	7	1296	32,659,200

EXPLANATION.—*L*, load in lbs.; *V*, velocity in feet per second; *T* ÷ 3600, working hours per day; *LV*, transport per second; *LVT*, transport per day. This table has reference to conveyance on common roads only, and those evidently in bad order as respects the resistance to traction upon them.

Work of a Horse on a Grade.—If a horse can haul on a level 00 pounds, on a grade approximately the following loads can be auled at the same speed:

With a rise of—

1 in 100	1 in 50	1 in 40	1 in 30	1 in 20	1 in 10
90 lbs.	81 lbs.	72 lbs.	64 lbs.	40 lbs.	25 lbs.

POWER REQUIRED FOR ROLLING MILL MACHINERY.

	Horse-Power running idle.	Horse-Power doing full work.
Lathe, Cambria, 61″ roll turning, 35″ roll, 42 rev. per hour	1.1	4.8
Lathe, Bement, 63″ roll turning, 35″ roll, 40 rev. per hour	1.4	4.8
Lathe, Bement, same starting up	10.8	
Lathe, Bement, 63″ roll turning, 28″ roll, 48 rev. per hour	1.5	5.9
Lathe, Garrison, 40″ roll turning, 39″ roll, 48 rev. per hour	1.6	6.7
Straightening press, working on rails 80 lbs. to yard, 41 strokes per min	3.0	14.8
Straightening press, same, starting	14.8	
Punch for rails, punching three 1¼″ diam. holes in ½″ metal at the rate of 34 strokes per min	......	3.0
Punch for rails, starting, on account of heavy fly-wheel	8.9	
Hot saw, cutting 20″ × ½″ I beams, speed 1800 per min., cut 2½ min	4.6	31.
Hot saw, cut 1 min	......	84.
" cut 55 sec	......	92.
Cold saw, Newton, on 80 lb. rails, diam. 20″, width $\frac{3}{16}$″, 192 teeth, 8 rev. per min.	......	3.8

POWER CONSUMED BY STURTEVANT STEEL PRESSURE BLOWERS, WITH OUTLET FULLY OPEN.

Size blower.	4 oz. blast.		5 oz. blast.		6 oz. blast.		7 oz. blast.		8 oz. blast.	
	Rev.	H.P.	Rev.	H.P.	Rev.	H.P.	Rev.	H.P.	Rev.	H.P.
2	3103	2.1	3445	3.0	3756	3.9				
3	2456	3.0	2743	4.2	3006	5.4				
4	2224	4.2	2470	5.7	2692	7.5				
5	1814	5.0	2026	8.4	2215	10.8	2387	13.8		
6	1619	7.8	1797	10.8	1960	14.1	2009	18.0	2258	21.9
7	1344	10.8	1507	15.0	1641	19.5	1768	24.9	1898	31.2
8	1200	13.5	1330	19.2	1445	25.2	1565	31.8	1675	39.0
9	1035	17.7	1145	24.9	1250	32.7	1350	41.4	1446	50.7
10	902	23.7	995	33.6	1085	43.5	1168	55.2	1253	67.5

POWER USED BY FANS.

Air Velocity Feet per Minute.	Size of Fan.	24	30	34	36	42	48	54	60	72
600	Cubic feet per minute . .	1884	2940	3780	4236	5772	7536	9540	11778	16962
	Revolutions per minute .	310	247	220	206	177	155	137	124	103
	Horse-power	.066	.103	.132	.148	.208	.271	.353	.435	.636
900	Cubic feet per minute . .	2826	4410	5670	6354	8658	11304	14310	17667	25473
	Revolutions per minute .	464	372	332	310	265	232	206	185	155
	Horse-power	.139	.258	.360	.413	.588	.792	1.000	1.253	1.870
1200	Cubic feet per minute . .	3768	5880	7560	8472	11544	15072	19080	23556	33924
	Revolutions per minute .	618	495	441	412	353	310	275	247	206
	Horse-power	.256	.477	.650	.754	1.083	1.483	1.908	2.400	3.590
1500	Cubic feet per minute . .	4710	7350	9450	10590	14430	18840	23850	29445	42405
	Revolutions per minute .	773	620	552	515	441	386	343	308	258
	Horse-power	.400	.735	1.012	1.165	1.700	2.350	3.250	3.820	5.780
2000	Cubic feet per minute . .	6280	9800	12600	14120	19240	25120	31800	39260	56540
	Revolutions per minute .	1030	822	734	685	586	514	456	410	342
	Horse-power	.805	1.420	1.954	2.260	3.310	4.570	5.980	7.650	11.58

POWER REQUIRED FOR PIPE THREADING MACHINE.

	H.-P.
3″ pipe, machine running light..	1.2
8″ " " "	1.5
Cutting 1½″ pipe at 40 rev. of machine per min...............	2.0
" 2″ " 32 " " "	2.5
" 3″ " 21 " " "	2.7
" 4″ " 12 " " "	2.9
Threading 1½″ " 45 rev. per min., 22.4 lineal ft. per min.	2.2
" 2″ " 32 " " 20 " "	2.9
" 3″ " 21 " " 19 " "	3.1
" 4″ " 12 " " 14 " "	5.0

The methods of transmitting power are principally the following:

Shafting with pulleys and belts.
Shafting with pulleys and ropes or rope driving.
Shafting and gear-wheels.
Shafting and friction clutches.
Pneumatic, by compressed air.
Electrical, by dynamos, line, and motors.

Shafting, which was formerly made of wrought iron, is now largely made of steel. It must be large enough to transmit the desired power without being twisted too much, and it must also be large enough to stand the pull of belts, its own weight, and the weight of pulleys, without being deflected or bent enough to cause trouble. The hangers or shaft supports should, of course, be placed as close as possible to the pulleys, and should be, in general, for light shafting not over 8 feet apart.

The following two formulæ will give the necessary sizes of shaft, and allowable distance of hangers for either rolled iron or steel shafting.

Let R = number of revolutions per minute, $H.P.$ = number of horse-power to be transmitted, d = diameter of shaft, and L = distance in feet between the hangers; then

$$d = \sqrt[3]{\frac{70\ H.P.}{R}}, \quad \text{or} \quad H.P. = \frac{d^3 R}{70}.$$

$$L = \sqrt[3]{140\ d^2}, \quad \text{or} \quad d = \sqrt{\frac{L^3}{140}}.$$

These formulæ are short methods of expressing the following rules:

To find the diameter of a shaft to transmit a certain horse-power at a certain speed, multiply the horse-power by 70 and divide by the number of revolutions per minute and find the cube root of the quotient; or

To find the horse-power which a certain shaft will transmit at a given speed, multiply the cube of the diameter by the revolutions per minute and divide by 70.

To find the allowable distance between hangers, multiply the square of the diameter by 140 and find in the tables the cube root of the product.

The first formula gives the size of shaft to transmit a certain *number of horse-power* at a certain speed. The second or lower *formula tells how near* together the hangers must be for that si *f shaft. If it is not* possible to put the hangers as near as t the shaft must be made larger and its diameter will be found by using the second formula.

Example.—What size of shaft is necessary to transmit 100 H.P. at 200 rev. per minute? Taking the first formula we have $d = \sqrt[3]{\frac{70 \times 100}{200}} = \sqrt[3]{35}$. Looking in a table of cube roots we find that $\sqrt[3]{35}$, or $d_1 = 3.27''$.

Suppose we find that the hangers cannot be placed nearer than 10 feet. To see if the diameter 3.27″ is enough, take the second formula $d = \sqrt{\frac{L^3}{140}} = \sqrt{\frac{10 \times 10 \times 10}{140}}$, or $d = \sqrt[3]{7.1} = 2.66''$. From this we see that the 3.27″, or 3¼″, shaft will be strong enough even with the hangers at 10 feet distance apart.

Belting.—While there are several methods of connecting shafts so that one turns the other, the most common way is by means of belts.

Rubber and leather belts.—Rubber belts will transmit nearly as much power as leather belts with the same tension; and they have this advantage, that they may be made of any length, width, or thickness, and yet always run straight, providing the pulleys are in line. Besides, their first cost is much less than those of leather; but they will not last over half as long. They cannot be run in situations where the belt rubs, nor as cross-belts, or through forks, as shifting-belts; and when they give out, it is almost impossible to repair them.

If a rubber belt runs off, and becomes entangled in the machinery, ten chances to one it will be completely ruined; whereas, a leather belt, under like circumstances, will sustain very little injury. When saturated with oil, they soon rot, and when situated in cold, damp places, they are liable to freeze, which has a tendency to separate the different thicknesses and ruin the belt. Besides, *they often freeze to the face of pulleys when standing still, and when started up,* the gum facing is torn off, which ruins *e belt.*

A leather belt, if made of good stock, not overstrained and properly treated, will last for twenty years. When partly worn out, it may be cut up and used over again for a narrower or shorter belt; and when entirely unfit for the transmission of power, it may be used for different purposes around a factory; but when rubber belts are worn out, they are of no value whatever.

Belts derive their power to transmit motion from the friction between the surface of the belt and the pulley, and from nothing else, and are governed by the same laws as in friction between flat surfaces. The friction increases regularly with the pressure. The great difference often observed in the friction of belts is due simply to their elasticity of surface; that is, the more elastic the surface the greater the friction.

In taking power from any source of motion, there are two points which control us; all the others we can control and modify to a certain extent. Ordinary belts will sustain safely a working tension of 45 lbs. per inch in width; the rule to determine the width of belt and size of pulley required to transmit a given horse-power is easily found. Since a horse-power is 33,000 pounds raised one foot high per minute, we must adjust the width and velocity of belts so as to effect the required result. Thus, if the belt moves with a velocity of 733 feet per minute, a belt five inches wide will transmit five horse-power, provided the effective tension is 45 lbs. per inch. If the velocity be increased to 1466 feet per minute, the same belt with the same tension will transmit ten horse-power. So that a five-inch belt, applied to a five-foot pulley making 120 revolutions per minute, would transmit ten horse-power when the effective tension is 225 pounds.

By taking the actual effective tension of the belt, and multiplying it by the actual velocity, we get what may be called the i dicated horse-power of the belt, which corresponds to the indica horse-power of the engine. And, finally, by measuring the a ual power transmitted — which may be done by means of a amometer — we can get the actual power transmitted. B based upon the amount of belt surface in contact with the p on similar data, cannot be made to give reliable results. For tical purposes, velocity and power to resist tension are the available elements of the calculation. Actual tension, adhe-n, friction, etc., can all be varied at will, and consequently form certain dependence for the calculations of the mechanic and gineer.

On the scientific principle that the adhesion, and consequently e capability of leather belts to transmit power from motors to achines, is in proportion to the pressure of the actual weight of e leather on the surface of the pulley, it is manifest that, as onger belts have more weight than shorter ones, and that broader elts of the same length have more weight than narrower ones, it may be adopted as a rule that the adhesion and capability of belts to transmit power are in the ratio of their relative lengths and breadth. A belt of double the length or breadth of another under the same circumstances, will transmit more than double the power. For this reason it is desirable to use long belts. By doubling the velocity of the same belt, its effectual capability for transmitting power is also doubled.

Good stock is the first requirement of a belt, which, if spongy, will not meet that demand. It must be firm, but pliable; the grain or hair side should be free from wrinkles; the stock should show no irregularities in dressing, but be of an even thickness throughout; the splices should be mathematically true, and if rivets are employed, they should be inserted on the hair side, and the burrs sent home before riveting; the edges should be parallel and perfectly straight. In handling a belt, examine it carefully, double it up, the hair side out, and press it together; if it crack under this treatment, it should be rejected, as the rational use of a belt consists in utilizing the whole amount of power it will transmit.

Belts are sometimes used having a transmitting power of doub the capacity necessary where they are employed, while quite ften they are much too narrow for the work required of t e first instance shows a useless waste of material, the poor economy; as, in order that it may perform the work required, it is necessary frequently to take it up, as a result of which the weak points succumb to the strain, and it is torn asunder; or if not, the shaft is likely to be drawn out of line, or the bearing overheated.

In using a new belt a few days, if it present a mottled appearance on the side next to the pulleys, it may be set down that it is not furnishing the full capacity of its power. The spots referred to indicate that certain portions of the belt do not touch the pulley, and that its entire transmitting power is not utilized. If the face of the pulley is true, and the belt is as nearly perfect as possible, the defect may be remedied by the judicious application of rendered tallow and fish oil, two parts of tallow to one of oil, melted and allowed to cool. A new belt should be used a day or two before it is oiled, and frequent application of small quantities are better than too liberal oiling at long intervals.

If a belt, of the proper size for the work it has to do, slip on the pulley, it is caused by the centrifugal force, which tends to throw it outward; a corresponding degree of tension will check the defect.

Belts should be put on by a person acquainted with their use, as the wear of the belt depends considerably on the manner in which it is put on; therefore, the following suggestions, if practised, will be of much service to persons employed in this capacity. The ends to be joined should be cut perfectly square, in order that one side may not be drawn tighter than the other. Good lace-leather, if properly used, will give better satisfaction than any patent fastening.

Where belts run vertically, they should always be drawn moderately tight, or the weight of the belt will not allow it to adhere closely to the lower pulley; but in all other cases they should be slack. In many instances, the tearing out of lace-holes is unjustly *attributed* to poor belting; when, in reality, the fault lies in having *a belt too short,* and trying to force it together by lacing, and t

Length of Belt.—To find the length of belt necessary to connect two pulleys, of course the simplest and most accurate method is to measure it. If, however, it is necessary to ascertain it before the pulleys are in place, the following rules may be applied:

Open Belt.—Add together the diameters of the two pulleys and multiply the sum by 3.1416; to half the product thus obtained add twice the distance between centres of shafts. If the pulleys are of the same diameter, or nearly so, the result obtained by this rule will be accurate, otherwise it will be slightly too small.

Crossed Belt.—Divide the sum of the diameters of the two pulleys by twice the distance between centres and to the quotient thus obtained add 1.571. Multiply this sum by the sum of the diameters of the two pulleys, and to the product add twice the distance between centres. The result will very closely agree with the belt length required, the result being the more accurate the greater the distance between centres.

Example.—18″ pulley and 12″ pulley, 20 feet between centres.

$$\text{Open belt} = \frac{(1.5 \times 1)\ 3.1416}{2} + 2 \times 20 = 43'\ 11''.$$

$$\text{Crossed belt} = \left(\frac{1+1.5}{2} + 1.571\right)\ 2.5 + 40 = 44'\ 1''.$$

To calculate the width of belt to transmit a given horse-power there are various rules which give results differing considerably from each other. This is because different writers are not agreed as to the safe allowable strain to put on a belt, nor as to the relative value of double and single belts. The faster the belt runs the more power it will transmit at a certain degree of tightness, so that a 2-inch belt, with a speed of 2000 feet per minute, will transmit safely twice the power that it will at 1000 feet per minute.

Allowance must be made for special cases, such as quarter turn, crossed, vertical belts, and belts running from very large to very small pulleys.

The following tables give the speed in feet per minute for various sized pulleys and rotary speeds. The ordinary velocities for belts are between 2000 and 5000 feet per minute.

VELOCITY.

Velocity in Feet per Second of Belts, Wire Ropes, or of Circumference of Revolving Wheels or Pulleys.

Diam. Pulley.	Revolutions per Minute of Wheel or Pulley.									
	110	120	130	140	150	160	170	180	190	200
Inches.	V	V	V	V	V	V	V	V	V	V
1	.47996	.52360	.56723	.61086	.65450	.69813	.74176	.78540	.82903	.87266
2	.95993	1.0472	1.1345	1.2217	1.3090	1.3963	1.4835	1.5708	1.6581	1.7453
3	1.4399	1.5708	1.7017	1.8326	1.9635	2.0944	2.2253	2.3562	2.4870	2.6180
4	1.9199	2.0944	2.2689	2.4435	2.6180	2.7925	2.9671	3.1416	3.3160	3.4906
5	2.3998	2.6180	2.8362	3.0543	3.2725	3.4907	3.7088	3.9270	4.1451	4.3633
6	2.8800	3.1416	3.4034	3.6652	3.9270	4.1888	4.4506	4.7124	4.9742	5.2360
7	3.3597	3.6652	3.9706	4.2760	4.5815	4.8869	5.1924	5.4978	5.8032	6.1086
8	3.8397	4.1888	4.5378	4.8869	5.2360	5.5851	5.9341	6.2832	6.6322	6.9813
9	4.3196	4.7124	5.1051	5.4978	5.8905	6.2832	6.6759	7.0686	7.4612	7.8540
10	4.7996	5.2360	5.6723	6.1086	6.5450	6.9813	7.4177	7.8540	8.2903	8.7266
11	5.2796	5.7596	6.2395	6.7195	7.1990	7.6794	8.1994	8.6394	9.1193	9.5992
12	6.7596	6.2832	6.8068	7.3304	7.8540	8.3776	8.9012	9.4248	9.9483	10.472
13	6.2395	6.8060	7.3740	7.9412	8.5085	9.0757	9.6429	10.210	10.777	11.345
14	6.7195	7.3304	7.9412	8.5521	9.1630	9.7738	10.385	10.996	11.606	12.217
15	7.1995	7.8540	8.5085	9.1630	9.8175	10.472	11.126	11.781	12.435	13.090
16	7.6794	8.3776	9.0757	9.7738	10.472	11.170	11.868	12.566	13.264	13.963
18	8.6394	9.4248	10.210	10.996	11.781	12.566	13.352	14.137	14.422	15.708
20	9.5993	10.472	11.345	12.217	13.090	13.963	14.835	15.708	16.580	17.453
21	10.079	10.966	11.912	12.828	13.744	14.661	15.577	16.493	17.409	18.326
24	11.519	12.566	13.613	14.661	15.709	16.755	17.802	18.850	19.897	20.944
27	12.959	14.137	15.315	16.493	17.671	18.850	20.027	21.206	22.384	23.562
30	14.399	15.708	17.017	18.326	19.635	20.944	22.253	23.562	24.871	26.180
33	15.839	17.278	18.718	20.159	21.597	23.038	24.478	25.918	27.358	28.798
36	17.280	18.850	20.420	21.991	23.562	25.133	26.704	28.274	29.845	31.416
39	18.719	20.420	22.122	23.824	25.525	27.227	28.929	30.631	32.332	34.034
42	20.159	21.992	23.824	25.656	27.489	29.322	31.154	32.987	34.819	36.652
45	21.599	23.562	25.525	27.489	29.452	31.416	33.379	35.343	37.306	39.270
48	23.039	25.132	27.227	29.322	31.416	33.510	35.605	37.699	39.792	41.888
51	24.579	26.704	28.929	31.154	33.379	35.605	37.830	40.055	42.279	44.506
54	26.019	28.274	30.621	32.987	35.343	37.699	40.055	42.411	44.767	47.124
60	28.800	31.416	34.034	36.652	39.270	41.888	44.506	47.124	49.742	52.360
66	31.678	34.558	37.437	40.317	43.197	46.077	48.956	51.836	54.710	57.596
72	34.557	37.700	40.841	43.982	47.124	50.265	53.407	56.549	59.690	62.832
78	37.437	40.840	44.244	47.647	51.050	54.454	57.858	61.261	64.664	68.068
84	40.317	43.984	47.647	51.313	54.980	58.643	62.308	65.973	69.639	73.304
90	43.197	47.125	51.051	54.978	58.905	62.832	66.759	70.686	74.613	78.540
96	46.076	50.264	54.454	58.643	62.830	67.021	71.209	75.398	79.587	83.776
102	48.956	53.404	57.858	62.308	66.760	71.209	75.660	80.111	84.561	89.012
108	51.836	56.548	61.261	65.973	70.685	75.398	80.111	84.823	89.535	94.248
114	54.716	59.692	64.664	69.638	74.615	79.587	84.561	89.535	94.509	99.484
120	57.595	62.832	68.068	73.304	78.540	83.776	89.012	94.248	99.484	104.72
126	60.476	65.972	71.471	76.969	82.465	87.965	93.462	98.960	104.46	109.95
132	63.355	69.116	74.875	80.634	86.395	92.153	97.913	103.67	109.43	115.19
138	66.235	72.256	78.278	84.299	90.320	96.342	102.36	108.38	114.41	120.43
144	*69.115*	*75.400*	*81.681*	*87.965*	94.250	100.53	106.81	113.10	119.38	125.66
150	*71.995*	*78.540*	*85.085*	*91.630*	98.175	104.72	111.26	117.81	124.35	130.90
160	*76.794*	*83.776*	*90.757*	*97.738*	104.72	111.70	118.68	125.66	132.64	139.63
180	*86.394*	*94.248*	*102.10*	*109.96*	117.81	125.66	133.52	141.37	149.22	150.08
200	*87.266*	*104.72*	*113.45*	*122.17*	130.90	139.63	148.35	157.08	165.80	174.53
240	*115.19*	*126.66*	*136.13*	*146.61*	157.08	167.55	178.02	188.50	198.97	209.44

VELOCITY.

Velocity in Feet per Second of Belts, Wire Ropes, or of Circumference of Revolving Wheels or Pulleys.

Diam. Pulley.	Revolutions per Minute of Wheel or Pulley.									
	210	220	230	240	250	260	270	280	290	300
Inches.	V	V	V	V	V	V	V	V	V	V
1	.91630	.95993	1.0036	1.0472	1.0908	1.1345	1.1781	1.2218	1.2654	1.3090
2	1.8326	1.9199	2.0071	2.0944	2.1816	2.2689	2.3562	2.4435	2.5307	2.6180
3	2.7489	2.8798	3.0107	3.1416	3.2724	3.4034	3.5343	3.6652	3.7961	3.9270
4	3.6652	3.8397	4.0142	4.1888	4.3633	4.5378	4.7124	4.8869	5.0614	5.2360
5	4.5814	4.7997	5.0178	5.2360	5.4580	5.6723	5.8905	6.1086	6.3268	6.5450
6	5.4977	5.7596	6.0214	6.2832	6.5450	6.8068	7.0686	7.3304	7.5921	7.8540
7	6.4140	6.7195	7.0249	7.3304	7.6335	7.9412	8.2467	8.5521	8.8575	9.1630
8	7.3303	7.6794	8.0285	8.3776	8.7265	9.0757	9.4248	9.7738	10.123	10.472
9	8.2466	8.6394	9.0320	9.4248	9.8175	10.210	10.603	10.995	11.388	11.781
10	9.1610	9.5993	10.036	10.472	10.908	11.345	11.781	12.218	12.654	13.090
11	10.079	10.559	11.039	11.519	11.999	12.479	12.959	13.439	13.919	14.398
12	10.996	11.519	12.043	12.566	13.090	13.613	14.137	14.660	15.184	15.708
13	11.912	12.479	13.046	13.615	14.180	14.748	15.315	15.882	16.450	17.017
14	12.828	13.439	14.050	14.662	15.271	15.882	16.493	17.104	17.715	18.326
15	13.744	14.399	15.052	15.709	16.362	17.017	17.671	18.326	18.980	19.635
16	14.661	15.359	16.054	16.776	17.453	18.151	18.850	19.548	20.246	20.944
18	16.493	17.279	18.061	18.851	19.635	20.420	21.206	21.991	22.776	23.562
20	18.326	19.199	20.071	20.944	21.816	22.689	23.562	24.435	25.307	26.180
21	19.242	20.159	21.748	21.991	22.907	23.824	24.790	25.656	26.573	27.489
24	21.991	23.038	24.085	25.133	26.180	27.227	28.274	29.321	30.369	31.416
27	24.740	25.918	27.096	28.274	29.452	30.630	31.809	32.987	34.165	35.343
30	27.489	28.798	30.107	31.416	32.725	34.034	35.343	36.652	37.961	39.270
33	30.238	31.678	33.117	34.558	35.997	37.437	38.877	40.317	41.757	43.194
36	32.987	34.557	36.128	37.699	39.270	40.841	42.412	43.982	45.553	47.124
39	35.735	37.437	39.138	40.841	42.542	44.244	45.946	47.647	49.349	51.051
42	38.485	40.317	42.149	43.982	45.815	47.647	49.480	51.313	53.145	54.978
45	41.233	43.197	45.160	47.124	49.085	51.051	53.014	54.978	56.941	58.905
48	43.982	46.077	48.171	50.266	52.360	54.454	56.549	58.643	60.737	62.832
51	46.731	48.956	51.182	53.407	55,630	57.857	60.083	62.308	64.533	66.759
54	49.480	51.836	54.192	56.549	58.905	61.261	63.617	65.973	68.329	70.686
60	54.978	57.596	60.214	62.832	65.450	68.068	70.686	73.304	75.922	78.540
66	60.476	63.356	66.235	69.115	71.990	74.874	77.755	80.634	83.514	86.394
72	65.973	69.116	72.256	75.399	58.540	81.681	84.823	87.964	91.106	94.248
78	71.471	74.875	78.278	81.682	58.085	88.488	91.892	95.295	98.698	102.10
84	76.969	80.635	84.299	87.965	91.630	95.294	98.960	102.63	106.29	109.96
90	82.466	86.395	90.320	94.248	98.175	102.10	106.03	109.55	113.88	117.81
96	87.964	92.154	96.342	100.53	104.72	108.91	113.10	117.29	121.47	125.66
102	93.462	97.914	102.36	106.81	111.26	115.71	120.17	124.61	129.07	133.52
108	98.960	103.67	108.38	113.10	117.61	122.52	127.23	131.95	136.66	141.37
114	104.46	109.43	114.40	119.38	124.35	129.33	134.30	139.28	144.25	149.23
120	109.96	115.19	120.43	125.66	130.90	136.13	141.37	146.66	151.84	157.08
126	115.45	120.95	126.45	131.95	137.44	142.94	148.44	153.94	159.44	164.93
132	120.96	126.67	132.47	138.23	143.99	149.80	155.51	161.27	167.03	172.79
138	126.45	132.47	138.49	144.51	150.53	156.60	162.58	168.60	174.62	180.64
144	131.94	138.23	144.51	150.80	157.09	163.41	169.65	175.93	182.21	188.50
150	137.44	143.99	150.52	157.09	163.62	170.17	176.71	183.26	189.80	196.35
160	*146.61*	*153.59*	160.54	167.76	174.53	181.51	188.56	195.48	202.46	209.44
180	*164.93*	*172.79*	180.61	188.51	191.35	204.20	212.06	219.91	227.76	235.62
200	*183.26*	*191.99*	200.71	209.44	218.16	226.89	247.90	244.35	253.07	261.80
240	*219.91*	*230.38*	240.85	251.33	261.80	272.27	282.74	293.21	303.69	314.16

VELOCITY.

Velocity in Feet per Second of Belts, Wire Ropes, or of Circumference of Revolving Wheels or Pulleys.

Diam, Pulley.	Revolutions per Minute of Wheel or Pulley.									
	310	320	330	340	350	360	370	380	390	400
Inches.	V	V	V	V	V	V	V	V	V	V
1	1.3526	1.3963	1.4399	1.4835	1.5271	1.5708	1.6144	1.6581	1.7017	1.7454
2	2.7052	2.7925	2.8798	2.9761	3.0543	3.1416	3.2289	3.3162	3.4034	3.4906
3	4.0579	4.888	4.3197	4.4506	4.5815	4.7124	4.8433	4.9743	5.1051	5.2360
4	5.4105	5.5850	5.7596	5.9341	6.1080	6.2832	6.4577	6.6324	6.8068	6.9813
5	6.7632	6.9813	7.1995	7.4176	7.6360	7.8540	8.0722	8.2905	8.5085	8.7266
6	8.1158	8.3776	8.6394	8.9012	9.1630	9.4248	9.6866	9.948	10.210	10.472
7	9.4684	9.7738	10.079	10.385	10.690	10.996	11.301	11.606	11.912	12 217
8	10.821	11.170	11.519	11.868	12.217	12.566	12.915	13.265	13.613	13.963
9	12.174	12.566	12.959	13.352	13.744	14.137	14.530	14.922	15 315	15.708
10	13.526	13.963	14.399	14.835	15.271	15.708	16.144	16.581	17.017	17.453
11	14.879	15.359	15.839	16.319	16.798	17.279	17.759	18.239	18.718	19.198
12	16.232	16.755	17.279	17.802	18.326	18.850	19.373	19.897	20.420	20.944
13	17.584	18.151	18.719	19.286	19.853	20.420	20.988	21.555	22.122	22 690
14	18.937	19.548	20.159	20.769	21.384	21.991	22.602	23.213	23.824	24.434
15	20.289	20.944	21.599	22.253	22.907	23.562	24.216	24.872	25.525	26.180
16	21.652	22.340	23.038	23.736	24.434	25.133	25.831	26.530	27.227	27.296
18	24.347	25.133	25.918	26.704	27.489	28.274	29.060	29.846	30.630	31.416
20	27.052	27.925	28.798	29.671	30.543	31.416	32.289	33.162	34.034	34 906
21	28.405	29.321	30.238	31.154	32.071	32.987	33.903	34.820	35.735	36.652
24	32.463	33.510	34.558	35.605	36.652	37.699	38.746	39.795	40.841	41.888
27	36.521	37.699	38.867	40.055	41.234	42.412	43.590	44.769	45.946	47.124
30	40.579	41.888	43.187	44.506	45.815	47.124	48.433	49.743	51.051	52.360
33	44 637	46.077	47.507	48.956	50.395	51.836	53.276	54.717	56.156	57.596
36	48.695	50.265	51.826	53.407	54.980	56.549	58.119	59.691	61.261	62.832
39	52.753	54.454	56.146	57.858	59.560	61.261	62.963	64.666	66.366	68.068
42	56.810	58.643	60.466	62.308	64.140	65.974	67.806	69.640	71.471	73.304
45	60.868	62.832	64.786	66.759	68.720	70.686	72.649	74.614	76.576	78.540
48	64.926	67.020	69.105	71.209	73.305	75.398	77.493	79.589	81.681	83.776
51	68.984	71.209	73.425	75.660	77.885	80.111	82.336	84.563	86.787	89.012
54	73.042	75.398	77.745	80.111	82.465	84.823	87.179	89.537	91.892	94.248
60	81.158	83.776	86.394	89.012	91.630	94.248	96.866	99.486	102.10	104.72
66	89.274	92.153	95.033	97.913	100.79	103.67	106.55	109.43	112.31	115.19
72	97.389	100.53	103.67	106.81	109.95	113.10	116.24	119.38	122.52	125.66
78	105.51	108.91	112.31	115.72	119.12	122.52	125.93	129.33	132.73	136.14
84	113.62	117.29	120.95	124.62	120.28	131.95	135.61	139.28	142.94	146.61
90	121.74	125.66	129.59	133.52	137.44	141.37	145.30	149.22	153.15	157.08
96	129.85	134.04	138.23	142.42	146.61	150.80	154.99	159.17	163.36	167.55
102	137.97	142.42	146.87	151.32	155.72	160.22	164.67	169.12	173.57	178.02
108	146.08	150.80	155.51	160.22	164.93	163.65	174.36	179.07	183.78	188.50
114	154.20	159.17	164.15	169.12	174.20	179.07	184.05	189.02	193.99	198.97
120	162.32	167.55	172.79	178.02	183.26	188.50	193.73	198.97	204.20	209.44
126	170.31	175.93	181.43	186.92	192.42	197.92	203.42	208.92	214.41	219.90
132	178.55	184.31	190.07	195.83	201.58	207.35	213.10	218.87	224.62	230.38
138	186.66	192.68	198.71	204.73	210.75	216.77	222.79	228.82	234.83	240.86
144	194.78	201.06	207.35	213.63	219.91	226.19	232.48	238.76	245.04	251.32
150	202.89	209.44	215.99	222.53	229.07	235.62	242.16	248.72	255.25	261.80
160	216.52	223.40	230.38	237.36	244.34	251.33	258.31	265.30	272.27	279.26
180	243.47	*251.33*	*259.18*	*267.04*	274.89	282.74	290.60	298.46	306.30	314.16
200	*270.52*	*279.25*	*287.98*	*296.71*	305.43	314.16	322.89	331.62	340.34	349.06
240	*284.05*	*335.10*	*345.58*	*356.05*	366.52	376.99	387.46	397.95	408.41	418.88

A 2″ belt will transmit twice as much power as a 1″ belt, whe both are run at the same speed. Therefore, when we have foun what power a 1″ belt will transmit at various speeds, we can ge the power transmitted by any other width by multiplication.

The following table gives such values for single and doubl belts of the *best quality*, when the belt is open and horizontal.

Power Transmitted by T″ Single and Double Belts at Various Speeds.

Speed feet per minute.	H. P Per 1″ width single belt.	H. P Per 1″ width double belt.	Speed feet per minute.	H. P Per 1″ width single belt.	H. P. Per 1″ width double belt
500	0 833	1 332	2800	4.665	7 465
600	1 000	1 600	2900	4 833	7.732
700	1 166	1 865	3000	5.000	8.000
800	1 333	2 132	3100	5.165	8.265
900	1 500	2 400	3200	5.333	8.532
1000	1 666	2 665	3300	5.500	8.800
1100	1.833	2.932	3400	5.666	9.065
1200	2.000	3.200	3500	5.833	9.332
1300	2.166	3.465	3600	6.000	9.600
1400	2.333	3.732	3700	6.166	9 865
1500	2 500	4.000	3800	6.333	10.232
1600	2.666	4 265	3900	6.500	10.400
1700	2 833	4 532	4000	6.666	10.665
1800	3.000	4.800	4100	6.833	10.932
1900	3.166	5 065	4200	7.000	11.200
2000	3.333	5.332	4300	7.166	11.465
2100	3.500	5.600	4400	7.333	11.730
2200	3.666	5.865	4500	7.550	12.080
2300	3.833	6.132	4600	7.666	12.265
2400	4.000	6.400	4700	7.783	12.452
2500	4.166	6.665	4800	8.000	12.800
2600	4.333	6 932	4900	8.166	13.065
2700	4.500	7.200	5000	8.333	13.332

Example.—What horse-power will a 10″ single open belt transmit, the driving pulley having 30″ diameter and making 310 revolutions per minute. From the table of belt speeds we find t in this case is 40.57 × 60, or about 2400 feet per min

At this speed a 1" belt will transmit 4 H.P. A 10" belt, therefore, will transmit 40 H.P.

Special cases, where the belts are crossed, vertical, or quarter turn, must have the results modified. The result as given above must be multiplied by the figures in the following table:

	Multiplier.
Double horizontal, open belts	1.6
Single vertical, open belts	.8
Double vertical, "	1.2
Single horizontal, large to small pulleys	.2
Double horizontal, " "	.3
Quarter turn, single belts	.5
" double belts	.8

Example.—If the 10″ belt above were vertical, what would be the horse-power which it could transmit safely?

Ans. 40 × .8 = 32 H.P.

Suppose also the driven pulley were much smaller than the 30″ driver above, say 6″. Then if the belt were horizontal it would transmit

40 × .2 = 8 H.P., if single,
40 × .3 = 12 H.P., if double;
and 40 × .2 × .8 = 6.4 H.P., if single vertical,
40 × .2 × 1.2 = 9.6 H.P., if double vertical.

To find the width of belt when the horse-power is given, first assume that the belt is horizontal and open and find width. Then if it is crossed or vertical, *divide* the result by the proper number obtained from the above table.

Example.—Wanted to transmit 100 H.P. from a 60″ pulley turning at 300 rev. per minute to a 30″ pulley, using a double belt; what width is necessary? The small pulley is nearly vertically above the large. What width belt will be necessary?

From the table of belt speeds we find that the speed in th case is 78.54 × 60 = 4712 rev. per minute. At this speed a 1″ single horizontal belt will transmit 7.78 H.P. Therefore, to transmit 100 H.P. we need 100 ÷ by 7.78, or a 12″ belt. But since the belt runs vertical, we look up in the table of special cases and find the number corresponding to this case to be .8. Dividing 12″ by .8, we get 15″ as the width of a single belt. But a double belt will carry 1.5 times as much, so that we can use a double belt 15 ÷ 1.6, or 9″ belt.

Rule *for finding the change required in the length of a belt when one of the pulleys on which it runs is changed for one of a different size.*—Take three times the difference between the diameters of the pulleys and divide by 2. The result will be the length of belt to cut out or put in.

How to measure a coil of belting.—Add the diameter of the hole, in inches, to the outside diameter of the roll; multiply by the number of coils in the roll; then multiply this by the decimal ·1309, and the product will be the number of feet in the roll. To have the exact length, the average diameter must be used if the roll is not perfectly round, and fractional parts of an inch must not be omitted in the calculation.

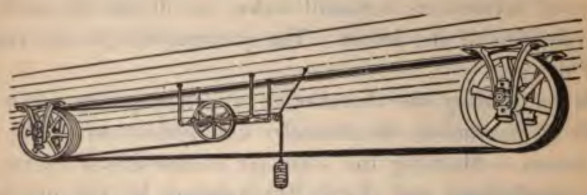
How to put on a belt.—Never place a belt on the pulley in motion; always place it first on the loose pulley or the pulley at rest; then run it on the pulley in motion. If the belt is very heavy, and the pulleys run at a very high speed, it is advisable to slack on the speed of the engine; but when this is impracticable or inconvenient, care must be taken to mount the belt on the exact face. The person engaged in so doing must have a firm footing, and prevent his clothing from getting in contact either with the belt or pulley. Where the belt is heavy, and the location such that it is impossible to get a solid footing and exert strength in running on the belt, it is best to stop the engine and mount the belt on the pulley as far as possible. Then take a small rope, *double it, slip one* end through the arms and around the belt and *rim of the pulley, and* the other end through the loop formed by *he double of the rope*; then stand on the floor on the oppos side, and draw on the rope, when the belt will be hugged to the periphery of the pulley. When motion is communicated, it may be slipped on without any trouble, while by letting go the end of the rope when the belt is on the pulley, the noose will be undone and the rope thrown off.

Rule *for finding the required size of a driving-pulley for any required speed.*—Multiply the diameter of the driven pulley by the number of revolutions it should make, and divide the product by the revolutions of the driver. The quotient will be the required size of driver.

Rule *for finding the diameter of a driven pulley for a given number of revolutions, the diameter and revolutions of the driver being known.*—Multiply the diameter of the driver by its number of revolutions, and divide the product by the number of revolutions of the driven pulley. The quotient will give the proper size of the driven pulley.

Rope Driving.—The use of rope made of cotton or manilla is being very largely extended where it is desired to transmit power to considerable distances. The cost of rope is much less than that of belting, and moreover the pulleys do not have to be lined up so accurately when rope is used.

The pulleys used are grooved, usually V-shaped and at an angle of 30° to 60°, the practice of engineers varying in this respect. Some engineers also use a curved groove. The sides of the grooves, whatever may be their form, must be perfectly smooth and polished so as to avoid cutting the rope fibres. The diameters of the pulleys must be properly chosen with reference to the diameter of the rope, for to attempt to carry a large and stiff rope around a pulley of small diameter would result in the rapid wearing of the rope. There are two general methods of using ropes where it is desired to use several working side by side on the grooves of the same *pulley.* One is to put them on like so *many spliced belts, one working* in each groove. The difficulty *xperienced in this method* of working is that they do not all pull *ually, and this is especially* the case when driving from a larg to a small pulley. It may be largely overcome by making the grooves of the smaller pulley with a sharper angle. The other method is to wrap the rope around the pulleys as many times as there are grooves, and then carry it through idlers so arranged as to allow the tension to be varied, and then carrying back to the starting-point and splicing it. This method is shown clearly in the figure.



ROPE TRANSMISSION.
"Wound System." With Take-Up.

Idlers whenever used should be arranged, if possible, so that the rope will always be bent in one direction, as changing the direction of bending greatly increases the wear.

The speeds allowable vary from about 25 to 100 feet per second, with perhaps the most common practice at about 80 feet per second. The tension on the rope is made up of three separate tensions: 1st, the initial tension when not in motion; 2d, that due to centrifugal force; 3d, that necessary to transmit the power. The sum of all these must not be allowed to exceed the safe working strength of the rope. The following tables give the breaking weight of various sizes, and also what would be considered the safe weight if they were used to support a weight, not being in motion in any way. This safe load is taken at one-quarter of the breaking load. For rope driving, however, a much greater factor of safety must be used, and the safe working strength for rope driving will be taken at about one-eighth of the safe load T when at rest, or one-thirty-second of the breaking load *S.* *The tables also give* the smallest allowable diameter of pulley *for each size rope.*

ROPES.

Hemp Ropes, White. Three Strands.

Diam. Pulley. Feet.	Size of Rope.		Strength.		Weight per Ft. Pounds.	Length per Lb. Feet.
	Diam. Inches.	Circum. Inches.	Break. Pounds.	Safety. Pounds.		
D	*d*	*c*	*S*	*T*	*w*	*l*
21.	6 in.	17.1	324000	81000	9 4	.1064
19.	5½	15.7	272000	68000	7.9	.1266
16.5	5 in.	14.25	225000	56250	6.52	.1533
14.	4½	12.1	182000	45500	5.28	.1894
12.	4 in.	11.4	144000	36000	4.18	.2392
11.	3¾	10.7	126000	31500	3.67	.2725
10.	3½	10.	110000	27500	3.2	.3125
9.	3¼	9.27	95000	23750	2.76	.3613
8.	3 in.	8.57	81000	20250	2.35	.4255
7.	2¾	7.85	68000	17000	1.97	.5076
6.	2½	7.14	56200	14050	1.63	.6135
5.25	2¼	6.43	45500	11375	1.32	.7575
4.25	2 in.	5.70	36000	9000	1.04	.9615
3.4	1¾	5.00	27500	6875	0.80	1.25
2.75	1½	4.28	20200	5050	0.588	1.700
2.1	1¼	3.97	14000	3500	0.407	2.457
1.5	1 in.	2.86	9000	2250	0.261	3.831
1.22	⅞	2.5	6900	1725	0.200	5.000
0.97	¾	2.14	5050	1262	0.147	6.803
0.74	⅝	1.78	3500	875	0.102	9.803
0.53	½	1.43	2240	560	0.065	15.38
0.34	⅜	1.07	1260	315	0 036	27.77
0.18	¼	0.71	560	140	0.016	62.5

Manilla Ropes. Three Strands.

Diam. Pulley. Feet.	Size of Rope.		Strength.		Weight per Ft. Pounds.	Length per Lb. Feet.
	Diam. Inches.	Circum. Inches.	Break. Pounds.	Safety. Pounds.		
D	*d*	*c*	*S*	*T*	*w*	*l*
26.4	6 in.	17.1	216000	54000	8.64	.1157
23.2	5½	15.7	181500	45375	7.26	.1377
20.	5 in.	14.25	150000	37500	6.00	.1666
17.2	4½	12.1	121000	30250	4.86	.2057
14.4	4 in.	11.4	96000	24000	3.84	.2604
13.	3¾	10.7	84400	21100	3.38	.2958
11.8	3½	10.	73600	18400	2.94	.3401
10.5	3¼	9.27	63500	15875	2.53	.3952
9.35	3 in.	8.57	54000	13500	2.16	.4629
8.2	2¾	7.85	45400	11350	1.81	.5524
7.1	2½	7.14	37500	9375	1.5	.6666
6.	2¼	6.43	30400	7600	1.21	.8264
5.	2 in	5.70	24000	6000	0.96	1.041
4.	1¾	5.00	18400	4600	0.725	1.379
3.3	1½	4.28	13500	3350	0 54	1.852
2.5	1¼	3.57	9380	2345	0.375	2.666
1.8	1 in.	2.86	6000	1500	0.24	4.166
1.46	⅞	2.5	4600	1150	0.184	5.435
1.17	¾	2.14	3380	845	0.135	7.407
0.89	⅝	1.78	2350	587	0.093	10.75
0.63	½	1.43	1500	375	0.060	16.66
0.41	⅜	1.07	845	211	0.033	30.30
0.22	¼	0,71	375	93	0.015	66.66

ROPES.

Tarred Hemp Ropes. Four Strands.

Diam. Pulley.	Size of Rope.		Strength.		Weight per Ft.	Length per Lb.
Feet.	Diam. Inches.	Circum. Inches.	Break. Pounds.	Safety. Pounds.	Pounds.	Feet.
D	*d*	*c*	*S*	*T*	*w*	*l*
36.	6 in.	18 in.	230000	57500	15.1	.0662
32.	5½	16½	194000	48500	12.7	.0784
28.	5 in.	15 in.	160000	40000	10.5	.0952
24.	4½	13½	130000	32500	8.52	.1174
20.	4 in.	12 in.	102500	25625	6.72	.1488
18.	3¾	11¼	90000	22500	5.92	.1689
16.	3½	10½	78500	19625	5.16	.1938
14.6	3¼	9¾	67700	16925	4.44	.2252
12.9	3 in.	9 in.	57700	14425	3.78	.2645
11.4	2¾	8¼	48400	12100	3.18	.3144
9.9	2½	7½	40000	10000	2.63	.3802
8.4	2¼	6¾	32400	8100	2.13	.4695
7.	2 in.	6 in.	25600	6400	1.68	.5952
5.8	1¾	5¼	19600	4900	1.29	.7752
4.6	1½	4½	14400	3600	0.945	1.058
3.5	1¼	3¾	10000	2500	0.656	1.524
2.5	1 in.	3 in.	6400	1600	0.420	2.381
2.	⅞	2⅝	4900	1225	0.322	3.105
1.6	¾	2¼	3600	900	0.236	4.237
1.2	⅝	1⅞	2500	625	0.164	6.097
0.9	½	1½	1600	400	0.105	9.523
0.58	⅜	1⅛	900	225	0.059	16.95
0.31	¼	¾	400	100	0.026	38.46

Cotton Ropes. Three Strands of Fine Yarns.

Diam. Pulley.	Size of Rope.		Strength.		Weight per Ft.	Length per Lb.
Feet.	Diam. Inches.	Circum. Inches.	Break. Pounds.	Safety. Pounds.	Pounds.	Feet.
D	*d*	*c*	*S*	*T*	*w*	*l*
14.7	6 in.	18 in.	18000	4500	7.2	0.1389
12.9	5½	16½	15125	3781	6.05	0.1653
11.2	5 in.	15 in.	12500	3125	5.00	0.2000
9.5	4½	13½	10125	2531	4.05	0.2469
8.0	4 in.	12 in.	8000	2000	3.20	0.3125
7.2	3¾	11¼	7030	1782	2.81	0.3559
6.5	3½	10½	6125	1531	2.45	0.4082
5.8	3¼	9¾	5281	1320	2.11	0.4739
5.2	3 in.	9 in.	4500	1125	1.80	0.5555
4.5	2¾	8¼	3781	945	1.52	0.6579
4.	2½	7½	3125	781	1.25	0.8000
3.4	2¼	6¾	2531	633	1.01	0.9901
2.8	2 in.	6 in.	2000	500	0.80	1.250
2.3	1¾	5¼	1531	383	0.61	1.639
1.8	1½	4½	1125	281	0.45	2.222
1.4	1¼	3¾	781	195	0.31	3.226
1 ft.	1 in.	3 in.	500	125	0.20	5.000
0.82	⅞	2⅝	383	96	0.15	6.666
0.65	¾	2¼	281	70	0.11	9.009
0.5	⅝	1⅞	195	49	0.078	12.82
0.35	½	1½	125	31	0.05	20.00
0.23	⅜	1⅛	70	17	0.028	35.71
0.125	¼	¾	31	8	0.012	83.33

The following tables give the horse power transmitted safely, according to the formulæ of Mr. C. W. Hunt, of New York; also the sag of rope between pulleys:

Horse-power of Transmission Rope at Various Speeds.

Computed from formula (2), given above.

Diam. of Ropes.	Speed of the Rope in feet per minute.											Smallest Diam. of Pulleys in inches.
	1500	2000	2500	3000	3500	4000	4500	5000	6000	7000	8000	
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	24
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 8	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

Sag of the Rope between Pulleys.

Distance between Pulleys in feet.	Driving Side.	Slack Side of Rope.		
	All Speeds.	80 ft. per sec.	60 ft. per sec.	40 ft. per sec.
40	0 feet 4 inches	0 feet 7 inches	0 feet 9 inches	0 feet 11 inches
60	0 " 10 "	1 " 5 "	1 " 8 "	1 " 11 "
80	1 " 5 "	2 " 4 "	2 " 10 "	3 " 8 "
100	2 " 0 "	3 " 8 "	4 " 5 "	5 " 2 "
120	2 " 11 "	5 " 3 "	6 " 3 "	7 " 4 "
140	3 " 10 "	7 " 2 "	8 " 9 "	9 " 9 "
160	5 " 1 "	9 " 3 "	11 " 3 "	14 " 0 "

Gearing.—If on two parallel shafts we mount two pulleys of such diameter that their faces just touch, we can by turning one shaft drive the other through friction. The surfaces of the pulley faces are not smooth, and, if looked at under the microscope, will be found to be made up of alternate hills and valleys, and it is by the pushing of a hill on one pulley against an adjacent hill on the other pulley that the motion is transmitted. The pulleys may be considered then as gear wheels having an infinite number of teeth meshing into each other. Suppose that we cut larger teeth, making larger alternate elevations above and depressions beneath the cylindrical surface of the pulley face, along which surface we supposed the two pulleys first touched. The tooth of one wheel will fit into the space of the other, and the origi cylindrical surface will have disappeared. It is, however, s considered to exist, and is called the *pitch surface.* The diame of this cylinder is called the *pitch diameter.* The *pitch* of a g wheel is the distance measured along this pitch circle or surfa from one side of a tooth to the same side of the next tooth. T pitch is divided into two parts: the *thickness,* which is the width the tooth, and the *space.* The space is a little wider than t tooth, and the difference between the two is called the *backla* In cut gears this difference is very small indeed. Only gears the same pitch will work together, and when they have the sa pitch the number of teeth is proportional to their diameters.

Spur Gears are used to connect shafts which are parallel each other.

Bevel Gears are employed where the shafts are at an ang with each other. With bevel gears the pitch is measured at t larger end of the tooth.

Kinds of Teeth.—There are two forms in common use, call the *cycloid* and the *involute,* the latter being employed where t number of teeth is small. Two wheels to be geared together mu have not only the same pitch, but also the same tooth form.

Rule *for finding the diameter of toothed wheels.*—Multiply t number of teeth by the number of thirty-seconds of an inch co tained in the pitch: the product will be the diameter in tenths a hundredths of an inch; or, multiply the number of teeth by t true pitch, and the product by ·3184. These results give only t diameter between the pitch-line, on one side, and the same line the other side, and not the entire diameter from point to point teeth on opposite sides. It must also be borne in mind that the results are only approximate diameters, since the wheel often vari from the computed diameter in consequence of shrinkage and oth causes.

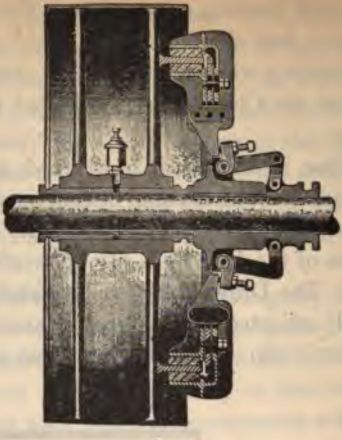
Rule *for finding the required number of teeth in a pinion to ha any given velocity.*—Multiply the velocity or number of revolutio of the driver by its number of teeth or its diameter, and divid

and divide the p[illegible] number of teeth of the driver.
he quotient will be the diameter of pinion.

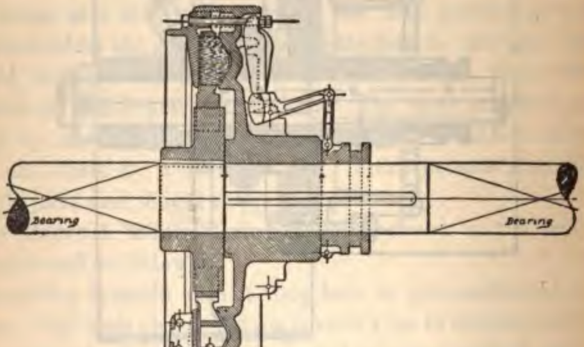
e *for finding the number of revolutions of a pinion or driven,*
the number of revolutions of driver and the diameter or the
r of teeth of driver and driven are given.—Multiply the
r of revolutions of driver by its number of teeth or its
er, and divide the product by the number of teeth or the
er of the driven.

for finding the number of revolutions of a driver, when the
ons of driven and teeth, or diameter of driver and driven, are
-Multiply the number of teeth or the diameter of driven
evolutions, and divide the product by the number of teeth
liameter of driver.

for finding the number of revolutions of the last wheel at the
a train of spur-wheels, all of which are in a line, and mesh
e another, when the revolutions of the first wheel, and the
of teeth, or the diameter of the first and last are given.—
y the revolutions of first wheel by its number of teeth or
ieter, and divide the product by the number of teeth or
neter of the last wheel; the result is its number of revo-



Cut-off Clutch Couplings.—The arrangement for connecti two sections of a shaft is shown plainly in the accompanyi figure.



Another cut shows the friction clutch pulley, shaft, and t *ever form of clutch* shifter. The shifter may also be oper *a wheel* and spur-gear or wheel and worm-gear.

Pneumatic transmission of power has many important applications, and is coming into extensive use for operating cranes, hoists, drills, riveting machines, coal-mining machinery, railroad signals, shop tools, sand-blasts, brakes, etc. It is also used for cleaning carpets and railroad car cushions, refrigerating, pumping, tunnelling, and for carrying messages or packages through tubes. Some pneumatic locomotives are in use for operating street cars, while for driving cars in mines they are quite common. The most extensive installations are to be found in Paris, where one central station is laid out for 24,000 H.P., and supplies some hundreds of motors of sizes from ⅛ H.P. to 50 H.P., the air being compressed to about six atmospheres.

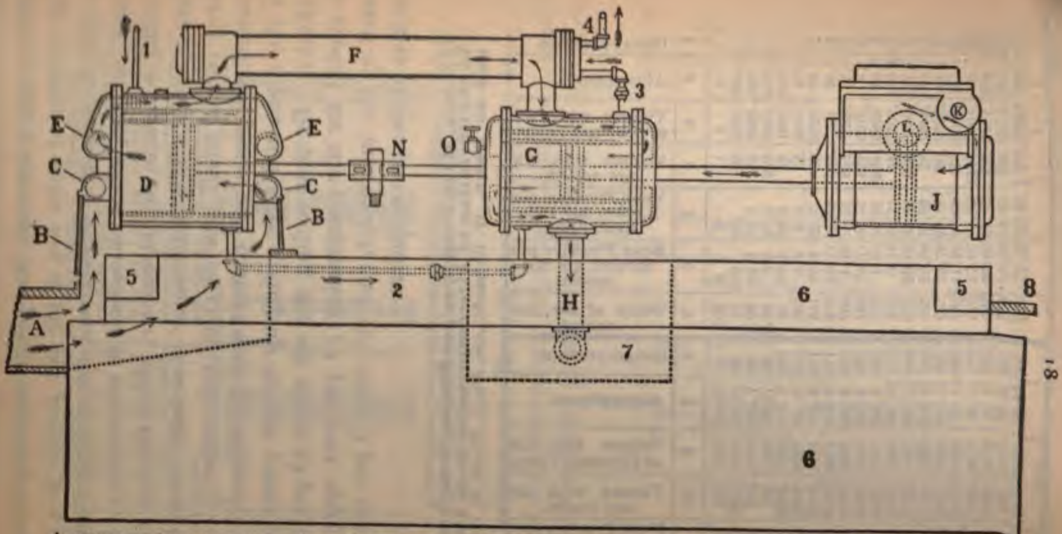
The compressors are pumps driven by belt or gear-wheels, or are directly driven by a water-wheel (by means of a crank), or by a steam-cylinder and piston. In this last case, which is the most common, the air-piston and steam-piston are mounted on the two ends of the same piston-rod. On the steam end steam is admitted at its maximum pressure, and is allowed to expand till it reaches a low pressure at the end of the stroke. The reverse takes place in the air-cylinder. Here air is admitted at atmospheric pressure and fills the cylinder. On the return stroke the pressure gradually increases, till at the end of the stroke the pressure rises to that of the reservoir into which it is pumping. From this it can be seen that when the steam-pressure is least, the ai pressure against which it is working is greatest; and, therefo very heavy fly-wheels have to be used to store up the surp energy at the first part of the stroke and to give it out on the l part. To equalize more nearly the work at different parts of t stroke, the compression may be divided into two stages by using large cylinder for performing the first part, say, from atmosphe to 30 pounds, and a smaller cylinder for finishing the compressi

The compound air compressor is the name given to such arrangement from its resemblance to the compound engine. addition to equalizing the strains on the machine, it also is mu more efficient—*i. e.*, compresses a given amount of air with a le amount of steam used in the steam-cylinder. For very high pre ures, as for 2000 pounds per sq. in., the compression is divided in three or even four stages by using three or four air-cylinders as t case may be. The steam end is also made compound or triple e pansion to secure the greatest economy in the use of steam. (course, where two steam-cylinders are used they may cross co pound or tandem, and the same is true of the air-cylinders. T Rand Drill Co. use the cross compound, while the Norwalk Ir Works Co. use the tandem arrangement.

The cut shows a single steam-cylinder and a tandem compoun air compressor with names of the different parts of the machin

The Intercooler.—When air is compressed its temperatu rises to an extent depending on the amount of compression ar the original temperature at which the air was taken in. The ri in temperature is shown in the following table:

Temperature of air before compression,	60°	90°
Temperature of air compressed to 15 lbs.	177°	212°
" " " 30 "	255°	294°
" " " 45 "	317°	362°
" " " 60 "	369°	417°
" " " 75 "	416°	465°
" " " 90 "	455°	507°
" " " 105 "	490°	545°
" " " 120 "	524°	580°



Arrows on the water pipes show the direction of water circulation. When pistons move as indicated by the arrow on the piston rod, steam and air circulate in direction shown by arrows in the cylinders.

A—Inlet Conduit for Cold Air.
B—Removable Hoods of Wood.
C—Inlet Valve.
D—Intake Cylinder.
E—Discharge Valve.
F—Intercooler.
G—Compressing Cylinder.

H—Discharge Air Pipe.
J—Steam Cylinder.
K—Steam Pipe.
L—Exhaust Steam Pipe.
N—Swivel Connection for Crosshead.
O—Air Relief Valve, to effect Easy Starting after stopping with all pressure on the pipes.

1—Cold Water Pipe to Cooling Jacket.
2 & 3—Water Pipes
4—Water Overflow or Discharge.
5—Stone on End of Foundation.
6—Foundation
7—Space to Get at Underside of Cylinder
8—Floor Line

This rise in temperature has two bad effects: it makes lubrication difficult, and it increases the power necessary to compress a certain number of cubic feet of air per minute to a certain number of pounds pressure. To overcome this difficulty both cylinders are water-jacketed, which obviates it to some extent; but most of the cooling is done in the intercooler, which receives the air from the first cylinder. This intercooler is a tank through which runs a large coil of small pipe carrying cold water. The heated compressed air comes into contact with the extensive cooling surface of the pipes, and after giving up its heat passes on to the second cylinder. By thus cooling the air about 15 per cent. less power is needed for the compression, 10 per cent. approximately being saved by the intercooler, and the other 5 per cent. by the water-jackets of the two cylinders.

Volumes, Mean Pressures per Stroke, Temperatures, etc., in the Operation of Air-compression from 1 Atmosphere and 60° Fahr. (F. Richards, *Am. Mach.*, March 30, 1893.)

Gauge-pressure.	Atmospheres.	Volume with Air at Constant Temp.	Volume with Air not cooled.	Mean Pressure per Stroke; Air Constant Temp.	Mean Pressure per Stroke; Air not cooled.	Temp. of Air; not cooled.	Gauge-pressure.	Atmospheres.	Volume with Air at Constant Temp.	Volume with Air not cooled.	Mean Pressure per Stroke; Air Constant Temp.	Mean Pressure per Stroke; Air not cooled.	Temp. of Air; not cooled.
1	2	3	4	5	6	7	1	2	3	4	5	6	7
0	1	1	1	0	0	60°	80	6.442	.1552	.266	27.88	36.64	432
1	1.068	9363	.95	.96	.975	71	85	6.782	.1474	.2566	28.16	37.94	447
2	1.136	.8803	.91	1.87	1.91	80.4	90	7.122	.1404	.248	28.89	39.18	459
3	1.204	.8305	.876	2.72	2.8	88.9	95	7.462	.134	.24	29.57	40.4	472
4	1.272	.7861	.84	3.53	3.67	98	100	7.802	.1281	.2324	30.21	41.6	485
5	1.34	.7462	.81	4.3	4.5	106	105	8.142	.1228	.2254	30.81	42 78	496
10	1.68	.5952	.69	7.62	8.27	145	110	8.483	.1178	.2189	31.39	43.91	507
15	2.02	.495	.606	10.33	11.51	178	115	8.823	.1133	.2129	31.98	44.98	518
20	2.36	.4237	.543	12.62	14.4	207	120	9.163	.1091	.2078	32.54	46.04	529
25	2.7	.3703	.494	14.59	17.01	234	125	9.503	.1052	.2020	33.07	47.06	540
30	3.04	3289	.4538	16.34	19.4	252	130	9.843	.1015	.1969	33.57	48.1	550
35	3.381	.2957	.42	17.92	21.6	281	135	10.183	.0981	.1922	34.06	49.1	560
40	3.721	.2687	.393	19.32	23.66	302	140	10.523	.095	.1878	34.57	50.02	570
45	4.061	.2462	.37	20.57	25.59	321	145	10.864	.0921	.1837	35.09	51.	580
50	4.401	.2272	.35	21.69	27.69	339	150	11.204	.0892	.1796	35.48	51 89	589
55	4.741	.2109	.331	22.76	29.11	357	160	11.88	.0841	.1722	36.29	53.65	607
60	5 081	.1968	.3144	23.78	30 75	375	170	12.56	0796	.1657	37.2	55.39	624
65	5.422	.1844	.301	24.75	32.82	389	180	13.24	.0755	.1595	37.96	57.01	640
70	5.762	.1735	.288	25 67	33.88	405	190	13.93	.0718	.154	38.68	58.57	657
75	6.102	.1639	.276	26 55	35.27	420	200	14.61	.0685	.149	39.42	60 14	672

The following table, taken from Kent's Hand-book, will be found useful in determining the power required for various cases.

Horse-power required to compress and deliver one cubic foot of Free Air per minute to a given pressure with no cooling of the air during the compression; also the horse-power required, supposing the air to be maintained at constant temperature during the compresion.

Gauge-pressure.	Air not cooled.	Air constant temperature.
5	.0196	.0188
10	.0361	.0333
20	.0628	.0551
30	.0846	.0713
40	.1032	.0843
50	.1195	.0946
60	.1312	.1036
70	.1476	.1120
80	.1599	.1195
90	.1710	.1261
100	.1815	.1318

Horse-power required to compress and deliver one cubic foot of Compressed Air per minute at a given pressure with no cooling of the air during the compression; also the horse-power required, supposing the air to be maintained at constant temperature during the compression.

Gauge-pressure.	Air not cooled.	Air constant temperature.
5	.0268	.0251
10	.0606	.0559
20	.1488	.1300
30	.2573	.2168
40	.3842	.3138
50	.5261	.4166
60	.6818	.5266
70	.8508	.6456
80	1.0302	.7700
90	1.2177	.8979
100	1.4171	1.0291

The horse-power given above is the theoretical power, no allowance being made for friction of the compressor or other losses, which may amount to 10 per cent or more.

Capacity of Compressors: Norwalk Iron Works Co.—List of standard steam-driven compressors; 10 per cent. should be deducted from the theoretical capacity given in table for losses in friction, heating, etc.

Diameter of Air-cylinder.	Length of Stroke.	Diameter of Compressing Cylinder.	Diameter of Steam-cylinder.	Revolutions or Double Strokes per Minute.	Capacity Cubic Feet per Minute.	Steam Pipe.	Exhaust Pipe.	Air Pipe.	Water Pipe.	Horse Power.
8	10	5	8	200	116	2	2½	2	½	15
10	12	6¾	10	180	195	2½	3	2½	¾	28
14	16	9½	14	150	427	3	4	4	1	55
16	16	9½	16	150	558	3	4	4	1	80
20	24	13½	20	110	960	5	6	5	1¼	125
22	24	13½	22	110	1160	5	6	5	1¼	150
26	30	17½	24	90	1659	6	8	6	1¼	215
28	30	17½	28	90	1924	8	10	6	1¼	250
32	36	21½	30	80	2686	8	10	8	1½	350

Capacity at high altitudes is less than at sea-level. Multiply the figures given above by the percentages in the following table to get the capacity at different heights.

Height above sea =	1000	2000	3000	4000	5000
Per cent..............	97	94	91	89	86

Regulation of pressure is obtained by cutting off the supply of steam to the steam-cylinder when the pressure gets too high, and thus slowing down the engine to the slowest speed at which it will pass the dead centres, and reversing the operation when the pressure is too low. To do this a balanced valve is placed in the steam supply-pipe, which valve is attached to a piston that works in a little cylinder to which leads a pipe from the air-reservoir. A small safety-valve, which can be adjusted to blow at any pressure, is placed in this pipe, so that when the pressure rises beyond this point it blows and lets air into the little air-cylinder, thus driving up the piston and closing the steam-valve. The piston would be driven to the top of the cylinder, thus shutting off the steam-supply at once, were it not that a fine slot cut in the cylinder is uncovered as the little piston rises, and thus lets out the air, the engine having a part only of the steam shut off. If the pressure in the air-receiver rises still higher, the little piston rises accordingly and the engine is still farther slowed down. If no air is being used from the reservoir, the main safety-valve on the reservoir, which is set a couple of pounds higher than the little pressure-regulating valve, will blow and relieve the pressure on the reservoir.

Reservoirs or receivers are steel tanks of a strength sufficient to stand the pressures to be used, which are placed one near the compressor and one near the point where the compressed air is to be used. They are, or should be, provided with a man-hole for cleaning and for drawing off any water that may collect in them. They perform several important purposes, viz.:

They may, if large enough, act to store power; but usually, except with pneumatic locomotives, they are not made of sufficient ze to store any considerable amount. The one near the compressor serves to take up its pulsations, and the pipe-system thus takes air at a constant pressure instead of a fluctuating one. The receiver near the air-motors supplies sudden demands without the pressure dropping appreciably, and thus prevents fluctuations of flow in the pipe line. Both, therefore, tend to promote a steady flow in the pipe line at a uniform pressure and velocity, and thus reduce the loss of pressure by friction in the pipe line to a minimum.

They also allow any water which may be in the compressed air to separate and escape from it. While the best size of receiver to be used depends upon the special conditions of each case, the following list shows the sizes commonly used with the compressors in the preceding table:

Diameter.	Length.	Size pipe.
24 inches.	4 feet.	2½ inches.
30 "	5 "	4 "
36 "	8 "	5 "
36 "	13 "	6 "
42 "	16 "	8 "

The pipe line is one of the most important parts of a compressed air-system of power transmission, and the size of the pipe must be carefully determined. If it is too large, money will be wasted; if it is too small, there will be great loss of pressure owing to friction. Pressure and power are lost by friction just as in water-pipe, but whereas in hydraulics the lost power bears the same proportion to the total power as does the loss of pressure or head to the total pressure, this is not the case with compressed air, the loss in power being less in proportion than the loss in head. The loss in pressure for a pipe 2000 feet long is practically double the loss for the same diameter pipe 1000 feet in length; that is, the loss in pressure varies proportionally with the length. If we send in one case 100 cu. ft. per minute through a pipe, and in another case 200 cu. ft. through the same pipe, the loss of pressure in the second case will be 4 times that in the first. That is, *doubling the velocity gives 4 times* the friction loss.

In remote portions of a mine it is of interest to know the quantities of air that will flow through small pipes, when the pressure is drawn down from a large main which furnishes a supply at constant pressure. Below we give such a table:

Flow of Compressed Air Through Pipes.

Cubic Feet of Free Air Delivered in Compressed Form at the Stated Various Pressures.

UNIFORM PRESSURE AT THE ENTRANCE OF THE PIPE EIGHTY POUNDS GAUGE.

VARIOUS PRESSURES AT THE POINT OF DELIVERY

Nominal Size of Pipe ☞	1 in.		1¼ in.		1½ in		2 in.		2½ in.	
Length of Pipe in Feet ☞	50	100	100	300	100	300	200	500	250	600
79.8	23.2	16.4	35.2	20.3	63.6	36.7	84.7	53.6	142.0	91.7
79.6	33.1	23.4	49.7	28.7	89.9	51.9	119.6	75.7	200.9	129.6
79.4	40.4	28.6	61.0	35.2	109.1	63.0	146.5	92.7	244.4	157.7
79.2	46.8	33.1	70.3	40.6	127.1	73.4	169.1	107.1	283.2	183.1
79.0	52.3	37.0	78.6	45.4	142.0	82.0	189.1	119.7	317.1	204.6
78.8	57.1	40.4	86.1	49.7	155.4	89.7	207.0	131.0	348.4	224.8
78.6	61.6	43.6	93.0	53.7	168.0	97.0	223.3	141.3	377.0	243.9
78.4	65.9	46.6	99.2	57.3	179.3	103.5	238.7	151.1	399.6	258.4
78.2	70.3	49.7	105.4	60.8	190.5	110.0	252.9	160.1	424.1	273.6
78.0	73.7	52.1	110.8	64.0	200.7	115.9	266.5	168.7	446.7	288.6
77.8	77.2	54.6	116.2	67.1	209.9	121.2	279.2	176.7	469.0	302.6
77.6	80.7	57.1	121.4	70.1	219.1	126.5	291.5	184.5	489.6	315.9
77.4	84.0	59.4	126.3	72.9	228.1	131.7	303.4	192.0	509.3	328.6
77.2	87.1	61.6	131.1	75.7	236.7	136.6	314.4	199.0	528.3	340.8
77.0	90.3	63.7	135.4	78.2	245.2	141.6	325.5	206.0	546.5	352.6
76.8	92.9	65.7	139.8	80.7	252.4	145.7	336.1	212.7	564.2	364.0
76.6	95.6	67.7	143.9	83.1	259.8	150.0	346.2	219.1	581.3	375.0
76.4	98.4	69.6	148.1	85.5	267.6	154.5	356.0	225.3	597.5	385.5
76.2	101.0	71.5	152.1	87.8	274.7	158.7	365.6	231.4	613.8	396.0
76.0	103.8	73.4	156.1	90.1	281.3	162.4	375.6	237.3	629.3	406.0
75.8	106.3	75.2	159.7	92.2	288.4	166.6	383.9	243.0	644.5	415.8
75.6	108.7	76.9	163.3	94.3	295.5	170.6	392.8	248.6	659.2	425.3
75.4	111.0	78.5	167.0	96.4	301.7	174.2	401.4	254.0	673.8	434.7
75.2	113.3	80.1	170.4	98.4	307.9	177.8	409.7	259.3	687.8	443.8
75.0	115.5	81.7	173.9	100.4	314.3	181.5	417.9	264.5	701.6	452.7

ELBOWS AND BENDS.

We give below an original table showing the effect of elbows. The friction is stated as being equal to a certain length of straight pipe of same size. The friction of the straight pipe is given on page 60. An elbow with radius of half the diameter of the pipe is as short as can be made. The beneficial effect of even a little curve, in comparison with a short, sharp turn, is evident at a glance.

Radius of Elbow				Equivalent length of straight pipe				
Radius of Elbow	5	diameters.	Equivalent length of straight pipe				7.85	diameters.
"	"	3	"	"	"	"	8.24	"
"	"	2	"	"	"	"	9.03	"
"	"	1½	"	"	"	"	10.36	"
"	"	1¼	"	"	"	"	12.72	"
"	"	1	"	"	"	"	17.51	"
"	"	¾	"	"	"	"	35.09	"
"	"	½	"	"	"	"	121.20	"

Flow of Compressed Air Through Pipes.

Final Pressure at the Point of Delivery—80 lbs. Gauge.

Cubic Feet of Free Air Delivered in Compressed Form at 80 lbs. Gauge Pressure, per Minute.

Nominal Size of Pipe in Inches ☞		1		1¼		1½		2		2½		3		3½		4		4½		5		6		7		8	
Length of Pipe in Feet ☞		50	100	100	300	250	500	250	750	250	750	500	1500	750	2000	1000	3000	1500	3000	2000	4000	2000	5000	3000	10000	3000	10000
Gauge Pressure at the Entrance to the Pipe.	80.2	23.7	16.8	35.6	20.7	40.1	28.4	76.0	49.0	143	83	163	95	210	128	263	153	288	211	383	271	558	352	694	379	999	546
	80.4	33.1	23.4	49.7	29.0	56.0	39.6	106.1	61.6	200	116	228	132	292	179	368	213	416	295	535	379	781	493	970	530	1397	763
	80.6	41.1	29.0	60.9	35.4	68.7	48.6	130.0	75.5	245	142	279	162	358	220	451	262	506	361	656	464	957	605	1189	650	1712	936
	80.8	47.0	33.2	70.3	41.0	79.3	56.0	150.1	87.1	283	164	322	187	420	254	521	302	589	417	757	536	1105	699	1373	750	1977	1080
	81.0	52.5	37.1	78.7	45.7	88.7	62.8	168.0	97.5	312	184	361	211	463	284	582	338	659	465	847	600	1236	780	1535	839	2210	1208
	81.2	57.5	40.7	86.2	50.1	97.3	68.8	184.2	107.0	348	202	397	229	507	311	642	370	721	511	930	658	1356	857	1685	921	2437	1326
	81.4	62.2	44.0	93.2	54.2	105.1	74.3	199.0	115.5	375	218	428	248	549	337	690	400	781	552	1004	711	1464	925	1819	994	2619	1431
	81.6	66.5	47.0	99.7	58.0	112.4	79.5	212.9	123.5	402	233	457	266	586	360	738	428	835	591	1074	760	1566	989	1946	1063	2802	1531
	81.8	70.6	50.0	105.8	61.5	119.3	84.4	225.8	131.0	426	247	485	282	622	381	783	454	886	627	1139	807	1662	1049	2065	1128	2974	1624
	82.0	74.4	52.6	111.5	65.0	125.8	88.9	238.1	138.2	449	261	512	297	657	402	826	479	934	661	1202	851	1753	1107	2178	1190	3136	1714
	82.2	78.1	55.2	117.5	68.3	132.0	93.4	250.0	145.1	472	274	537	312	689	422	867	503	1071	694	1262	894	1840	1162	2286	1249	3292	1799

To properly proportion the size of pipe for a transmission system we must consider the cost of coal, compressors, and pipe, and the pressure to be used, and to get the best results skilled judgment and experience are necessary. For small and simple installations which are run usually at a pressure near 80 pounds, and where the distances are comparatively short, the following tables, taken from the catalogue of the Norwalk Iron Works Company, will be found useful. In the first table (page 63) the figures in the first column, less 80, give the loss of pressure due to friction. Thus, with a 1 inch pipe we can transmit 55.2 cubic feet per minute a distance of 100 feet with a loss of 2.2 pounds, a very moderate loss. If we should want to run 200 feet, the same pipe will give us a loss of about 4.4 pounds, which might be allowable for some cases, while for others a larger pipe would be desirable.

Air Motors are of various types, from the reciprocating rock drill to the rotary engine type used in the Paris system, Ordinary steam engines can be used as air motors, and likewise ordinary steam-driven pumps. The quantity of air used per horse-power varies with the size of units, as does the water consumption in a steam engine. Moreover, this quantity can be very much lessened if just before the compressed air goes into the motor it be heated to about 350° F., and the hot air used expansively. When so heated the quantity of air used per horse-power hour is for engines of ½ horse-power, with air at 80 pounds pressure, about 800 cubic feet. For an 80 horse-power engine under similar conditions a test showed a consumption of 465 cubic feet per hour.

Efficiency of Compressed Air Systems.—There are losses in the engine due to friction, losses in the compressor due to friction and heating, losses in the pipe line due to friction, losses in valves, etc., and losses in the motor. The efficiency of the engine and compressor may be taken at about 60 to 65 per cent., that of the pipe laid at from 95 to 98 per cent., and that of the motors from
o 80 per cent., depending on the size. The combined efficiency
omplete system—that is, the horse-power taken out of the

[illegible]

[illegible] machinery [illegible]

[illegible] for one-half the [illegible]

[illegible] was ample.

[illegible] high pressures [illegible]

[illegible] is used to [illegible]

[illegible] power was being [illegible]

[illegible] approximately 40 amperes [illegible]

[illegible] about 7 per cent.

[illegible] the pressure, the [illegible]

[illegible] the loss would be [illegible] of 7 per cent [illegible]

[illegible] transmit with a 7 per cent. [illegible]

[illegible] ire if we used a pressure of 1100 volts.

Where we want to run at practically constant speed whatever the load on the motor, the shunt-wound motor will be used. If, as for lathes, we want to have several speeds at which the motor will run steadily, this is accomplished by a regulating rheostat or controller. For planers or similar machines where there is during the reversal a large rush of current a compound-wound motor, with series coil aiding the shunt coil, is desirable. The series motor is advisable only where the machine is constantly changing its speed, as in street-car work.

For greater distances higher pressures than 500 volts are used, and alternate currents are used because of the ease with which we may lower their pressure to a value not dangerous to human life when we get to the point where we want to use them—that is, the motor. In alternate current systems the current may be generated at a safe pressure of, say, 300 volts, raised in a transformer to 5,000, 10,000 or even 15,000 volts, carried along a comparatively small wire at this pressure until near the motor, reduced in another transformer to 300 volts and used at that pressure. As transformers may be placed out of reach and require no attention, like motors and generators, the attendants are not subject to any greater danger than with the direct current systems.

The alternating current polyphase induction motor has practically the same characteristics as the direct current shunt motor, and will be used in similar cases.

To determine the proper size of motor for driving any particular tool can best be done by taking a motor and running the tool at its maximum speed and load, and with an ampèremeter and voltmeter noting the volts and ampères. Multiply the *largest* reading in ampères by the average reading of the voltmeter and divide the product by 750, or, to be more exact, by 46. This gives the electrical horse-power delivered to the motor. vide this by the efficiency of the motor, which will vary from to 95 per cent., according to the size. This result gives the d *horse-power of* the proper size motor.

uch experiments have been made on a large number of tools different kinds by the authors and others, and the results of ost importance will be found in an earlier part of this chapter ıder the heading, "Power Required for Machine Tools."

To calculate the line we must determine what electrical press- re we shall use, what power the motor will be, and what the llowable variation in the speed of the motor is between fully aded and running free. Suppose this variation is 8 per cent. he average motor has in itself a lack of regulation of about 3 er cent., so that the line should be large enough not to cause a ariation of over 5 per cent. If the system were a 110-volts sys- m and the motor 5 horse-power, taking a current of about 40 npères we should use such a size wire that the loss of pressure as 5.5 volts when 4 ampères flowed through it. The method of lculating the size under such conditions is given in the chapter on lectricity and need not be repeated here. When several motors e supplied from the same line it frequently happens that they e never all working at full load at any one time. When this is e case the line need not be calculated large enough for the sum their horse-powers. The exact allowance to be made is not a atter concerning which any definite rule can be laid down. hen the number of tools is small, say 5 or 6, a deduction of 15 25 per cent. should be made. With 15 or 20 such tools as ose used in an ordinary machine-shop, measurements have ıown that a wire calculated for one-half the sum of the powers the separate tools was ample.

The gain in using high pressures is enormous. Suppose that o. 10 B. & S. wire is used to connect motor and generator 500 et apart and 1 horse-power was being transmitted, the current at 0 volts being approximately 40 ampères. The loss in heating e wire would be about 7 per cent.

If we double the pressure, the loss will be ¼, or 1¾ per cent.

At 550 volts the loss would be $\frac{1}{25}$ of 7 per cent.

At 1100 " " " 100 of 7 "

we could transmit with a 7 per cent. loss 100 horse-power over *No. 10 wire if we used a pressure* of 1100 volts.

At 11,000 volts we could transmit 10,000 horse-power at 7 per cent. loss, or 100 horse-power 50,000 feet at 7 per cent. loss.

The size of generator is determined in a similar manner to that used in calculating the size of the line. While motors are rated in horse-power, generators are rated in kilo-watts, or K. W. One K. W. = 1000 watts or 1000 volt-ampères = $1\frac{1}{3}$ horse-power. If it is desired to select a generator to furnish current for one motor only of, say, 50 horse-power, the calculation is as follows: 50 horse-power = $37\frac{1}{2}$ K. W., the power delivered at the pulley of motor; $37.5 \div \frac{90}{100}$ (the efficiency) = $41\frac{2}{3}$ K. W., the electrical power delivered to the motor terminals. Suppose we had a 5 per cent. loss on the line, then $41\frac{2}{3} \div \frac{95}{100} = 43.78$ K. W., the size of generator. The nearest commercial size to this would be 45 K. W.

Efficiency of electric transmission depends largely upon the size of units employed. The efficiency of dynamos and motors of the same sizes is practically the same, and approximate values are given in the following table. These efficiencies are the *commercial efficiencies,* namely power taken out of the machine ÷ power put in.

H. P....................	$\frac{1}{2}$	1	2	3	5	10	15	20	25	50	100
K. W....................	$\frac{1}{2}$	1	2	3	4.5	8.7	12.7	16.7	20.7	40	80
Efficiency.............	70	80	81	82	85	87	89	90	91	93	95

The loss in the line may be made as small as desired by increasing the size of wire and hence the cost. On account of regulation of pressure it rarely exceeds 10 per cent. except for very long distances. It will be seen that the efficiency of motors and generators is considerably better than that of air compressors and air motors.

Lubricants.

To understand the quantity of oil required for steam-cylinders, slide-valves, and the reciprocating or revolving parts of steam-engines, we should first know what its objects are. The object of *oil is to dimi[illegible]ction,* by interposing a thin film between the *sliding or r[illegible]aces.* To insure perfect lubrication, t urfaces must be kept coated at all times, under all pressures and velocities. In steam-engines there is a sliding and rotating friction, and it is very doubtful if any one kind of oil is perfectly suited to both. Oil has no tendency to improve the character of a bearing; its functions being simply to keep them apart, prevent heat, and diminish friction.

Temperature exerts a very important influence over any lubricant. A thin oil has a tendency to run off too fast, while a thick one is not sure to flow. Tallow, and all other thick and greasy compounds, are exposed to the same objection, as the bearing generally gets hot before the lubricant begins to flow. Besides, what may be called a good lubricant, one that adheres to the rubbing surfaces under ordinary circumstances, may not be equally well adapted to all conditions, as the area of the bearing surfaces varies with the size of the journals, and the form of the boxes, which causes a difference in the velocity of rotation. From this, it follows, that a lubricant that would be retained between the frictional surfaces under a light load, would be entirely pressed out under a heavy one.

The quantity of lubrication that the cylinders and slide-valves of any engine require, depends on the condition of the engine, the amount of work it is performing, and on the pressure and temperature of the steam. If the load is light, the pressure low, and the engine in good order, very little lubrication is necessary; but if the pressure and speed are high, and the engine is working up to its full capacity, the cylinder and valves will require to be frequently lubricated. But in no case should an unnecessary quantity be used, as it is likely to produce a greater evil than the one it was intended to remedy. A person having charge of steam machinery should understand the work each part has to perform, the speed at which it runs, and the weight it has to sustain. Crank-pins and main-bearings require to be frequently oiled; but the condition of the bearing will determine the quantity of lubrication *needed. What is needed* in any case is a few drops of good *oil applied often. It may be* safely said that five times the quan-

[illegible] in the starting and rubbing surf
and [illegible] and cylinder of steam-engines, that is actu
necessary.

It is not by any means uncommon to see ignorant and in
persons [illegible] who have charge of steam-engines pouring o
oil [illegible] and [illegible] every five minutes duri
the day [illegible] is immediately thrown off by the shoes or th
[illegible] without rendering any service, which is a
waste of the necessary supplies in their charge, and has a
tendency to lower the profits of the establishment.

As an example of what may be done in the saving of oil the fol
lowing examples are given, taken from the Vacuum Oil Company's
reports, the oil used being their [illegible] W cylinder oil:

Corliss compound, 2[illegible] and 3[illegible] × 48, 8[illegible] revolutions per minute, 1
drop of oil per minute.

Corliss triple expansion, 2[illegible], 3[illegible], and 4[illegible] × 48, 1 drop in 2
minutes.

Porter-Allen compound, 2[illegible] and 3[illegible] × 36, 143 revolutions per
minute, [illegible] drop per minute.

Ball, 15 and 25 × 16, 240 revolutions per minute, 1 drop in 4
minutes.

Owing to the difference in the size of drops the actual quantity cannot be obtained from these figures.

On smaller engines, from 50 to 75 horse-power, one-half pint of good cylinder oil for 10 hours run is generally considered good. An expert by watching his engine *constantly* and carefully may diminish this considerably. A particularly good example with which the authors are familiar is the case of an 11½ × 14 Woodbury engine running at 265 revolutions, which uses one pint of
e best cylinder oil, costing $1.00 per gallon, in 200 hours, the
ing about once in four minutes. It is not advisable to
the oil consumption down too low, for unless the
stantly watched the risk of serious damage far out
s of the possible saving in oil.

nd the other parts of this engine a machine oil costing 50 cents per gallon is used, the cups being set to empty in about two and one-half hours and dropping at the rate of 20 per minute. This oil is run through a filter and then used over and over again. When a filter is used there is, of course, nothing to be gained by trying to run with a very slow rate of dropping.

The requirements of a good lubricant are the following:

Body sufficient to keep the surfaces apart.

As fluid as possible consistent with this.

Smallest possible friction.

Freedom from all materials tending to corrode metal.

Freedom from "gumming."

A high flashing point.

Must remain fluid at the coldest temperature to which it will be subjected.

Best lubricants for different purposes, as stated by Prof. Robert H. Thurston:

For very great pressures with slow speed, graphite, soapstone, tallow, and greases.

For heavy pressures at slow speed, lard, tallow, and greases.

For heavy pressures at high speed, sperm, castor, and heavy mineral oils.

For light pressures at high speed, sperm, refined petroleum, olive, rape, and cotton-seed oils.

For ordinary machinery, lard oil, tallow oil, and heavy mineral oils.

For steam cylinders, heavy mineral oils, lard, and tallow.

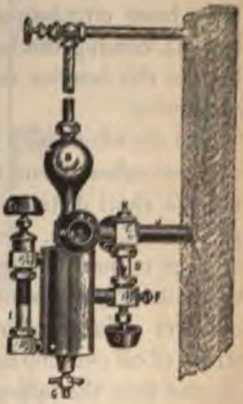
For watches and delicate mechanisms, clarified sperm, neat's-foot oil, porpoise, olive and light mineral oils.

Tests of Railway Master Mechanics' Association.—In these, 56 drops of oil were put into a dynamometer, which was run at 35 miles an hour, until the temperature was raised from 60° to 200° Fah. The exact number of revolutions necessary to produce this change of temperature was noted in each case, and is given in the last column of the following table:

[illegible]

the engine stops, is shown in the drawing. When the
s at rest oil stands below the level of disk *J*, which con-
e hole through which oil feeds. As the engine speeds up
rifugal force tends to throw oil up against the top of the
d, therefore, a pressure is set up tending to force the
the bearing. The higher the speed the greater the
, and hence the greater the quantity forced into the bear-
ch is just what is wanted, as the friction increases as the
creases.

der lubricators are generally made so that the oil, drop
, is made to bubble up through water before passing into
n-pipe leading to the steam-chest.
ut, which shows one of the most
forms, *J* is the pipe through
il is fed to the main steam-pipe,
alve for regulating the flow of
e oil-chamber, *I* the glass which
w much oil is in the chamber *A*,
alve closing the pipe *J*, and *B* is
nsation chamber in which col-
ndensed steam coming in from
r pipe. Oil is put in through *E*
and *C* are closed. *F* and *G* are
cocks for cleaning out the oil-
and sight-feed tube. The ope-
s as follows: After the cham-



been filled with oil *C* is opened slowly, and when water
densed so as to fill the sight-feed tube the valve *W*
d and the valve *D* adjusted to give the feed required.
rom the upper pipe, which extends almost to the bottom
il-chamber, condenses and forms a water-column whose
s well as the steam-pressure from *B* tends to force the oil
A bent pipe whose upper end is in the upper level of
as its lower end leading into the lower end of the sight-
s. *Therefore, the pressure* of steam in the pipe J tends

[illegible] are equ[illegible] and a[illegible]

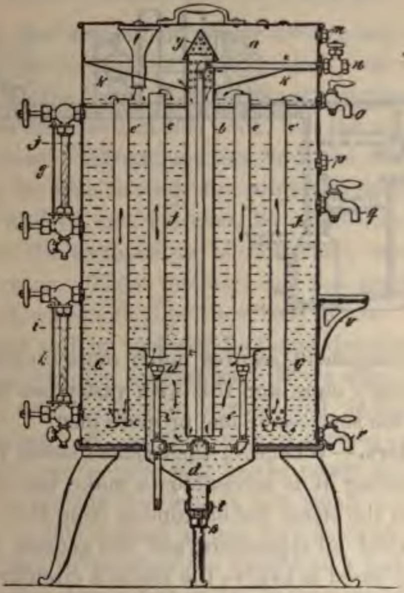
[illegible] and a [illegible] varieties [illegible] filter the dirty [illegible] where [illegible] large central [illegible] it is sub[illegible] These pipes [illegible] hot-air [illegible] to the [illegible] held in [illegible]

[illegible] after being [illegible] and [illegible] passes up the tubes [illegible] through the top of lower settling compartment [illegible] to prevent particles lighter than oil, such as [illegible] waste, etc., from passing up, which might do great damage to machine bearings. The oil passing up overflows upon the bottom of the second settling compartment [illegible], where it spreads [illegible] a large area and permits a further settling, the upper [illegible] overflowing the tops of the tubes [illegible], which are slightly [illegible] than the inflowing ones.

The oil then passes down these tubes and out at the small holes [illegible] small particles, being washed through the luke-warm water in space e, drop by drop, making the oil entirely clean and ready for use; it then passes above water line i into space f, where it accumulates for use. It is drawn off as [illegible] through cock g, or may be conducted away by attaching [illegible] plug p.

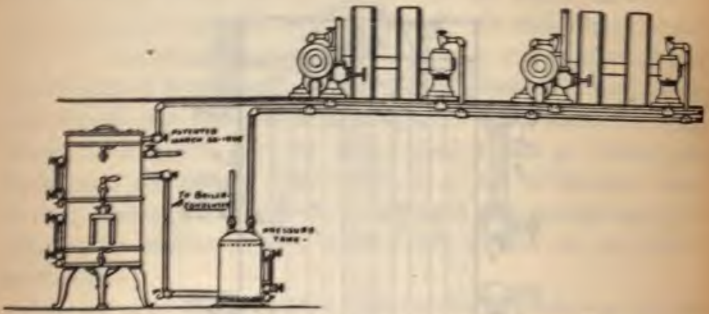
[illegible] when subjected to this process, is greatly benefited [illegible] of all small particles of grit or dirt; new oil is put [illegible] attached to the bottom of receiver a. Water-gaug *g* designates the height of oil in tank, and *h* the height of water in same.

If mechanical filters are used, such as powdered cork, charcoal, etc., through which the oil is allowed to percolate, they should be made so that it is very easy to get at these substances for cleaning, as they get dirty quickly, and when dirty are of course of no further use in helping to clean the oil.



Automatic oiling return systems are coming into extensive use in large plants having many units. A pipe leads from a pressure tank along near the bearings to be oiled, and into this main are tapped small pipes running to the bearings. In each of these small pipes is a *sight-feed. After passing through the bearings the oil is collected into a return* main which runs to the filter.

After passing through the filter it runs to the pressure tank and is again forced through the oil pipes. Pressure is kept on the tank by a pipe leading to the boiler. Another arrangement is with the oil purifier on a higher level than the bearings and with the pressure tank used to force the dirty oil up into the filter. The cut shows the first method.



Such an arrangement secures much more uniform lubrication than with ordinary cups, and this with vastly less labor; in large plants saving the services of one or more men.

Oil Separators.—Whenever the exhaust steam from an engine is used for heating it is advisable to make use of a device for separating from the steam the oil coming from the cylinder. Such devices are called oil separators, and the general principle upon which they are based is to give the steam a circular motion in the separator, so that by centrifugal force the oil will be thrown against the walls of the separator and will afterward drop down into a chamber, from which it may at any time be drawn off.

CHAPTER III.

MEASUREMENT OF POWER.

To measure the amount of power used in any case there are many methods available, the great majority of which require apparatus not in the hands of the ordinary engineer. They will not therefore be discussed in this book, but the reader is referred to J. J. Flathers' "Dynamometics and the Measurement of Power," should he wish to study the subject in detail. Nearly all measurements desired can, however, be made with a fair degree of accuracy by the methods to be described, using only easily obtained apparatus. These methods are the Indicator method, Electric method, and method of the Prony brake.

The indicator and its use will be found described fully in the chapter on steam-engine appliances. If we want to know what power is being used to drive a certain tool, indicate the engine with the tool thrown off and then with it thrown on. The difference between the two powers will be the power used to drive the tool. If the power for the tool is but small compared to the power without it, this method is not very accurate, it being similar to an attempt to measure the weight of a forkfull of hay by driving a loaded cart on a hay-scales, getting its weight, and then throwing off one forkfull and reweighing, and finally subtracting the second weight from the first. If the power to be measured is a large part of the total power furnished by the engine, the method is fairly accurate, say within 10 per cent., if carefully carried out.

The electrical method is, where feasible, the quickest and most accurate, as with good instruments the readings will be correct to within 2 per cent. If the machine whose power of consumption is to be measured is already operated by an electric motor direct, all that is necessary is to connect a voltmeter of proper range to the motor terminals, and an ammeter in series with the motor, and read the two instruments. The product of the two readings divided by 746 will give the horse power used by the motor and tool. Throw the tool off and take another reading and subtract the last measurement of power from the first. The result is the power used by the tool.

If the motor is driving several tools, measure the power first with all running and then throw off the machine to be measured and get the power now required. The difference will be the power of the tool. Of course, as with the indicator method, if the machine is small compared with the others run with it by the motor, the measurement will not be so accurate.

If the machine is not already driven by a motor, it is not difficult to arrange it temporarily to be operated by one, when the measurements can be taken as above.

Example.—With a direct current motor driving a line of shafting and a printing press the following readings are taken at intervals of 10 seconds. Ammeter: 22.5, 22.0, and 21.5 ampères. Voltmeter: 224, 222, and 220 volts. The average number of volts is 222, and the average number of ampères is 22. The power is 222 × 22, or 4884 watts. With the printing press not running the average number of volts is 223 and of ampères 10, and the power is 2230 watts. The power required to drive the press is, therefore, 4884 less 2230, or 2654 watts, and the horse-power is 2654 ÷ 746, ut 3½ H. P.

alternating current is used, it is necessary to have a watt- stead of the ammeter and voltmeter, as with such cur- product of ampères and volts divided by 746 does not rse-power.

ony brake is used to measure the power developed by , water-wheel, electric motor, gas engine, etc., in any the power need not be transmitted to any tools or t can be absorbed in the measurement. It consists, sketch, of two blocks of soft wood fitting a pulley the motor to be measured, and is so arranged that by tightening p on bolts they may be made to grip the pulley more tightly. ne of the blocks has an extension arm, from which is hung a pan carry weights, or else a spring balance, which is preferable. As he screws are tightened up the blocks with arm and weights end to be carried around with the pulley, but weights are added o prevent this and the arm is kept balanced in a horizontal position.

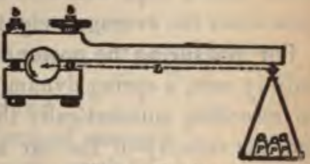
Measure the diameter of pulley, which we will suppose to be 2 feet; the distance from centre of shaft to point of suspension of the weights, which we will call 4 feet. Notice what weight, say 20 pounds, is in the pan and also the number of revolutions per minute of the pulley, which we will assume to be 200.

The principle of the method is simple if we remember the principle of moments discussed in Chapter I., and also that the

$$\text{horse-power} = \frac{\text{work in foot pounds per minute}}{33000}, \text{ or equals}$$

$$\frac{\text{force in pounds} \times \text{feet per minute through which it is exerted}}{33000}.$$

The arm is balanced between the action of two forces, one due to the friction of the motor-pulley on the block, which tends to rotate the arm in a direction opposite to the movement of the hands of a watch; the other due to the weight of the arm and weight in the pan. We will for simplicity consider that the weight of the arm is so small that it can be neglected. Taking moments about the centre of the shaft we have force of friction × radius of pulley = weight × distance L, therefore the force $= \frac{\text{weight} \times \text{L}}{\text{radius}}$, and this force is exerted by the motor, and is the total force exerted by the *motor, as no other* work is being done by it. The *number of feet per minute* through which this force is exerted is



Prony Brake.

[illegible] of the pulley in feet (3.14 × 2) multi- [illegible] per minute (200), [illegible] from the test

[illegible] 44 horse-power.

[illegible]

[illegible] the length of lever from centre [illegible] the number of revolutions per [illegible] the product by 33,000.

If the length of arm be made 5 feet 3 inches, the rule is simplified [illegible] to read, multiply the weight by the number of revolutions per minute and divide by 1000.

In using the brake the surface of the blocks should be well greased. In special cases, where this brake is much used, the pulley is made hollow and a stream of cooling water is made to run through it for the purpose of carrying off the heat that is developed. As mentioned above, a spring balance may be employed instead of weights. Another device is to have the arm put on so that its outer end tends to go down instead of up, and [illegible] by means of a stiff stick on the platform of a scales, [illegible] kept balanced by the sliding weight. In either of [illegible] weight is employed in the calculation.

In measuring the power required by vehicles, such as street or [illegible] used, with an arrangement [illegible] spring at each minute [illegible] From these two readings [illegible] the above. In the [illegible] can be made by [illegible] balance is inserted [illegible] and readings [illegible] observations [illegible] the average [illegible] the average [illegible]

QUESTIONS.

Of what elements are all machines made up?

What do machines do?

What is mechanics?

What is force?

What different kinds of force exist?

What is the unit of force?

Define inertia.

Give the laws of motion.

What is "perpetual motion," and why is it impossible?

What are the different kinds of motion?

Define velocity.

What is the difference between velocity and acceleration?

What is the relation between the velocity of a freely falling body and the height from which it has fallen?

Define mass.

What is the relation between the weight of a body and its mass?

Is its weight at different parts of the earth the same?

Is its mass always the same?

What is its relation to force and acceleration?

What is momentum?

What is energy?

How is energy related to force?

How many kinds of energy are there?

What are some of the principal forms of energy?

Whence comes all of the energy on the earth?

State, in a general way, the transformations of energy which occur in the production of mechanical power by means of the steam-engine.

Can we create or produce energy?

Can we produce force?

What is power?

What is the *difference between* power and energy?

Define a horse-power?

What is a moment or statical moment?

When two forces are acting in opposite directions upon a pivoted body how can we tell in what way the body will move?

What are the three classes of levers?

How does the wheel and axle differ from a lever?

With a single pulley do we gain any force?

With a set of pulleys how is it that a large weight can be raised by a small force?

Give the rule for the gain in force by using a wedge.

What other mechanical element does the screw resemble?

What are the principal methods of transmitting power?

Why is shafting now made of steel instead of iron.

In proportioning shafting what two requirements must be satisfied?

What are the advantages of belting over toothed gears for the transmission of power?

What are the advantages and disadvantages of rubber belts over leather?

What is a common rule for determining the width of belt to transmit a certain horse-power?

Why will a certain size belt 30 feet long transmit more horse-power than the same belt 20 feet long?

Why do the rules of different authorities for the calculation of width of belts differ so much from one another?

What advantage has rope driving over belt transmission?

What are the two general methods of using ropes?

What is the pitch of a gear wheel?

Define the thickness of a tooth.

Define backlash.

What are spur gears, and for what used?

How is pitch measured with bevel gears?

For what are friction clutches used?

On what general principle do they operate?

What are the advantages of pneumatic transmission of power *over other methods?*

Why are air compressors usually made duplex, or rather compound?

What is the advantage of the intercooler?

Why is the capacity of compressors less at high altitudes?

For what are receivers used?

How does the efficiency of air motors compare with that of electric motors?

Generally speaking, where are alternating current systems used for transmitting power?

What type of direct current motor is generally required for driving tools?

What is the advantage of using a 500-volt system rather than a 220-volt system?

What disadvantages occur to you?

What requirement determines the size of wire connecting generator and motor?

When several motors are supplied by one generator, is the generator size necessarily equal to the sum of the motor capacities?

For what purpose is a lubricant used?

What are the requirements for a good oil?

Describe an oil filter.

What is an oil separator, and on what principle does it operate?

Describe a system for automatic oiling.

What are the common methods of measuring power?

Which is the most accurate?

What instruments are needed in the electrical method, using direct currents?

Are these suitable when alternating currents are used?

Describe the Prony brake and its use.

What is the usual length of the lever arm, and why?

What is a dynamometer?

For what purpose is a spring dynamometer used?

How is the motion of a body down an inclined plane calculated?

What is the unit of work?

What are the six mechanical elements?

Give the rule for finding the diameter of a shaft to transmit a certain number of horse-power at a certain speed.

What is the objection to having belts run vertically?

What is the rule for determining the length of an open belt?

What is the rule for a crossed belt?

How would you measure the length of a belt coiled up?

When idlers are used in rope-driving what precautions should be taken in arranging them?

At what speeds do the ropes ordinarily travel?

How would you find the diameter of a driven-pulley to run at a certain speed, if you have given the diameter and number of revolutions of the driver?

What is the rule for finding the number of revolutions of a driven pinion when the number of revolutions of the driver is given and the number of teeth in each wheel?

How is the pressure in a pneumatic transmission regulated?

Give some figures showing the number of cubic feet of air used by air-motors for each horse-power-hour.

PART II.

HEAT, FUEL, GASES, WATER, AND STEAM.

CHAPTER IV.

HEAT.

According to the dynamical or mechanical theory, heat is the esult of motion among the atoms of matter, or, as it may be therwise stated, of inter-atomic movement; and this motion is apable of being propagated through space, from one body to nother, by undulations of a so-called ether assumed to be everyhere existent in the universe.

The relative effect of such heat producing motion, or, in other ords, the relative proportions of heat required to cause given ffects, may be accurately indicated by numbers, just as if heat ere a ponderable agent; and it is usual to speak of heat as if it ere an independent material substance: thus, it is said to be volved, or emitted, radiated, conducted, absorbed, and stored up, r accumulated. As a variable amount of the heat evolved in he combustion of a body is absorbed in the work of effecting lterations in the physical condition of the combustible elements ecessary to their effective oxidation, it is impossible to estimate he absolute quantity of heat evolved by the combustion of a ody; yet the relative quantities of heat evolved by the comustion of different bodies which may be utilized, can be accurately etermined.

One of the remarkable effects of the application of heat to atter is, *that the same amount* will affect equal weights of dis*ilar kinds in different degrees.* Thus, the amount of heat that will raise 1 lb. of water from 100° to 200° Fah, will raise 30 lbs. of mercury through the same range. The amount that will raise 1 lb. of water 1°, will raise 14 lbs. of air.

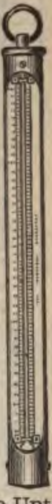
The capacity of a body for heat is termed its *specific heat*, and may be defined as the number of units of heat necessary to raise the temperature of 1 lb. of that body 1° Fah.

The thermal unit, or unit of heat, as it is termed, is the quantity of heat that will raise 1 lb. of pure water 1° Fah., or from 39° to 40° Fah.

Temperature is a measure, not of the amount of heat in a body, but of its tendency to give up its heat to other bodies. There is the same difference between temperature and heat as exists between pressure and work or energy. Heat corresponds to and is a form of energy. Temperature corresponds to pressure or force. Two bodies may be at the same temperature and yet possess very different quantities of heat. For example, a cubic inch of iron and a cubic foot of iron may both be put in the same oven, and after remaining there for a considerable time they could both be at the same temperature. The hand placed on each would feel that both were equally hot, and a thermometer laid on each would give the same reading, and finally, if they were placed so as to touch neither would give any heat to the other. But the cubic foot has 1728 times as many units of heat as has the cubic inch, as could be proved by putting the cubic foot in a tub of water containing 1728 pounds, and the cubic inch into a tub containing one pound. The rise in temperature would be the same in the two tubs. That is, the cubic foot raises the temperature a certain number of degrees, of 1728 times as much water as does the cubic inch; it has therefore 1728 times as many heat units.

The thermometer is the instrument used for measuring temperatures, and it depends upon the principle that liquids expand under the action of heat. While for a standard use is made of *the air thermometer*, yet for common use the mercury thermometer *is employed. It consists* of a bulb and glass stem of uniform sufficient quantity of mercury having been introduced, led to expel the air and moisture, and the tube is then ally sealed. The properties of mercury which render it le to all other liquids are these: it supports, before it re heat than any other fluid, and endures a greater cold ld congeal most other liquids.

The standard points are ascertained by immersing the thermometer in melted ice and in the steam of water boiling under the pressure of 14·7lbs. on the square inch, and marking the positions of the top of the column. The interval between those points is divided into the proper number of degrees,—100 for the Centigrade scale, 180 for Fahrenheit's, and 80 for Reaumur's.


The Uptake Thermometer.

The word "zero" is of Arabic origin, and means empty; hence nothing. Absolute zero is a temperature which is fixed by reasoning, although no opportunity ever occurs for observing it. It is the temperature corresponding to the disappearance of gaseous elasticity; or, in other words, the point where gas would become a solid, as where water becomes ice. This temperature is called zero in reference to all the gases, and the positions of the absolute zero on the scales would be


twell
neter.

umur's scale	219·2 below 0°
tigrade	273.1 "
hrenheit	461·22 "

for Comparing Degrees of Temperature Indicated by Dif- hermometers. 1. *Multiply* degrees of Centigrade by 9 and y 5; or *multiply* degrees of Reaumur by 9 and divide by 4. *to the quotient in either* case, and the sum is degrees Fahrenheit. 2. From degrees of Fahrenheit *subtract* 32; *multiply* th remainder by 5, and *divide* by 9 for degrees Centigrade; or *mu* *tiply* by 4, and *divide* by 9 for degrees Reaumur. The abbreviation for Fahrenheit is "Fah." or "F."; for degree, °.

TABLE FOR CHANGING FROM CENTIGRADE TO FAHRENHEIT DEGREES.

°F	°C	°F	°C	°F	°C	°F	°C
−40	−40	194	90	428	220	662	350
−31	−35	203	95	437	225	671	355
−22	−30	212	100	446	230	680	360
−13	−25	221	105	455	235	689	365
− 4	−20	230	110	464	240	698	370
5	−15	239	115	473	245	707	375
14	−10	248	120	482	250	716	380
23	− 5	257	125	491	255	725	385
32	0	266	130	500	260	734	390
41	5	275	135	509	265	743	395
50	10	284	140	518	270	752	400
59	15	293	145	527	275	761	405
68	20	302	150	536	280	770	410
77	25	311	155	545	285	779	415
86	30	320	160	554	290	788	420
95	35	329	165	563	295	797	425
104	40	338	170	572	300	806	430
113	45	347	175	581	305	815	435
122	50	356	180	590	310	824	440
131	55	365	185	599	315	833	445
140	60	374	190	608	320	842	450
149	65	383	195	617	325	851	455
158	70	392	200	626	330	860	460
167	75	401	205	635	335	869	465
176	80	410	210	644	340	878	470
185	85	419	215	653	345	887	475

For temperatures intermediate between the values in the abo table proceed as follows: Suppose we want to know what te perature Fahrenheit corresponds to 92° C.

From the table above, 90° C. corresponds to 194° F.
" " below, 2° C. " 3.6° F.
Adding, we have......92° C. " 197.6° F.

Or suppose we want to know what temperature centigrade corresponds to – 32° F. or 32° below zero.

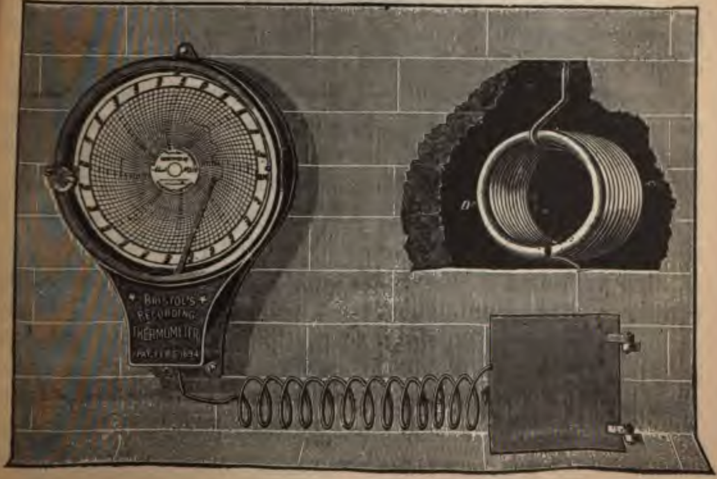
From the table above, – 31° F. corresponds to – 35° C.
" " below, 1° F. " .555° C.
Subtracting, we have – 32° F. " – 34.445° C.

Equivalent Values of Fahrenheit and Centigrade Degrees.—

1° C. = 1.8° F.
2° C. = 3.6° F.
3° C. = 5.4° F.
4° C. = 7.2° F.
5° C. = 9.0° F.

1° F. = 0.555° C.
2° F. = 1.111° C.
3° F. = 1.667° C.
4° F. = 2.222° C.
5° F. = 2.778° C.
6° F. = 3.333° C.
7° F. = 3.889° C.
8° F. = 4.444° C.
9° F. = 5.000° C.

Recording Thermometers.—The ordinary mercury thermometer is not capable of recording the rise and fall of the mercury



column, or that in recording instruments the expansion or ch of shape of a metal tube is employed instead of mercury. motion due to expansion is multiplied so as to give the nee considerable movement for a very slight change in the sha the tube. The cut illustrates one form of this instrument, w

is made like a steam-gauge. coiled hollow spring carrying pointer is connected by a pipe w coiled tube placed at the point w temperature it is desired to mea The tube is filled with alcohol, if the coil D is heated the alcoh panding puts an increased pressu the hollow coil in the instrument increases the reading of the ne The record is made by a special carrying fluid, which rests up paper dial carried on a metal which is made to turn by a c work. The dial being marked of hours and *parts of hours*, the tracings of the pen give a r of the variation of temperature throughout the day.

Pyrometers are instruments used for measuring very temperatures, such as 600° F. and upward, the mercury mometer not being available much above 600° F., as the v ization point is 675° F. The Chatelier pyrometer is an trical circuit, a junction of platinum and iridium, contain an iron tube. The tube is thrust into the place whose te ature it is desired to measure, and the junction attains the e of the place. This causes an electric pressure to b circuit proportional to the temperature, and this asured on a galvanometer in the circuit. The in ing previously been tested in a temperature within e standard thermometer and the reading of the stan , of the galvanometer having been noted, a comparis the reading of the galvanometer at any time with its standard reading will give the temperature of the chamber in which it is placed.

Color is a rough indication of temperature. For example, in heating up a bar of iron it commences to show color at about 1000° F., it is cherry-red at about 1700° F., orange at about 2200° F., and white at about 2500° F.

The effect of the application of heat to a body is to expand it [except in the case of a few substances, like water, at certain temperatures near their point of solidification], and the amount of expansion for each degree rise in temperature is quite regular and is called the coefficient of expansion. Gases expand $\frac{1}{492}$ of their volume at 32° F. for each degree F. of rise in temperature, and it is for this reason that the idea of an absolute zero of temperature has arisen. For gases of course contract $\frac{1}{492}$ of their volume for each degree the temperature falls. There would be then such a temperature that the volume would be zero and this temperature is called the absolute zero, it being 492° F. below freezing point, or −460° F.

For solids the *linear coefficient of expansion* or increase in length for one degree rise in temperature is usually of more value than the change in volume or cubical expansion. The cubical expansion equals three times the linear expansion.

COEFFICIENTS OF LINEAR EXPANSION OF SOLIDS.

Aluminum	.0000123	Masonry, brick	.0000025 .0000050
Brass, cast	.0000096	Plaster, white	.0000092
" plate	.0000105	Platinum	.0000048
Bronze	.0000099	Porcelain	.0000020
Cement, Portland	.0000059	Silver	.0000108
Concrete	.0000080	Slate	.0000058
Copper	.0000089	Steel, cast	.0000064
Glass, flint	.0000045	" tempered	.0000069
Gold	.0000079	Stone, sandstone	.0000065
Iron, wrought	.0000065	Tin	.0000116
" cast	.0000056	Wood, pine	.0000028
Lead	.0000157	Zinc	.0000141
Marble, between	*.000030* *.000080*		

COEFFICIENTS OF CUBICAL EXPANSION OF LIQUIDS.

Alcohol	.00061	Nitro-benzine	.00044
Benzine	.00077	Olive oil	.00041
Carbon bisulphide	.00082	Petroleum, sp. gr. = 85	.00055
Ether	.00012	Salt water, 1.6 p. c. solution	.00059
Hydrochloric acid	.00027	Sulphuric acid	.00027
Mercury	.00010	Turpentine	.00058

MELTING POINTS OF SOLIDS.

Owing to the difficulty of accurately determining the exact moment of melting the values given by different observers vary. Those in the table are an average of the best results.

Aluminum	1160°F.	Nickel	2732°F.
Antimony	815	Pitch	91
Bismuth	515	Platinum	3150
Brass, yellow	1850	Silver	1740
Copper	2000	Spermaceti	120
Gold	1975	Steel	2480
Glass	2380	Stearine	120
Iridium	3940	Stearic acid	160
Iron, pure	2975	Sulphur	240
" white pig	1970	Tallow	90
" gray	2190	Tin	445
Lard	95	Zinc	780
Lead	620	Wax	150
Mercury	−37.3		

BOILING POINTS OF LIQUIDS AT ATMOSPHERIC PRESSURE.

Acetic acid	248° F.	Linseed oil	600°F.
Alcohol	173	Mercury	670
“ wood	151	Naphtha	186
Ammonia, liquefied	− 37.3	Nitric acid	187
“ water	140	Petroleum, refined	316
Benzine	177	Sulphur	830
Chloroform	142	Sulphuric acid	613
Carbon bisulphide	118	Turpentine	313
Coal tar	325	Water, pure	212
Ether	96	“ sea	213
Glycerin	554	“ saturated brine	225
Hydrochloric acid (sol.)	230		

NOTE.—The temperature at which boiling takes place rises if the pressure s increased and is less if the pressure is less, so that on high mountains, as, or instance, 10,000 feet above sea level, the boiling point of water is 193° F. Roughly speaking water boils at 1° less for every rise in height above sea evel of 550 feet.

The mechanical equivalent of heat is the amount of work performed by the conversion of one unit of heat into work, and the *mechanical theory* of heat is based on the assumption that heat and work are mutually convertible.

The method by which the mechanical equivalent is determined is quite simple. A centrifugal churn is turned by an electric motor, the churn being jacketed with non-conductors of heat, so that the least possible heat is carried off by the outside air. A certain number of pounds of water, say 50, are put in the churn and the temperature, which we will suppose to be 60° F., is carefully measured. At a certain time the motor is started and run, say, 60 minutes, the ampères 1.628 and volts 100 being carefully noted, and also the temperature at the end of the 60-minutes' run, which we will suppose to be 70° F.

The power delivered to the motor is 1.628 × 100 Watts, or $\frac{1.628 \times 100}{746} = \text{H. P.}$ As the work in $\frac{\text{foot pounds per min.}}{33000} = \text{H.P.}$, we have the number of foot pounds of energy given to the motor equal to 432222, and if the efficiency of the motor is 90 per cent. the energy in foot pounds given to the water in the churn, and all used in heating it, is 90 per cent. of 432222 or 389000. This heat raised 50 pounds of water, 10° F., and therefore 500 heat units were produced, which were the exact equivalent of the 389000 foot pounds supplied the churn. Therefore the mechanical equivalent of one heat unit is 389000 ÷ 500, or 778 foot-pounds of work. Of course, in the many experiments which have been carried on to determine the value of the mechanical equivalent great refinements in the methods have been introduced which do not have any place in this volume.

The transference of heat from one body to another takes place of the relative value of materials. The first nine, while excellent non-conductors, are unsuitable, as they are liable to become carbonized and ignited from contact with hot pipes.

Substance 1 inch thick. Heat applied, 310° F.	Pounds of Water heated 10° F., per hour, through 1 square foot.	Solid Matter in 1 square foot 1 inch thick, parts in 1000.	Air Included, parts in 1000.
1. Loose wool	8.1	56	944
2. Live-geese feathers	9.6	50	950
3. Carded cotton wool	10.4	20	980
4. Hair felt	10.3	185	815
5. Loose lampblack	9.8	56	944
6. Compressed lampblack	10.6	244	756
7. Cork charcoal	11.9	53	947
8. White-pine charcoal	13.9	119	881
9. Anthracite-coal powder	35.7	506	494
10. Loose calcined magnesia	12.4	23	977
11. Compressed calcined magnesia	42.6	285	715
12. Light carbonate of magnesia	13.7	60	940
13. Compressed carbonate of magnesia	15.4	150	850
14. Loose fossil-meal	14.5	60	940
15. Crowded fossil-meal	15.7	112	888
16. Ground chalk (Paris white)	20.6	253	747
17. Dry plaster of Paris	30.9	368	632
18. Fine asbestos	49.0	81	919
19. Air alone	48.0	0	1000
20. Sand	62.1	527	471
21. Best slag wool	13.		
22. Paste of fossil meal with hair	16.7		
23. " " " asbestos	22.		

Cooling of Liquids and Solids.—The quickness with which a solid body cools in a liquid is approximately the same, whether it be placed near the surface or near the bottom. It is slightly less when the body is brought immediately under the surface. The nature of the external surface of the cooling body has but little influence. The velocity of cooling increases very considerably for the same body immersed in the same liquid with increasing temperature of the latter. If the cooling power of water be taken at 1, that of alcohol is equal to 0.56; mercury, 2.07; sulphate of copper, 1.03, and common salt, 1.05.

Latent Heat.—When heat is applied to a liquid its temperature, as indicated by a thermometer suspended in it, rises steadily, *and the product of its rise in temperature multiplied by its specific heat will equal the number of heat units applied to it.* A ches a point where vapor is given off, and, although heat ing added to it, the temperature no longer rises, but onstant till all of the liquid has been changed into vapor. which goes to change the state of the substance from liquid to that of a gas, and which does not show itself on nometer, is called latent heat. After all the liquid o vapor any further addition of heat raises the tempera- e vapor.

ent heat of vaporization of any substance is the number nits needed to change one pound of the substance from a a gaseous condition at a given atmospheric pressure.

IEAT OF VAPORIZATION.		Ether	164.
	965.	Acetic acid	152.8
	376.	Carbon disulphide	150.8
od	475.	Turpentine	133.
	167.	Mercury	111.6

Heat of Fusion.—When a solid is heated a similar curs, the temperature rising till the melting-point is and after that remaining constant till all is melted, ch it rises again if heat is still added. The heat neces- hange one pound from the solid to the liquid state at ric pressure is called the latent heat of fusion. The table values of the latent heats for several substances at a press- e atmosphere:

NT HEAT OF FUSION.		Cast iron	41.4
	175.	Silver	37.9
	148.	Tin	25.7
	142.6	Bismuth	22.7
	97.2	Sulphur	16.8
	50.6	Lead	9.7
	48.9	Mercury	5.1

eat of the liquid at any temperature is the number of s required to raise one pound of the substance from ng-point to that temperature.

tal heat at *any temperature* is the sum of the heat of the *hat temperature plus* the latent heat of vaporization.

grain of soot, if distributed evenly in fine particles throug cubic foot of steam, would color it blacker than the ace of spa Too much air produces smoke, even though it brings oxyge the fuel, for it tends to lower the temperature of the carbon be its igniting-point and thus prevents its complete combustion.

To ensure complete combustion it is necessary to have a ficient supply of air, to thoroughly mix the combustible air, and to have the combustible and the air maintained sufficiently high temperature. The higher the temperatur which the materials are fed to the fire the more perfect will the combustion.

The following table shows the number of heat units produ by the complete combustion in air of one pound of the substa

HEAT OF COMBUSTION.

Acetylene	20420	Gas, coal	9440 – 1
Alcohol	12930	" illuminating	9360 –
" wood	9560	Gunpowder	1300 –
Benzine	17960	Hydrogen to steam at 212°	5
Carbon to carbonic acid	13950	" to water at 32°	6
" disulphide	5840	Lard oil	16560 – 1
Carbonic oxide	4290	Olive oil	16790 – 1
Dynamite (75 per cent.)	2320	Petroleum	1

Spontaneous combustion.—This mysterious phenomenon attracted at different times the attention of chemists and ph ophers, and many theories have been advanced to account fo development. Galletly, who investigated the subject, found cotton-waste soaked in boiled linseed-oil, and wrung out, if exp to a temperature of 170°, set up oxidation so rapidly as to c actual combustion in 105 minutes. Coleman also instituted a extensive series of experiments upon fragments of cotton, li jute, and woollen waste saturated with oils of different nature

he theory which attributes spontaneous combustion to ce of pyrites in the coal, may partially account for *ed number of* fires; but Richter has shown that, for *oals experimented* upon, those which contained the es were not the most subject to spontaneous combustion. rding to him, air is rapidly absorbed by the coal, and the en of the air then combines with the organic components to uce carbonic acid and develop heat. According to all probties, however, the heat which determined the spontaneous bustion is due both to the oxidation of the iron and to that e carbonized matters. This confined in badly-ventilated holds dily reaches a temperature sufficiently high to produce comion.

hat most of the bituminous coals (English and American) are ect to spontaneous combustion when in bulk, and under favor- circumstances, has long been known. Experiments by Greennn have also proved conclusively that an exposure of bituous coal in heaps to the action of the weather for a period ying from two weeks to a year results in a large percentage of . This loss is in the nature of a slow or incomplete combus-; it is greater and more rapid in large heaps than in small, is also favored by the greater or less state of subdivision of coal, large fragments losing proportionably less than smaller s. The loss varies from 5 to 25 per cent.

he higher the temperature the more rapid is the combustion. heat around the coal-bunkers of steamships must necessarily very great, from their close proximity to the boilers and fures; and in sailing-ships containing large quantities of these ls in bulk, taken on board mostly wet, the generation of heat he point of ignition seems to be only a question of time. The phur and volatile matter in bituminous and hydrogenous coals the active agents in spontaneous combustion, and the finer the ticles the more favorable is the condition for producing that ult. The large number of disasters, which have occurred from spontaneous combustion of bituminous coals on board of steamps and sailing-vessels, has called public attention to the matter. though the manner by which bituminous coal stored in vessels comes ignited is not *yet determined*, it has been demonstrated *t the conditions for the work of* spontaneous combustion exist wherever large bodies of bituminous coal are stored in close compartments.

From the foregoing considerations, it would seem that, when spontaneous combustion takes place among coals or other substances, drowning out with water is not always effective; as, though it extinguishes the fire, it leaves in the coal a condition of things very favorable to a renewed ignition at any moment. A terrible explosion of coal-gas recently occurred on board of a steamship in Liverpool, by which fourteen men were injured, some of them seriously, in consequence of a quantity of wet coal having been placed in the bunkers and the hatches closed.

Fuel.

The word fuel is used to denote substances which may be burned by means of atmospheric air with sufficient rapidity to evolve heat capable of being applied to economical purposes. Fuel consists either of vegetable matter or of the products of the natural or artificial decomposition of such matter. Vegetable matter, which consists principally of woody tissue, is composed of carbon, hydrogen and oxygen, comprising the organic part, and a small proportion of so-called earthy matter, that which is inorganic. The sun is the source of the heat-producing power of fuel, since the organic parts are derived from water, and, except in particular cases, from the carbonic acid of the atmosphere, which are decomposed in the economy of plants by the action of solar light.

The principal fuels used in the production of steam are coal, coke, wood, petroleum, natural gas, peat, and refuse of various kinds, either animal or vegetable. These fuels are all made up of carbon and hydrogen, while most of them contain in addition oxygen, nitrogen, and sulphur, with traces of mineral substances. The carbon is the principal heat-producer and the hydrogen comes second, none of the other elements being of any value in the production of heat. In the process of combustion the carbon burns carbonic acid, the hydrogen to water, the sulphur to sulphurous the minerals to ashes, the nitrogen remains unchanged and xygen unites with the hydrogen to form steam.

lrogen in fuel must always be in association with carbon, but practically free from hydrogen may be procured abun- and applied as fuel. In all fuel containing carbon, hydrogen, ygen, the proportion of hydrogen may be equal to or greater, ver less, than that required to form water with the oxygen. nly the hydrogen in excess of this which is available as a of heat, so that, in the combustion of a substance whose ition is represented by carbon and water, the carbon alone ource of heat. The hydrogen existing in combination with in the state of water, so far from contributing to the actual of heat produced, must be evaporated at the expense of t developed by the combustion of the carbon.

compare different fuels, and assign them a value for heat- rposes based on their chemical constitution, we will find troleum is about 25 per cent. superior to all others theoret- in round numbers, it is capable of evaporating 15 lbs. of per pound of fuel, while a pound of anthracite coal can ate 11 lbs., and a pound of coke only about 9 lbs.; these varying, to a certain extent, with the different qualities of ls.

chemical properties of coal are, free carbon, hydro-carbons, r oxygen, and hydrogen, with solid matter termed ash; the tions of these vary considerably. In some instances, the atter is 25 per cent., while with superior coal, only 6 or 10 t. The products of combustion are carbonic acid gas, ni- air, ashes, and steam.

oxygen necessary for the combustion of coal is derived e atmosphere. One pound of carbon in combustion unites 66 lbs. of oxygen, and the product is 3·66 lbs. of carbonic as. From the above it will be seen that to the 2·66 lbs. gen 11 lbs. of air would have to be brought into contact e pound of coal (if *pure carbon*) to render its combustion complete; but, as coal contains hydrogen, it is found that instead of 11, 12 lbs. are required.

Carbon.—Vegetables, when burnt or distilled in close vessels till their volatile parts are entirely separated, leave a black, brittle and cinereous substance which constitutes the greater part of the woody fibre, and is called *charcoal*. Charcoal contains a portion of earthy and saline impurities, but, when entirely freed from these and other impurities, a solid, simple, combustible substance remains, which is called carbon. Carbon exists naturally in a state of greater purity than can be prepared by art. The diamond is pure carbon crystallized, and when pure is colorless and transparent. It is the hardest substance known; and, as it sustains a considerable degree of heat unchanged, it was formerly considered to be incombustible. It may, however, be consumed by a burning-glass, and even by the heat of a furnace. The difficulty of burning it appears to arise from its hardness; for Morveau and Tennant have rendered common charcoal so hard, by exposing it for some time to a violent fire in close vessels, that it endured a red heat without catching fire. Common charcoal contains only 64 parts of diamond, or pure carbon, and 36 of oxygen in every 100.

The common charcoal of commerce is usually prepared from young wood, which is piled up near the place where it is cut in conical heaps, covered with earth, and burnt with the least possible access of air. When the fire is supposed to have penetrated to the centre of the thickest pieces, it is extinguished by entirely closing the vents. When charcoal is wanted very pure, the product of this mode of preparing it will not suffice; for the manufacturing of the best gunpowder, it is distilled in iron cylinders. Chemists prepare it in small quantities in a crucible covered with sand, and after they have thus prepared it, they pound it, and
way the salts it contains by muriatic acid; the acid is re-
he plentiful use of water, and afterwards the charcoal
a low red heat. Pure charcoal is perfectly tasteless
in water.

wly prepared absorbs moisture with avidity. It

orbs oxygen and other gases, which are condensed in its
quantity many times exceeding its own bulk, and which
n out unaltered. Fresh charcoal allowed to cool without
e to air, and the gas then admitted, will absorb 2.25 times
of atmospheric air immediately, and 75 per cent. more
or five hours; of oxygen gas about 1.8 immediately, and
1 more; of nitrogen gas, 1.65 immediately.

following table (from D. K. Clark) gives the relative val-
everal combustibles, with perfect combustion. In practice
re than 60 to 70 per cent. of the evaporative effects will be
l. The coal is English coal, and gives a higher value than
an coals.

HEAT EVOLVED BY VARIOUS FUELS AND THEIR EQUIV-
ENT EVAPORATIVE POWER, WITH THE WEIGHT OF OXYGEN
D VOLUME OF AIR CHEMICALLY CONSUMED.

FUEL.	Weight of Oxygen Consumed per lb. of Fuel.	Quantity of Air Consumed per lb. of Fuel.		Total Heat of Combustion of 1 lb. of Fuel.	Equivalent Evaporative Power of 1 lb. of Fuel from and at 212°.
	Lbs.	Lbs.	Cu. ft. at 62°.	B. T. U.	Lbs.
n	8.0	34.8	457	62000	62.40
..{ Making Carbonic Acid.	2.66	11.6	152	14500	15.0
....	1.00	4.35	57	4000	4.17
erage dessicated.	2.45	10.7	140	14700	15.22
" "	2.49	10.81	142	13548	14.02
perfect	2.04	8.85	116	13108	13.57
....	2.74	11.85	156	17040	17.64
dessicated	1.40	6.09	80	10974	11.36
per cent. moisture	1.05	4.57	60	7951	8.20
5¾ per ct. moist.	0.98	4.26	56	8144	8.43
m	3.29	14.33	188	20411	21.13
m Oils	4.12	17.93	235	27531	28.50

tive Value of Coal.—The tables on pp. 106, 107, taken from
s," give the constituents and number of pounds of water
ated per pound of coal. These values are the theoretically
e values, and in practice not over 70 per cent. is liable to
ined.

[illegible] AMERICAN COALS.

	Constituents Per Cent by Weight					Fuel Value Per Lb. of Coal		
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	B.T.U. Calculated	B.T.U. by Calorimeter	Theoretical Evaporation in lbs. from and at 212°
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13772		14.1
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		12812	12.22
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		11756	12.17
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		11907	12.32
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.65		12537	12.97
[illegible]						9215		9.54
[illegible]	[illegible]	[illegible]	[illegible]	8.02	2.11	12964		14.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14420		14.9
[illegible]						13560		14.04
[illegible]						13565		14.35
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8500		8.50
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]	8.25				
[illegible]								
[illegible]	[illegible]	[illegible]	[illegible]	10.46	0.98		11468	11.87
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		11529	11.93
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		11791	12.19
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12567		13.0
[illegible]						13025		13.43
[illegible]	[illegible]	[illegible]	[illegible]	18.52			9848	10.19
[illegible]		[illegible]	[illegible]	[illegible]	1.20		9035	9.35
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		10143	10.50
[illegible]		[illegible]	[illegible]	[illegible]			9401	9.73
[illegible]		[illegible]	[illegible]	[illegible]	0.31		10710	11.08
[illegible]		[illegible]	[illegible]	[illegible]	2.32	12175		12.60
[illegible]		[illegible]	[illegible]	[illegible]	1.45		9739	10.09
[illegible]		[illegible]	[illegible]	[illegible]	3.49		9954	10.30
[illegible]		[illegible]	[illegible]	[illegible]	5.10		10269	10.63
[illegible]		[illegible]	[illegible]	[illegible]	3.27		10332	10.69
[illegible]		[illegible]	[illegible]	13.33	4.30	11723		12.10
[illegible]		[illegible]	[illegible]	[illegible]	2.39	11479		11.9
[illegible]						13123		13.58
[illegible]						12659		13.10
[illegible]		[illegible]	[illegible]	[illegible]	3.53	11763		12.2
[illegible]		[illegible]	[illegible]	[illegible]	4.42		10395	10.76
[illegible]		[illegible]	[illegible]	[illegible]	4.02	11720		12.1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.27	11406		11.8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.62		9261	9.58
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		10294	10.65
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.27		10647	11.02
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.38		10080	10.44
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.06		9765	10.10
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.83		9828	10.18
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.38		11403	11.80
[illegible]	[illegible]	[illegible]	[illegible]	4.31	0.92		10584	10.96
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.04		11245	11.63
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.32		9450	9.78
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.71		10626	11.00
[illegible]								
[illegible]	3.50	22.70	63.00	1.00	0.98	14020		14.5
[illegible]						13588		14.38
[illegible]						14146		14.64
[illegible]						13097		13.56

TABLE OF AMERICAN COALS (*continued*).

COAL.	Constituents in Per Cent of Total Weight.					Fuel Value per Lb. of Coal.		
Name or Locality.	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	B. T. U. Calculated.	B. T. U. by Calorimeter.	Theoretical Evaporation in lbs., from and at 212°.
INDIAN TERRITORY.								
Atoka	6.66	35.42	51.32	6.60	3.73		11088	11.47
Choctaw Nation	1.59	23.31	66.85	8.25	1.18		12789	13.23
IOWA.								
Good Cheer	10.85	30.32	31.38	27.45	7.32		8702	9.01
KENTUCKY.								
Caking						14391		14.89
Cannel						15198		16.76
Cannel						13360		13.84
Lignite						9326		9.65
MISSOURI.								
Bevier Mines							9890	10.24
MARYLAND.								
Cumberland						12226		12.65
George's Creek						13500		13.98
NEW MEXICO.								
Coal	2.35	35.53	50.24	11.88	0.61		11756	12.17
OHIO.								
Briar Hill, Mahoning Co.	2.47	31.83	64.25	1.45	0.56	13714		14.2
Hocking Valley	8.25	35.88	53.15	2.72	0.43	13414		13.9
PENNSYLVANIA.								
Anthracite						14199		14.70
Anthracite						13535		14.01
Anthracite						14221		14.72
Anthracite, Pea	2.04	6.36	78.41	13.19		12300		12.73
Anthracite, Buckwheat	3.88	3.84	81.32	10.96	0.67	12200		12.63
Cannel						13143		13.60
Connellsville						13368		13.84
Pittsburgh (av.)	1.50	35.34	54.94	7.92	1.97		13104	13.46
Pittsburgh Coking	1.43	30.22	61.87	6.48	1.35	14415		14.9
Youghiogheny	1.96	34.06	58.98	5.00			12936	13.39
Youghiogheny	2.02	32.14	58.96	6.88	0.88		12600	13.03
Reynoldsville	1.20	27.12	65.88	5.80			12921	13.44
TENNESSEE.								
Glen Mary, Scott Co.	2.15	31.47	61.63	4.75	0.94		13167	13.63
TEXAS.								
Ft. Worth	14.42	30.03	42.53	13.02	1.47		9450	9.78
Ft. Worth	4.00	34.72	49.27	11.41	1.56		11403	11.80
Lignite						12962		13.41
WEST VIRGINIA.								
New River						14200		14.70
New River						13400		13.87

Classification of Coals.—Rankine classifies them as follows:

1. Anthracite, consisting almost wholly of carbon.
2. Semi-bituminous coal, having 70 to 80 per cent. of carbon.
3. Bituminous, caking coal, with 50 to 60 per cent. of carbon.
4. Cannel or long flaming coal, having 75 to 85 per cent. of carbon.
5. Lignite or brown coal, having 50 to 75 per cent. of carbon.

The 2d and 3d are used most for steam coals. No. 1 is found principally in the Alleghany mountains, No. 2 in Maryland and Virginia, No. 3 in the Mississippi valley, No. 4 in Pennsylvania and Indiana, and No. 5 in Colorado and Texas.

Sizes and space occupied by coal, per ton of 2240 pounds, anthracite:

Lump	32.2 cu. ft.	Stove	34.8 cu. ft.
Broken	33.9 "	Chestnut	35.7 "
Egg	34.5 "	Pea	36.7 "

The Value of Wood as Fuel Compared with Coal.—Two and a half pounds of dry wood are equal to one pound (average quality) of soft coal, and the fuel value of the same weight of different woods is very nearly the same,—that is, a pound of hickory is worth no more for fuel than a pound of pine, assuming both to be dry. If the value be measured by the weight, it is important that the wood be dry, as each 10 per cent. of moisture or water in the wood will detract about 12 per cent. from its value as a fuel.

The weight of one cord of different woods (air-dried) is as follows:

Hickory, or Hard Maple	4500 lbs.
White Oak	3850 "
Beech, Red Oak, and Black Oak	3250 "
Poplar, Chestnut, and Elm	2350 "
Pine	2000 "

***The fuel value of* wood,** as compared with coal, is about as s:

l air-dried Hickory, or Hard Maple, equal to 2000 lbs. coal.
d air-dried White Oak equal to . . . . 1725 " "
d air-dried Beech, Red Oak, or Black Oak
al to . . . . 1450 " "
l air-dried Poplar, Chestnut, or Elm equal to 1050 " "
d air-dried Average of Pine Wood equal to 925 " "

mparative value of different kinds of wood for fuel.

bark Hickory	100	Yellow Oak	60
ıt Hickory	95	Hard Maple	59
e Oak	84	White Elm	58
e Ash	77	Red Cedar	56
Wood	75	Wild Cherry	55
Oak	73	Yellow Pine	54
e Hazel	72	Chestnut	52
e-Tree	70	Yellow Poplar	51
Dak	67	Butternut and White Birch	43
e Beech	65		
Birch	62	White Pine	30

her Solid Fuels.—Sawdust and shavings are largely used in and have an evaporative power practically the same as an weight of wood of the same state of dryness. Spent tan when dry has considerable evaporative power. The refuse gas works, known a breeze, has a high heat value, as has asse," the refuse of sugar cane. Peat, cotton stalks, straw, are also used to some extent. An approximate idea of the ve value of some of these compared to good coal is given in able below.

ORETIC EVAPORATING POWER OF SUBSTANCES FROM 212° F.

	12 lbs.	Tan (dry)	4 lbs.
eat	6 "	Cotton stalks	3 "
se	4 "	Straw	2½ "

uid Fuels—Petroleum.—The high evaporative power of leum, about 21 pounds of water per pound of fuel, has led *reat deal of experiment in* its use for making steam. It has *important advantages,* among which may be mentioned:

It is cleaner, having no ash residue, and is more easily handled, allowing a smaller number of men to handle a given horse-power of boilers. It gives a steadier fire, occupies for an equal number of heat units about two-thirds as much space as coal, and can be more readily managed in the matter of starting and stopping fires in the boiler furnace. Moreover, it makes no cinders and little or no smoke. With all these advantages it is the question of relative cost of coal and oil at different points that determines the advisability of its use at those places. Coal at about $3.00 per ton is about equal to petroleum at 2 cents per gallon, as far as the fuel cost for evaporating a pound of water is concerned. The saving of labor, etc., must be calculated for each particular case.

Composition of Petroleum.—Analyses of many different petroleums give the following as the chemical composition:

Carbon	82 to 85 per cent.
Hydrogen	11 to 15 "
Oxygen	5 to 6 "

When distilled it gives off at different temperatures different products, each having distinctive properties. Some of the more common are:

Gasolene, distilling at about	140°–160° F.
Benzine " "	160°–200°
Naphtha " "	200°–250°
Kerosene " "	350°–450°
Oils used for lubrication	450° and above.

Weight of petroleum differs with its composition, but may be taken roughly as about eight-tenths that of water.

Gaseous fuels possess many of the advantages of petroleum for use in boiler furnaces. The principal ones available are natural gas, illuminating gas, water gas, and producer gas. While the relative proportions of the chemical constituents of natural gas differ considerably in the different parts of the country where this found, yet the following tables will give a fairly close idea mposition of these gases. These tables are taken from *of Mr.* Emerson McMillan:

COMPOSITION OF GASES—VOLUME AND WEIGHT.

	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

	Natural Gas.	Coal Gas.	Water Gas.	Producer Gas.
Hydrogen	0.268	8.21	5.431	0.458
Marsh gas	90.383	57.20	1.931	1.831
Carbonic oxide	0.857	15.02	76.041	25.095
Olefiant gas	0.531	10.01	0.000	0.000
Carbonic acid	0.700	1.97	10.622	2.517
Nitrogen	6.178	3.75	3.380	69.413
Oxygen	0.666	1.43	0.965	0.000
Water vapor	0 000	2.41	1.630	0.686
Sulphydric acid	0.417	-----	-----	-----
	100.000	100.000	100.000	100.000

The comparative evaporating values have been calculated on the assumption that 20 per cent. more air entering at a temperature of 60° F. is admitted to the fire-box than would just supply the amount of oxygen necessary for perfect combustion, and also that the temperature of the gas escaping from the boiler flue is 500° F.

	Natural Gas	Illuminating Gas.	Water Gas.	Producer Gas.
Cubic feet of gas	1000	1000	1000	1000
Weights per 1000 cu. ft	45.5	32	45.5	66
Pounds water evaporated	893	591	262	115

Fuel Value Compared with Coal.—Roughly, 30,000 cubic feet of natural gas, 45,000 cubic feet of illuminating gas, 10,000 *cubic feet of water gas, and 120,000* cubic feet of producer gas *are equal in evaporating* power to one pound of good coal.

CHAPTER VI.

AIR AND OTHER GASES.

Gases.—All liquids if heated to a sufficiently high temperature reach a point at which their physical state changes, and they evaporate into the gaseous condition. In this condition most of them are colorless and without odor. They exert a pressure in all directions and are elastic to the highest degree. They are acted upon by gravity just like bodies in the liquid and solid conditions, and therefore have weight. Many substances exist naturally in the gaseous state, although they may all be liquefied by subjecting them to a sufficiently low temperature and pressure. Among the most important elementary gases are oxygen, nitrogen, and hydrogen.

Perfect gases are those which follow what is known as the law of *Boyle* or *Mariotte*, viz.: If the temperature be kept constant, the volume occupied by a gas varies inversely as the pressure put upon it. Thus when a gas is compressed into half its original bulk its pressure is double; when compressed into a third of its original bulk its pressure is trebled; when compressed into a fourth of its original bulk its pressure is quadrupled; and generally the pressure varies inversely as the bulk into which the gas is compressed. So in like manner, if the volume be doubled, the pressure is made one-half of what it was before,—the pressure in every case being reckoned from 0, or from a perfect vacuum.

Thus, if we take the average pressure of the atmosphere at 14.7 pounds on the square inch, a cubic foot of air, if suffered to expand into twice its bulk, by being placed in a vacuum measuring two cubic feet, will have a pressure of 7.35 pounds above a perfect vacuum, and also of 7.35 pounds below the atmospheric pressure whereas, if the cubic foot be compressed into a space of half a cubic foot, the pressure will become 29.4 pounds above a perfect vacuum, and 14.7 above the atmospheric pressure. The specific gravity of any one gas to that of another will not exactly conform to the same ratio under different degrees of heat, and other pressures of the atmosphere.

Law of Charles.—Perfect gases also follow this law, which is—"the volume of a gas at constant pressure is proportional to its absolute temperature;" that is, to the temperature measured above the absolute zero, which, it will be remembered, is 460° below the Fahrenheit zero. The expansion in volume for a gas for each degree rise in temperature is found to be $\frac{1}{497}$ of its volume. Therefore to find the volume at any temperature, having given the volume at any other temperature as 0° F., we have the following rule: Subtract 32 from the temperature and multiply the result by .00204. Add to this product and then multiply it by the gas at 32° F. The result will be the volume at the temperature desired.

Application of Boyle's and Charles' Laws.—Another way of expressing the two laws is, that the product of pressure by volume is proportional to the Absolute Temperature of the gas. [The absolute temperature is the temperature or number of degrees above the absolute zero.] If $p =$ the pressure at any temperature, $t°$ F., and $v =$ the volume, while $p' =$ the pressure and $v' =$ volume at some other temperature, $t'°$ F., then the above rule may be expressed as follows: $\frac{p \times v}{p' \times t'} = \frac{460 + t}{460 + t'}$. The number 460 is the number of degrees which the absolute zero is below the Fahrenheit zero.

Example.—10 cubic feet of air at atmospheric pressure and 40° F. are compressed by a pressure of 29.4 pounds per square inch, and the temperature when measured is found to be 50° F. What volume does the air now occupy? Here $p = 14.7$ pounds per square inch, $v = 10$ cubic feet, $t = 40°$ F., $t' = 50°$ F., and $p' = 29.4$ pounds per square inch. Substituting these values we have [illegible] = [illegible] = [illegible]. Solving this for v′ we have

v′ = [illegible] = 5.1 cubic feet.

The following table gives the specific gravities and weights per cubic foot of a number of gases:

Gas.		Sp. gr.	Grammes per cubic centimetre.	Pounds per cubic foot.
Air		1.000	0.001293	0.08071
Ammonia		0.597	0.000770	0.04807
Carbon dioxide		1.529	0.001974	0.12323
Carbon monoxide		0.967	0.001234	0.07704
Chlorine		2.422	0.003133	0.19559
Coal gas	from	0.340	0.000421	0.02628
	to	0.450	0.000558	0.03483
Cyanogen		1.806	0.002330	0.14546
Hydrofluoric acid		2.370	0.002937·	0.18335
Hydrochloric acid		1.250	0.001616	0.10088
Hydrogen		0.0696	0.000090	0.00562
Hydrogen sulphide		1.191	0.001476	0.09214
Marsh gas		0.559	0.000727	0.04538
Nitrogen		0.972	0.001257	0.07847
Nitric oxide, NO		1.039	0.001343	0.08384
Nitrous oxide, N_2O		1.527	0.001970	0.12298
Oxygen		1.105	0.001430	0.08927
Sulphur dioxide		2.247	0.002785	0.17386
[illegible]		0.469	0.000581	0.03627

Examples of perfect gases are Air, Oxygen, Hydrogen, and [illegible] substances in the gaseous condition when they [illegible] with the liquid from which they are produced.

Oxygen [illegible] enters into chemical combination with a [illegible] number of substances, in which it exists in a concrete

state; it is by the application of heat, or of acids, to some of
ubstances containing it, that it is usually procured in the
of gas. Oxygen gas is the only one that can be breathed by
als for any length of time with impunity. The power of at-
heric air in supporting respiration is owing to the oxygen.
gen combines with all the metals, and in this state they are
d metallic oxides, depriving them of their metallic lustre, and
g them an earthy or rusty appearance. Any of the metals
capable of combining with different proportions of oxygen.
e with one proportion are called *protoxides;* of two, (*binoxides.*)

itrogen.—Nitrogen gas is most easily described by including
y of its negative qualities. It has no taste; it unites with
gen in several proportions; it also unites with hydrogen.
ugh incapable of being breathed above its base, nitrogen is a
ponent portion of all animal substances; it is lighter than oxy-

Nitrogen gas may be variously obtained. If the oxygen be
acted from the atmospheric air, this substance will remain, and
generally be very pure, unless the oxygen has been extracted
espiration. If iron filings and sulphur, moistened with water,
ut into a jar containing atmospheric air, this gas will in a day
o be all the air that remains in the jar, as the oxygen will
bsorbed by the iron and sulphur. Phosphorus or sulphuret
me or potass, inclosed with common air in a jar, will produce
ilar effect.

drogen.—Hydrogen, like oxygen and nitrogen, is invisible,
ic, and inodorous; but the last quality it seldom possesses, be-
it is very seldom perfectly dry, and when it contains water
lution, like alkaline sulphurets, its odor is considerably fetid.
rogen with oxygen forms water; and it is by the decomposi-
of water that chemists obtain it in the greatest abundance
purity. For this purpose iron filing or turnings, or granu-
zinc, are put into a retort, and covered with sulphuric acid
ed with four times its weight in water. A violent effervescence
s, a large quantity of gas is evolved, and issuing from the
is collected in the usual manner by the pneumatic app

ratus. In this experiment the acid is not decomposed; it is the oxygen of the water with which the acid is diluted that seizes upon and oxidizes the metal, and the hydrogen, in the same portion of water being thus disengaged, passes over in the state of gas. The hydrogen obtained by using zinc is the purest, that obtained by using iron generally containing some carbon.

Hydrogen combines with a larger quantity of oxygen than any other body; its combustion, therefore, when mixed with oxygen, produces a more intense heat than any other combustion.

It is the lightest of all known substances, having a weight per cubic foot only one-sixteenth that of oxygen, one-fourteenth that of nitrogen, and one-seven-hundredths that of air.

The flow of gases under pressure is taken up under the subject of air, which acts like other gases in this respect.

Air.

The atmosphere is known to extend at least 45 miles above the earth. Its aggregate weight has been calculated at upwards of 77,000,000,000 of tons, or equivalent to the weight of a solid globe of lead 60 miles in diameter. Hence, this enormous weight reposes incessantly upon the earth's surface, and upon every object, animate or inanimate, solid, liquid, or aëriform. 100 cubic inches of air at the surface of the earth, when the barometer stands at 34 inches, and at a temperature of 60° Fah., weigh about 31 grains, being thus about 815 times lighter than water, and 11,065 times lighter than mercury. The component parts of the air are about 79 measures of nitrogen gas and 21 of oxygen; or, in other words, air consists of (by volume) oxygen, 21 parts; nitrogen, 79 parts (by weight); oxygen, 77 parts; nitrogen, 23 parts.

Now, since the air is possessed of weight, it must be evident that a cubic foot of air at the surface of the earth has to support the weight of all the air directly above it; and that, therefore, the *higher we ascend* in the atmosphere, the lighter will be the cubic *foot of air; or, in other* words, the farther from the surface of the t is at the surface; at 14 miles it is 16 times lighter; and at 21 niles it is 64 times lighter. It requires 13,817 cubic feet of air o make one pound; consequently, one cubic foot of air at the surface of the earth weighs 527 grains, or ¼ of an ounce avoirdupois; but under a pressure of 5½ tons to the square inch, air becomes as dense, and would weigh as much per cubic foot, as water.

The Barometer.

The barometer is an instrument used for observing the pressure and elasticity, or variations in density, of the atmosphere. Its essential part is a well-formed glass tube, closed at one end, perfectly clear and free from flaws, 33 or 34 inches long, of uniform bore, filled with pure mercury, and inverted; the open end being inserted in a cup partly filled with the same metal, so that the mercury in the tube may be supported by atmospheric pressure. In the more elaborate patterns the cup is made of leather arranged so that it can be raised or lowered by a milled screw so as to bring the level of mercury in the cup even with the zero on the scale. The upper end of the mercury column is read by a sighting piece carrying a vernier.

When changes in the weight of the atmosphere take place gradually they are imperceptible to human sensation; and if it were not for this instrument it would be impossible to estimate accurately atmospheric conditions. If, in fine, clear weather, a rain-storm is approaching, the increasing humidity of the atmosphere will be noted by the fall of the barometer long before it will be perceived by ordinary observers. Hence, the condition of the barometer is an indication of not only the weather at the time, but of that which is to follow during the course of several hours. It is in a constant state of variation, governed by the condition of the air. The mercury in the barometer stops falling at 30 inches at sea-level.

The pressure of the atmosphere at sea-level is 14.7 pounds per *square inch, pressing equally* in all directions. This has been ascertained from the following illustration. Because the height of a column of air of one square inch area exactly balances a column of mercury of the same area 30 inches in height, and also a column of water 33.86 feet in height, it follows that a column of air, 30 inches of mercury, and 33.86 feet of water weigh the same, and since the last two weigh respectively 14.7 pounds per square inch, a full column of air must weigh the same. A cubic foot of water evaporated under a pressure of one atmosphere, or 15 pounds per square inch, occupies a space of 1700 cubic feet.

TABLE

SHOWING THE WEIGHT OF THE ATMOSPHERE PER SQUARE INCH CORRESPONDING WITH DIFFERENT HEIGHTS OF THE BAROMETER.

Barometer in Inches.	Atmosphere in Pounds.	Barometer in Inches.	Atmosphere in Pounds.	Barometer in Inches.	Atmosphere in Pounds.
28·0	13·72	29·1	14·26	30·1	14·75
28·1	13·77	29·2	14·31	30·2	14·80
28·2	13·82	29·3	14·36	30·3	14·85
28·3	13·87	29·4	14·41	30·4	14·90
28·4	13·92	29·5	14·46	30·5	14·95
28·5	13·97	29·6	14·51	30·6	15·00
28·6	14·02	29·7	14·56	30·7	15·05
28·7	14·07	29·8	14·61	30·8	15·10
28·8	14·12	29·9	14·66	30·9	15·15
28·9	14·17	30·0	14·70	31·	15·19
29·0	14·21				

The Aneroid Barometer is a portable form and operates upon an entirely different principle. In consists of a hollow cylinder very short in proportion to its diameter, and made of very thin metal corrugated in rings concentric with the axis of the cylinder. The air is exhausted from the inside of the cylinder, and its ends are therefore pressed toward each other by the pressure of the atmosphere. The greater this pressure the more the ends are *pressed together,* and the motion produced by pressure is multi*plied and read by* a needle working over a graduated circular it is at the surface; at 14 miles it is 16 times lighter; and at 21 miles it is 64 times lighter. It requires 13,817 cubic feet of air to make one pound; consequently, one cubic foot of air at the surface of the earth weighs 527 grains, or ¼ of an ounce avoirdupois; but under a pressure of 5¼ tons to the square inch, air becomes as dense, and would weigh as much per cubic foot, as water.

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When changes in the weight of the atmosphere take place gradually they are imperceptible to human sensation; and if it were not for this instrument it would be impossible to estimate accurately atmospheric conditions. If, in fine, clear weather, a rain-storm is approaching, the increasing humidity of the atmosphere will be noted by the fall of the barometer long before it will be perceived by ordinary observers. Hence, the condition of the barometer is an indication of not only the weather at the time, but of that which is to follow during the course of several hours. It is in a constant state of variation, governed by the condition of the air. The mercury in the barometer stops falling at 30 inches at sea-level.

The pressure of the atmosphere at sea-level is 14.7 pounds per quare inch, pressing equally in all directions. This has be scientific books, generally, the n

numbers... to be 15 pounds; so th

2, 3, 4, etc., atmospheres mean

30, 60, 90, 120, etc., inches in

45, 60, etc., pounds on every

...ion. Because the heig

...on exactly balances a col

inches in height, and also a

...it follows that a column of

...feet of water weigh the same,

...vely 14.7 pounds per square

...n the same. A cubic foot of

...re of one atmosphere, or 15

...a space of 1700 cubic feet.

T... ...BLE

OF ALTITUDES ABOVE SEA-L...

PHERIC PRESSURES, DEDU...

DEN EXPEDITION TO THE

LOCATION.

Altoona, Pa.
Cairo, Ill.
Cheyenne, Wy. Ter.
Cincinnati, O.
Cresson, Pa.
Denver, Col.
Golden City, Col.
Lake Champlain
" Erie
" Huron
" Michigan.
" Ontario.
Louisville, Ky.
Mt. Lincoln, Col.
New Albany, Ind.
Ogden, Utah
Omaha, Neb.
Pike's Peak, Col.
Pittsburg, Pa.
Rock Island, Ill.
St. Louis, Mo.
Terre Haute, Ind.

...SPHERE PER SQUARE INCH CORRE...

...IGHTS OF THE BAROMETER.

...mosphere in Pounds.	Barometer in Inches.	Atmosphere in Pounds.
14·26	30·1	14·75
14·31	30·2	14·80
14·36	30·3	14·85
14·41	30·4	14·90
14·46	30·5	14·95
14·51	30·6	15·00
14·56	30·7	15·05
14·61	30·8	15·10
14·66	30·9	15·15
14·70	31·	15·19

...portable form and operates upon

... It consists of a hollow cylinder

...diameter, and made of very thin

...ure with the axis of the cylinder.

...side of the cylinder, and its ends

...other by the pressure of the

...ssure the more the ends are

...produced by pressure is multi-

... a graduated circular

The pressure

above the surf

al. While this [illegible] ers the atmospheric [illegible]

Measurement of Heights [illegible]—[illegible] able the height [illegible] eing only necessary [illegible]

eading of arometer in inches, emp. 60° F.	[illegible]	[illegible]	[illegible]
30.	[illegible]	[illegible]	[illegible]
29.5	[illegible]	[illegible]	[illegible]
29	[illegible]	[illegible]	[illegible]
28.5	[illegible]	[illegible]	[illegible]
28	[illegible]	[illegible]	[illegible]
27.5	[illegible]	[illegible]	[illegible]

To calculate [illegible] use the following [illegible] table corresp[illegible] of the barom[illegible] barometer rea[illegible] level.

Deg. Fah.	Multiplier.	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]
15	[illegible]	[illegible]	[illegible]
20	[illegible]	[illegible]	[illegible]
25	[illegible]	[illegible]	[illegible]
30	[illegible]	[illegible]	[illegible]
35	[illegible]	[illegible]	[illegible]
40	[illegible]	[illegible]	[illegible]
45	[illegible]	[illegible]	[illegible]
50	[illegible]	[illegible]	[illegible]

Another method of [illegible] the height by using the thermometer will be found [illegible] on page [illegible]

Volume of Air at Various Temperatures.—[illegible] air at *32° F. is heated at constant pressure*, [illegible] *different temperatures* as given in the table on pp. 122 and 123.

area of orifice in square inches, multiply also by 1060, a
divide by the absolute temperature.

The flow of gases through pipes will be found tre
the Transmission of Power by Compressed Air.

TABLE

SHOWING THE FORCE OF THE WIND IN POUNDS PER SQU
DIFFERENT VELOCITIES.

Miles per Hour.	Feet per Second.	Force per Square Foot Pound.	
1	1·47	0·005	Hardly
2	2·93	0·020	Just pe
3	4·4	0·044	
4	5·87	0·079	Gentle,
5	7·33	0·123	
6	8·8	0·177	
7	10·25	0·241	
8	11·75	0·315	Pl
9	13·2	0·400	
10	14·67	0·492	
12	17·6	0·708	
14	20·5	0·964	
15	22·00	1·107	
16	23·45	1·25	
18	26·4	1·55	[illegible]
20	29·34	1·968	
25	36·67	3·075	
30	44·01	4·429	[illegible]
35	51·34	6·027	
40	58·68	7·873	
45	66·01	9·963	[illegible]
50	73·35	12·30	
55	80·7	14·9	
60	88·02	17·71	
65	95·4	20·85	
70	102·5	24·1	
75	*110·*	27·7	
80	*117·36*		
100	*14*		

				0·47
				0·49
				0·50
				0·51
			[illegible]	0·50
			[illegible]	0·52
			[illegible]	0·51
			29·87	0·53
			30·40	0·53
			30·93	0·54
			31·47	0·56
			32·03	0·57
			32·60	0·56
			33·16	0·56
		[illegible]	33·72	0·59
		2·334	34·31	0·59
		2·374	34·90	0·60
		2·415	35·50	0·60
		2·456	36·10	0·62
		2·498	36·72	0·63
	[illegible]	2·541	37·35	0·63
	[illegible]	2·584	37·98	0·64
	265	2·627	38·62	0·64
	266	2·671	39·26	0·67
	267	2·716	39·93	0·66
	268	2·761	40·59	0·67
	269	2·807	41·26	0·69
	270	2·854	41·95	0·69
	271	2·901	42·64	0·71
[illegible]	272	2·949	43·35	0·71
[illegible]	273	2·997	44·06	0·72
	274	3·046	44·78	0·75
[illegible]	275	3·097	45·53	0·73
0·41	276	3·147	46·26	0·75
0·41	277	3·198	47·01	0·77
[illegible]	278	3·250	47·78	0·77
[illegible]	279	3·303	48·55	0·80
0·42	280	3·357	49·35	0·79
0·43	281	3·411	50·14	0·81
0·44	282	3·466	50·95	0·81
0·45	283	3·521	51·76	0·81
0·45	284	3·576	52·57	0·82
0·47	285	3·632	53·39	0·84

TABLE — (*Continued.*)

ures mos- res.	Pressures in Lbs. per Sq. Inch.	Differ- ences.	Temp. Fah.	Pressures in Atmos- pheres.	Pressures in Lbs. per Sq. Inch.	Differ- ences.
5	1·40	0·07	157	0·300	4·41	0·09
0	1·47	0·03	158	0·306	4·50	0·03
2	1·50	0·04	159	0·308	4·53	0·14
5	1·54	0·03	160	0·318	4·67	0·11
7	1·57	0·08	161	0·325	4·78	0·19
2	1·65	0·03	162	0·338	4·97	0·10
4	1·68	0·04	163	0·345	5·07	0·12
7	1·72	0·06	164	0·353	5·19	0·12
1	1·78	0·04	165	0·361	5·31	0·14
4	1·82	0·05	166	0·371	5·45	0·12
7	1·87	0·04	167	0·379	5·57	0·02
0	1·91	0·09	168	0·387	5·69	0·13
6	2·00	0·04	169	0·396	5·82	0·13
9	2·04	0·05	170	0·405	5·95	0·15
2	2·09	0·06	171	0·415	6·10	0·15
6	2·15	0·05	172	0·425	6·25	0·16
0	2·20	0·06	173	0·436	6·41	0·13
4	2·26	0·06	174	0·445	6·54	0·15
8	2·32	0·06	175	0·455	6·69	0·16
2	2·38	0·06	176	0·466	6·85	0·15
6	2·44	0·09	177	0·476	7·00	0·15
2	2·53	0·04	178	0·488	7·15	0·21
5	2·57	0·09	179	0·501	7·36	0·18
1	2·66	0·03	180	0·513	7·54	0·12
3	2·69	0·12	181	0·521	7·66	0·15
1	2·81	0·07	182	0·531	7·81	0·17
6	2·88	0·06	183	0·543	7·98	0·19
0	2·94	0·07	184	0·556	8·17	0·19
5	3·01	0·08	185	0·569	8·36	0·18
0	3·09	0·10	186	0·581	8·54	0·18
7	3·19	0·04	187	0·593	8·72	0·17
0	3·23	0·09	188	0·605	8·89	0·19
6	3·32	0·08	189	0·618	9·08	0·21
1	3·40	0·10	190	0·631	9·29	0·21
8	3·50	0·10	191	0·646	9·50	0·22
5	3·60	0·09	192	0·661	9·72	0·22
1	3·69	0·02	193	0·676	9·94	0·22
9	3·81	0·09	194	0·691	10·16	0·20
5	3·90	0·08	195	0·705	10·36	0·21
1	3·98	0·11	196	0·719	10·57	0·22
8	4·09	0·10	197	0·734	10·79	0·22
5	4·19	0·06	198	0·749	11·01	0·22
	4·25	0·16	199	0·764	11·23	0·22

[illegible]

Specific Heat of Water.—[illegible]

gradually descend until it reaches the temperature of 39.2° Fah.; at this point the contraction will cease; and, although the cold acting on the bulb is far below this point, the liquid will gradually ascend until it reaches 32° Fah., or freezing point, when it will solidify. The point at which the liquid commences to ascend is called its "point of maximum density."

One of the most curious phenomena connected with water before and after freezing, may be demonstrated as follows: Take a tall jar and fill it with water, say at 60° Fah.; at the top of the jar fix a small mercurial thermometer, and another one at the bottom; then place the jar at rest, exposed to the cold. The lower thermometer will be observed to fall more rapidly than the top one, until it reaches 39·2° Fah., when it will remain stationary. The top thermometer will now fall, and continue to do so until the water freezes; the bottom thermometer still remaining at 39·2° Fah. These effects are easily explained: the particles of water at the top being exposed to the cold, decrease in temperature, thus becoming denser, and fall to the bottom, their places being taken up by warmer particles, which in their turn undergo the same change, until the whole volume has completely circulated, and attained a temperature of 39·2° Fah. The particles now, instead of becoming denser, actually expand, and so remain at the top until a thin layer of ice is formed. This is exactly what takes place in our lakes and ponds during every frost; the circulation continues until the whole mass attains the temperature of 39·2° Fah., when it is gradually and finally arrested; a thin layer of ice is then formed at the top, acting as a cloak to the interior, which, remaining always at 39·2° Fah., preserves the animals and fishes from the action of intense cold.

Were it not for this fact, our lakes and rivers would all be frozen at the bottom, and, as water is a bad conductor of heat, they would in time be converted into a solid block of ice, which would defy the hottest rays of a tropical sun to melt. Thus we *see that such a* wise provision of Nature depends entirely on an *ent exception to* a universal law, which is so slight that it

	5	6
5	[illegible]	[illegible]
6	280	103
7	[illegible]	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]
11	[illegible]	[illegible]
12	[illegible]	[illegible]
13	[illegible]	[illegible]
14	[illegible]	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]

TABLE

SHOWING THE QUANTITY OF WATER PER LINEAL FOOT IN PUMPS, OR VERTICAL PIPES OF DIFFERENT DIAMETERS.

Diameter of Pump in Inches.	Number of Gallons per Lineal Foot.	Number of Cubic Feet per Lineal Foot.	Diameter of Pump in Inches.	Number of Gallons per Lineal Foot.	Number of Cubic Feet per Lineal Foot.
2	·136	·0218	8	2·176	·3490
2¼	·172	·0276	8¼	2·314	·3712
2½	·212	·0340	8½	2·456	·3940
2¾	·257	·0412	8¾	2·603	·4175
3	·306	·0490	9	2·754	·4417
3¼	·359	·0576	9¼	2·909	·4666
3½	·416	·0668	9½	3·068	·4923
3¾	·478	·0766	9¾	3·232	·5184
4	·544	·0872	10	3·400	·5454
4¼	·614	·0985	10¼	3·572	·5730
4½	·688	·1104	10½	3·748	·6013
4¾	·767	·1230	10¾	3·929	·6302
5	·850	·1363	11	4·114	·6599
5¼	·937	·1503	11¼	4·303	·6902
5½	1·028	·1649	11½	4·496	·7212
5¾	1·124	·1803	11¾	4·694	·7529
6	1·224	·1963	12	4·896	·7853
6¼	1·328	·2130	12½	5·312	·8521
6½	1·436	·2304	13	5·746	·9217
6¾	1·549	·2489	13½	6·196	·9939
7	1·666	·2672	14	6·664	1·0689
7¼	1·787	·2866	15	7·650	1·2271
7½	1·912	·3067	16	8·704	1·3962
7¾	2·042	·3275	18	11·016	1·7670

One cubic foot of water weighs 62½ lbs., and contains 7½ U. S. gallons.

***One cubic foot of* ice** weighs 57 lbs.

TABLE

SHOWING THE CAPACITY OF CISTERNS AND TANKS. COMPUTED IN BARRELS OF 31½ GALLONS.

DEPTH IN FEET.	DIAMETER IN FEET. 5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
5	23·3	33·6	45·7	59.7	75·5	93·2	112·8	134·3	157·6	182·8	209·8	238·7	269·5	302·1	336·6	373·0
6	28·0	40·3	54·8	71·7	90·6	111·9	135·4	161·1	189·1	219·3	251·8	286·5	323·4	362·6	404·0	447·6
7	32·7	47·0	64·0	83·6	105·7	130·6	158·0	188·0	220·6	255·9	293·7	334·2	377·3	423·0	471·3	522·2
8	37·3	53·7	73·1	95·5	120·9	149·2	180·5	214·8	252·1	292·4	335·7	382·0	431·2	483·4	538·6	596·8
9	42·0	60·4	82·2	107·4	136·0	167·9	203·1	241·7	283·7	329·0	377·7	429·7	485·1	543·8	605·9	671·4
10	46·7	67·1	91·4	119·4	151·1	186·5	225·7	268·6	315·2	365·5	419·6	477·4	539·0	604·3	673·3	746·0
11	51·3	73·9	100·5	131·3	166·2	205·1	248·2	295·4	346·7	402·1	461·6	525·2	592·9	664·7	740·6	820·6
12	56·0	80·6	109·7	143·2	181·3	223·8	270·8	322·3	378.2	438·6	503·5	572·9	646·8	725·1	807·9	895·2
13	60·7	87·3	118·8	155·2	196·4	242·4	293·4	349·1	409·7	475·2	545·5	620·7	700·7	785·5	875·2	969·8
14	65·3	94·0	127·9	167·1	211·5	261·1	315·9	376·0	441·3	511·8	587·5	668·4	754·6	846·0	942·6	1044·4
15	70·0	100·7	137·1	179·0	226·6	279·8	338·5	402·8	472·8	548·3	629·4	716·2	808·5	906·4	1009·9	1119·0
16	74·7	107·4	146·2	191·0	241·7	298·4	361·1	429·7	504·3	584·9	671·4	763·9	862·4	966·8	1077·2	1193·6
17	79·3	114·1	155·4	202·9	256·8	317·0	383·6	456·6	535·8	621·4	713·4	811·6	916·3	1027·2	1144·6	1268·2
18	84·0	120·9	164·5	214·8	272·0	335·7	406·2	483·4	567·3	658·0	755·3	859·4	970·2	1087·7	1211·9	1342·8
19	88·7	127·6	173·6	226·8	287·0	354·3	428·8	510·3	598·9	694·5	797·3	907·1	1024·1	1148·1	1279·2	1417·4
20	93·3	134·3	182·8	238·7	302·1	373·0	451·3	537·1	630·4	731·1	839·3	954·9	1078·0	1208·5	1346·5	1492·0

TABLE

SHOWING THE CAPACITY OF CISTERNS IN GALLONS FOR EACH 10-INCH DEPTH.

DIAMETER IN FEET.	GALLONS.	DIAMETER IN FEET.	GALLONS.	DIAMETER IN FEET.	GALLONS.
2·	19·5	6·5	206·8	12	705·
2·5	30·5	7·	239·8	13	827·4
3·	44·6	7·5	275·4	14	959·7
3·5	59·97	8·	313·3	15	1101·6
4·	78·33	8·5	353·7	20	1958·4
4·5	99·14	9·	396·5	25	3059·9
5·	122·4	9·5	461·4	30	4406·4
5·5	148·1	10·	489·6	35	5990·
6·	176·2	11·	592·4	40	7831·

Rule *for finding the quantity of water which any square or rectangular box or tank is capable of containing in cubic feet or U. S. gallons.*—Multiply the length of the side by the length of the end and by the depth, all in inches. Divide this product by 1728; this quotient will be the number of cubic feet of water the tank will contain. To find the number of U. S. gallons, multiply the number of cubic feet by 7·5.

Rule *for finding the cubical contents of a triangular tank.*—Multiply the length of the base of the triangle by half its perpendicular height and by the length of the tank, all in inches. Divide this product by 1728; this quotient will be the number of cubic feet of water the tank will contain. To find the number of U. S. gallons, multiply the number of cubic feet by 7·5.

Rule *for finding the contents of an elliptic or oval tank in cubic feet or gallons.*—Multiply the long diameter in inches by the short diameter in inches, this product by ·7854, and this last product [illegible] height of the tank in inches; then divide by 1728, and the [illegible] ll be the contents of the tank in cubic feet, which, if multiplied [illegible] 7·5, gives the number of U. S. gallons in the tank.

Water [illegible]

[illegible]

[illegible] is the pressure per square inch [illegible]

[illegible] table gives the [illegible]

	Pressure	Head
[illegible]	[illegible]	[illegible]

e pressure in pounds per square inch [illegible] d, it follows that to get the pressure [illegible] multiply the pressure at 1 foot head [illegible] The pressure to 57 feet is equal to the pressure due to 50 plus the due to 7 feet.

ple—*What* will be the pressure due to a head of 125?

[illegible] 100 feet 100 times [illegible] = 432.8

[illegible] = 96.56

[illegible] 34.624

[illegible] 3.029

[illegible] .013

[illegible] pounds pressure [illegible] head [illegible] calculated [illegible]

[illegible]

ample.—A tank has a hole in the bottom and water is ped into it so as to keep always five feet depth. At what city will the water come out?

rom the table of square roots, the square root of 5 is 2.232; multiying by 5 we obtain 11.16 feet per second as the velocity of flow.

he quantity of water in cubic feet per minute flowing out of above tank is equal to the velocity multiplied by the area. If hole had a diameter of 4 inches, the area will be 12.566 uare inches, or .872 square feet. The velocity is 11.16 × 60, or 9.6 feet per minute, and the number of cubic feet of water scaping per minute is .872 × 669.6 = 583.89 cubic feet per minute.

Flow from Orifice in the Side of Tank.—In this case the paricles at the upper part of the hole have a less head and less velocity than those at the lower part. The following table, taken from the catalogue of the Pelton Water Wheel Company, gives the quantity in cubic feet of water discharged per minute, through an orifice one inch square, under any head of water from 3 to 72 inches.

FOR TANK MEASUREMENT.

HEADS IN INCHES.	Cubic Feet Disch'd per minute.	HEADS IN INCHES.	Cubic feet Discharged per minute.	HEADS IN INCHES.	Cubic feet Disch'd per minute.	HEADS IN INCHES.	Cubic feet Discharged per minute.	HEADS IN INCHES.	Cubic feet Disch'd per minute.
3	1.12	17	[illegible]	31	[illegible]	45	[illegible]	59	[illegible]
4	1.27	18	[illegible]	32	[illegible]	46	[illegible]	60	[illegible]
5	1.40	19	[illegible]	33	[illegible]	47	[illegible]	61	[illegible]
6	1.52	20	[illegible]	34	[illegible]	48	[illegible]	62	[illegible]
7	1.64	21	[illegible]	35	[illegible]	49	[illegible]	63	[illegible]
8	1.75	22	[illegible]	36	[illegible]	50	[illegible]	64	[illegible]
9	1.84	23	[illegible]	37	[illegible]	51	[illegible]	65	[illegible]
10	1.94	24	[illegible]	38	[illegible]	52	[illegible]	66	[illegible]
11	2.03	25	[illegible]	39	[illegible]	53	[illegible]	67	[illegible]
12	2.12	26	[illegible]	40	[illegible]	54	[illegible]	68	[illegible]
13	2.20	27	[illegible]	41	[illegible]	55	[illegible]	69	[illegible]
14	2.28	28	[illegible]	42	[illegible]	56	[illegible]	70	[illegible]
15	2.36	29	[illegible]	43	[illegible]	57	[illegible]	71	[illegible]
16	2.43	30	[illegible]	44	[illegible]	58	[illegible]	72	[illegible]

[illegible] = $113\frac{1}{11}$ [illegible]

[illegible]

he above table gives the theoretical horse-power, bu [illegible] would be less than this. The [illegible] of horse-power obtained would be from 70 to 85 per cen [illegible] table, depending on the size and type of wheel use

he following table does away with the last part of the cal [illegible] and gives the horse-power for each cubic foot of water u [illegible] heads, with a wheel efficiency of 85 per cent., so [illegible] obtaining the number of cubic feet and the head it is [illegible] to look up the number corresponding to the head [illegible] it by the number of cubic feet per minute.

Head in Feet.	Horse Power.	Head 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	.144882	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

Assuming that 33⅓% of the indicated horse-power is wasted between the engine and pump cylinder.

What a Horse-Power will raise per Minute.		2 H. P. will raise per Minute.		3 H. P. will raise per Minute.		4 H. P. will raise per Minute.		5 H. P. will raise per Minute.		6 H. P. will raise per Minute.		7 H. P. will raise per Minute.		8 H. P. will raise per Minute.	
Gals. or Feet.	Feet or Gals.	Gals. or Feet.	Feet or Gals.	Gals. or Feet.	Feet or Gals.	Gals. or Feet.	Feet or Gals.	Gals. or Feet.	Feet or Gals.	Gals. or Feet.	Feet or Gals.	Gals. or Feet.	Feet or Gals.	Gals. or Feet.	Feet or Gals.
2,500	1	5,000	1	7,500	1	10,000	1	12,500	1	15,000	1	17,500	1	20,000	1
1,250	2	2,500	2	3,750	2	5,000	2	6,250	2	7,500	2	8,750	2	10,000	2
833	3	1,666	3	2,500	3	3,333	3	4,166	3	5,000	3	5,833	3	6,666	3
625	4	1,250	4	1,875	4	2,500	4	3,125	4	3,750	4	4,375	4	5,000	4
500	5	1,000	5	1,500	5	2,000	5	2,500	5	3,000	5	3,500	5	4,000	5
416	6	833	6	1,250	6	1,666	6	2,083	6	2,500	6	2,916	6	3,333	6
357	7	714	7	1,070	7	1,428	7	1,785	7	2,142	7	2,500	7	2,857	7
312	8	625	8	937	8	1,250	8	1,562	8	1,875	8	2,187	8	2,500	8
277	9	555	9	833	9	1,111	9	1,388	9	1,666	9	1,944	9	2,222	9
250	10	500	10	750	10	1,000	10	1,250	10	1,500	10	1,750	10	2,000	10
125	20	250	20	375	20	500	20	625	20	750	20	875	20	1,000	20
83	30	166	30	250	30	333	30	416	30	500	30	583	30	666	30
62	40	125	40	187	40	250	40	312	40	375	40	437	40	500	40
50	50	100	50	150	50	200	50	250	50	300	50	350	50	400	50
41	60	83	60	125	60	166	60	208	60	250	60	291	60	333	60
35	70	71	70	107	70	142	70	178	70	214	70	250	70	285	70
31	80	62	80	93	80	125	80	156	80	187	80	218	80	250	80
27	90	55	90	83	90	111	90	138	90	166	90	194	90	222	90
25	100	50	100	75	100	100	100	125	100	150	100	175	100	200	100

CHAPTER VIII.

STEAM.

Steam is an elastic fluid resulting from the combinatio
with water, and, when the steam is not in contact with t
from which it is formed, it follows the same general la
other gases. This law is as follows: All gases expand by he
part of their volume for every degree Fah., while their
pressure remains unaltered, and so long as the temperatu
gas remains unaltered, its elastic pressure will vary inve
the volume.

The temperature of the steam is always equal to th
water from which it is formed, and the elastic force
formed is equal to the pressure under which it is for
elastic force of steam, barometer at 30°, at 212° Fah
mosphere, or 14·7 lbs. per sq. inch; while at 250° Fa
force is two atmospheres, or 29·4 lbs. per sq. inch.
the pressure of the atmosphere.

If the mercury be in a vacuum, the pressure of
temperature of 212° Fah. will equal 30 [illegible]
due to a temperature of 250° Fah. it
if the mercury be exposed to the atm
250° Fah. will only equal 30 inch
Fah. there is no indication by a m
just balances the atmosphere.

Saturated steam is the vapo
temperature and pressure, and ei
water, or, if not in contact, wi
At a given temperature it alw

Superheated steam is prod

to a higher temperature than that corresponding to the t which it was generated.

y steam coming from the boiler has suspended in it ırticles of *water*, and the percentage which the weight isture bears to the weight of the steam varies with the s well as the individual boiler, but runs approximately :

sure............	60	70	80	90	100	110	120	130	140	150
oisture..........	3.2	3.5	3.8	4.1	4.4	4.6	4.8	5.1	5.3	5.5

urated steam is steam only, without any such water par- iechanical suspension.

ent heat of steam is heat that is neither sensible to the can it be indicated by the thermometer. The existence ent heat in water, while in the form of steam, may be the following illustration: If 5½ pounds of water, at re placed in a vessel communicating with another, in ter is kept at 212° F., and kept there till the former temperature of 212° F., and then weighed, it will be weigh 6½ pounds, showing that 1 pound of water has d to the 5½ pounds in the form of steam. This pound received in the form of steam had, when in that form, a re of 212° F. It still possesses the same temperature of howing that it has parted with 5½ times the number of temperature between 32° and 212°, which is 180, and 990°. This heat was combined with the steam, but not sible to the thermometer is called latent; in this connec- taken as a convenient number; 5.37 is more accurate.

bserve the time that a certain amount of heat takes to r from 32° to 212°, no matter what the time may be, it 5½ times as long for the same heat to evaporate the unt of water. It follows, that to evaporate water under re of the atmosphere requires 5½ times as much heat as necessary *to raise* the same amount from 32° F. to

The number of heat units required to change one pound of water at any temperature into steam at that temperature differs with different temperatures, and is called the latent heat at that temperature. Its value will be found in the steam tables following.

The heat of the liquid or that in water at any temperature is the number of heat units required to raise it from 32° F. to that temperature.

The total heat at any temperature is the sum of the *Latent Heat* and *Heat in Liquid*, and is the number of heat units required to raise water from 32° F. to the given temperature and evaporate it into steam at that temperature.

The volume of steam or relative volume at any temperature is the number of cubic inches which would be occupied at that temperature by the steam produced from one cubic inch of water, and is calculated by comparing the weight of a cubic foot of steam at the given temperature with the weight of a cubic foot of water at 39.4° F., its point of greatest density. For example, the difference in volume between water and steam at atmospheric pressure is 1669; that is, a given quantity of water, when converted into steam, will occupy 1669 times that which the water did. One cubic foot of steam, at atmospheric pressure, weighs .038 of a pound.

The steam from salt water is fresh, because no salt is carried away in the steam when evaporation from salt water takes place; and when the water is all evaporated, the original salt will be found in the vessel.

Steam having an elastic force or pressure not exceeding 15 pounds per square inch, is termed low-pressure steam, and at such pressures its use is now mostly confined to heating. Th pressures used for power generation are continually increasin ures of 200 pounds and over being not uncommon, whi many years since the upper limit of pressure was at 60 or

TABLE

TEAM PRESSURE IN POUNDS PER GAUGE; THE ABSOLUTE POUNDS AND INCHES OF MERCURY; THE TEMPERATURE; AT IN STEAM PER POUND; THE LATENT HEAT PER POUND; THE WATER; THE RELATIVE VOLUME, AND WEIGHT OF BIC FOOT, FOR VARIOUS PRESSURES.*

es of cury.	Temperature, Fah.	Total Heat per lb.	Latent Heat per lb.	Heat in Water per lb.	Relative Volume.	Weight per Cub. Ft.
036	102·	1145·05	1042·96	102·08	17983·	·00347
072	126·27	1152·45	1026·01	126·44	10353·	·00602
08	141·62	1157·13	1015·25	141·87	7283·8	·00856
44	153·07	1162·62	1007·23	153·39	5608·4	·01112
80	162·33	1163·45	1000·73	162·72	4565·6	·01366
6	170·12	1165·83	995·25	170·57	3851·0	·01619
2	176·91	1167·89	990·47	177·42	3330·8	·01837
3	182·91	1169·72	986·24	183·48	2935·1	·02125
	188·32	1171·37	982·43	188·94	2624·1	·02377
	193·24	1172·87	978·96	193·92	2373·0	·02628
	197·77	1174·26	975·76	198·49	2166·3	·02880
	201·96	1175·53	972·80	202·74	1993·0	·03130
	205·88	1176·73	970·02	206·71	1845·7	·03380
	209·56	1177·85	967·43	210·43	1718·9	·03629
	213·02	1178·91	964·97	213·94	1608·6	·03878
	216·30	1179·91	962·66	217·25	1511·7	·04123
	219·41	1180·86	960·45	220·41	1426·2	·04374
	222·38	1181·76	958·34	223·42	1349·8	·04622
	225·20	1182·63	956·34	226·28	1281·1	·04868
	227·92	1183·45	954·41	229·04	1219·7	·05119
	230·51	1184·25	952·57	231·67	1163·8	·05360
	233·02	1185·01	950·79	234·22	1112·9	·05605
	235·43	1185·74	949·07	236·67	1066·3	·05851
	237·75	1186·45	947·42	239·03	1023·6	·06095
	240·00	1187·14	945·82	241·31	984·23	·06338
	242·17	1187·80	944·28	243·52	947·86	·06582
	244·28	1188·44	942·77	245·67	914·14	·06824
	246·33	1189·07	941·32	247·75	882·80	·07067
	248·31	1189·67	939·90	249·77	853·60	·07308
	250·24	1190·26	938·92	251·74	826·32	·07550
	252·12	1190·83	937·19	253·64	800·79	·07791
	253·95	1191·40	935·88	255·52	766·83	·08031
	255·73	1191·94	934·61	257·33	754·31	·08271
	257·46	1192·47	933·36	259·11	733·09	·08510
	259·17	1192·99	932·15	260·84	713·08	·08749
	260·83	1193·49	930·96	262·53	694·17	·08987
	262·46	1193·99	929·81	264·18	676·27	·09225
	264·04	1194·47	928·67	265·80	659·31	·09462
	265·60	1194·94	927·56	267·38	643·21	·09700
	267·12	1195·41	926·47	268·94	627·91	·09936
	268·61	1195·86	925·40	270·46	613·34	·10172
	270·07	1196·31	924·36	271·95	599·46	·10407
	271·51	1196·75	923·33	273·42	586·23	·10642
	272·91	1197·18	922·32	274·86	573·58	·10877
	274·29	1197·60	921·33	276·27	561·50	·11111
	275·65	1198·01	920·36	277·65	549·94	·11344
	276·99	1198·42	919·40	279·02	538·87	·11577
	278·30	1198·82	918·47	280·35	528·25	·11810
	279·58	1199·21	917·54	281·67	518·07	·12042
	280·85	1199·60	916·63	282·97	508·29	·12273

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* John W. Hill.

TABLE

SHOWING THE STEAM PRESSURE IN POUNDS PER GAUGE; THE ABSOLUTE PRESSURE IN POUNDS AND INCHES OF MERCURY; THE TEMPERATURE, THE TOTAL HEAT IN STEAM PER POUND; THE LATENT HEAT PER POUND; THE HEAT OF THE WATER; THE RELATIVE VOLUME, AND WEIGHT OF STEAM PER CUBIC FOOT, FOR VARIOUS PRESSURES.

Pressure per Gauge.	Total lbs.	Inches of Mercury.	Temperature, Fah.	Total Heat per lb.	Latent Heat per lb.	Heat in Water per lb.	Relative Volume.	Weight per Cub. Ft.
36·304	51	103·84	282·10	1198·98	915·74	284·24	498·89	·12505
37·304	52	105·87	283·32	1200·35	914·86	285·50	489·85	·12736
38·304	53	107·91	284·53	1200·72	913·99	286·73	481·15	·12966
39·304	54	109·94	285·72	1201·08	913·13	287·95	472·77	·13196
40·304	55	111·98	286·89	1201·44	912·29	289·15	464·69	·13428
41·304	56	114·02	288·05	1201·80	911·46	290·34	456·90	·13652
42·304	57	116·05	289·11	1202·14	910·64	291·50	449·38	·13883
43 304	58	118·09	290·32	1202·49	909·83	292·65	442·12	·14111
44·304	59	120·12	291·42	1202·82	909·03	293·79	435·10	·14338
45·304	60	122·16	292·52	1203·16	908·25	294·91	428·32	·14566
46·304	61	124·19	293·60	1203·49	907·47	296·02	421·75	·14792
47·304	62	126·23	294·66	1203·81	906·70	297·11	415·40	·15018
48·304	63	128·27	295·71	1204·13	905·95	298·18	409·25	·15244
49·304	64	130·30	296·75	1204·45	905·20	299·25	403·29	·15469
50·304	65	132·34	297·78	1204·76	904·46	300·30	397·51	·15694
51·304	66	134·37	298·79	1205·07	903·73	301·34	391·90	·15919
52·304	67	136·41	299·79	1205·38	903·01	302·37	386·47	·16130
53·304	68	138·45	300·77	1205·68	902·30	303·38	381·18	·16366
54·304	69	140·48	301·75	1205·97	901·60	304·37	376·06	·16590
55·304	70	142·52	302·72	1206·27	900·90	305·37	371·07	·16812
56·304	71	144·55	303·67	1206·56	900·21	306·35	366·24	·17035
57 304	72	146·59	304·62	1206·85	899·53	307·32	361·53	·17256
58·304	73	148·63	305·55	1207·13	898·85	308·28	356·95	·17478
59·304	74	150·66	306·47	1207·42	898·19	309·23	352·49	·17690
60·304	75	152·70	307·39	1207·69	897·53	310·16	348·15	·17919
61·304	76	154·73	308·29	1207·97	896·88	311·09	343·93	·18139
62·304	77	156·77	309·18	1208·24	896·23	312·01	339·81	·18359
63·304	78	158·81	310·07	1208·51	895·59	312·92	335·81	·18578
64·304	79	160·84	310·94	1208·78	894·95	313·82	331·89	·18797
65·304	80	162·88	311·81	1209·04	894·33	314·71	328·08	·19015
66·304	81	164·91	312·67	1209·30	893·71	315·59	324·37	·19233
67·304	82	166·95	313·52	1209·56	893·09	316·47	320·74	·19451
68·304	83	168·99	314·36	1209·82	892·49	317·33	317·20	·19668
69·304	84	171·02	315·19	1210·07	891·88	318·19	313·74	·19885
70·304	85	173·06	316·02	1210·33	891·29	319·04	310·36	·20101
71·304	86	175·09	316·84	1210·58	890·69	319·89	307·07	·20317
72·304	87	177·13	317·65	1210·83	890·11	320·72	303·85	·20532
73·304	88	179·17	318·45	1211·07	889·52	321·54	300·70	·20747
74·304	89	181·20	319·25	1211·31	888·95	322·36	297·62	·20962
75·304	90	185·24	320·04	1211·55	888·38	323·17	294·61	·21185
76·304	91	185·27	320·82	1211·79	887·81	323·98	291·66	·21390
77·304	92	187·31	321·58	1212·03	887·25	324·78	288·78	·21603
78·304	93	189·35	322·36	1212·26	886·69	325·57	285·96	·21816
79·304	94	191·38	323·13	1212·49	886·13	326·36	283·21	·22029
80·304	95	193·42	323·88	1212·72	885·59	327·13	280·50	·22241
81·304	96	195·45	324·63	1212·95	885·04	327·91	277·86	·22453
82·304	97	197·49	325·38	1213·18	884·50	328·68	275·27	·22675
83·304	*98*	*199·53*	326·11	1213·40	883·97	329·43	272·73	·22873
84·304	*99*	*201·56*	326·84	1213·63	883 44	330·19	270·24	·23085
304	*100*	*203·60*	327·57	1213·85	882·91	330·94	267·80	·23296

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Pressure per Gauge.	Total lbs.	Inches of Mercury.	Temperature, Fah.	Total Heat per lb.	Latent Heat per lb.	Heat in Water per lb.	Relative Volume.	Weight per Cub. Ft.
86·304	101	205·64	328·29	1214·05	882·39	331·66	[illegible]	[illegible]
87·304	102	207·67	329·00	1214·29	881·87	332·42	[illegible]	[illegible]
88·304	103	209·71	329·71	1214·50	881·35	333·15	[illegible]	[illegible]
304	104	211·74	330·42	1214·73	880·85	333·88	[illegible]	[illegible]
304	105	213·78	331·11	1214·95	880·36	334·59	[illegible]	[illegible]
04	106	215·82	331·80	1215·16	879·86	335·30	[illegible]	[illegible]
4	107	217·85	332·49	1215·35	879·34	336·01	[illegible]	[illegible]
4	108	219·89	333·17	1215·56	878·83	336·73	[illegible]	[illegible]
	109	221·92	333·85	1215·76	878·35	337·41	[illegible]	[illegible]
	110	223·96	334·52	1215·97	877·86	338·11	[illegible]	[illegible]
	111	225·99	335·19	1216·17	877·38	338·79	[illegible]	[illegible]
	112	228·03	335·85	1216·38	876·96	339·42	[illegible]	[illegible]
	113	230·07	336·51	1216·58	876·42	340·16	[illegible]	[illegible]
	114	232·10	337·16	1216·77	875·92	340·85	[illegible]	[illegible]
	115	234·14	337·81	1216·97	875·47	341·50	236·11	[illegible]
	116	236·17	338·46	1217·17	875·00	342·17	234·39	[illegible]
	117	238·21	339·10	1217·36	874·54	342·82	232·70	[illegible]
	118	240·25	339·73	1217·56	874·07	343·49	[illegible]	[illegible]
	19	242·28	340·37	1217·75	873·61	344·14	229·30	[illegible]
	20	244·32	340·99	1217·94	873·15	344·79	227·56	[illegible]
	21	246·35	341·62	1218·13	872·70	345·43	226·10	[illegible]
	22	248·39	342·24	1218·32	872·25	346·07	224·80	[illegible]
	23	250·43	342·85	1218·51	871·80	346·71	222·96	[illegible]
	24	252·46	343·46	1218·69	871·35	347·34	221·39	[illegible]
	5	254·50	344·07	1218·88	870·91	347·97	219·50	[illegible]
	6	256·54	344·68	1219·07	870·47	348·60	218·20	[illegible]
	7	258·57	345·28	1219·25	870·03	349·22	216·70	[illegible]
	8	260·61	345·87	1219·43	869·58	349·85	215·39	[illegible]
	9	262·64	346·46	1219·61	869·16	350·45	213·79	[illegible]
	0	264·68	347·06	1219·79	868·74	351·05	212·27	·29419
	1	266·72	347·64	1219·97	868·31	351·66	210·90	·29618
	2	268·75	348·23	1220·15	867·88	352·27	209·50	·29826
		270·79	348·80	1220·32	867·46	352·86	208·10	·30013
		272·82	349·38	1220·50	867·04	353·46	206·70	·30209
		274·86	349·95	1220·67	866·62	354·05	205·18	·30406
		276·89	350·52	1220·85	866·21	354·64	204·10	·30601
		278·93	351·09	1221·02	865·79	355·23	202·80	·30796
		280·96	351·65	1221·19	865·38	355·81	201·50	·30990
		283·00	352·21	1221·36	864·97	356·39	200·20	·31186
		285·04	352·76	1221·53	864·56	356·97	198·78	·31385
		287·07	353·32	1221·70	864·16	357·54	197·80	·31586
		289·11	353·87	1221·87	863·76	358·11	196·60	·31788
		291·15	354·42	1222·04	863·36	358·67	195·40	·31990
		293·18	354·96	1222·20	862·96	359·24	194·20	·32190
		295·22	355·50	1222·37	862·57	359·80	192·83	·32354
		297·25	356·04	1222·53	862·17	360·36	191·90	·32592
		299·29	356·57	1222·69	861·78	360·91	190·80	·32794
		301·33	357·10	1222·85	861·39	361·46	189·70	·32985
		303·36	357·63	1223·02	861·01	362·01	188·60	·3
		305·40	358·16	1223·18	860·62	362·56	187·35	

TABLE

SHOWING THE STEAM PRESSURE IN POUNDS PER GAUGE
PRESSURE IN POUNDS AND INCHES OF MERCURY; THE
THE TOTAL HEAT IN STEAM PER POUND; THE LATENT H
THE HEAT OF THE WATER; THE RELATIVE VOLUME,
STEAM PER CUBIC FOOT, FOR VARIOUS PRESSURES.

Pressure per Gauge.	Total lbs.	Inches of Mercury.	Temperature, Fah.	Total Heat per lb.	Latent Heat per lb.	Heat in Wate per l
36·304	51	103·84	282·10	1198·98	915·74	28[illegible]
37·304	52	105·87	283·32	1200·35	914·86	28[illegible]
38·304	53	107·91	284·53	1200·72	913·99	28[illegible]
39·304	54	109·94	285·72	1201·08	913·13	28[illegible]
40·304	55	111·98	286·89	1201·44	912·29	28[illegible]
41·304	56	114·02	288·05	1201·80	911·46	2[illegible]
42·304	57	116·05	289·11	1202·14	910·64	2[illegible]
43·304	58	118·09	290·32	1202·49	909·83	2[illegible]
44·304	59	120·12	291·42	1202·82	909·03	2[illegible]
45·304	60	122·16	292·52	1203·16	908·25	[illegible]
46·304	61	124·19	293·60	1203·49	907·47	[illegible]
47·304	62	126·23	294·66	1203·81	906·70	
48·304	63	128·27	295·71	1204·13	905·95	
49·304	64	130·30	296·75	1204·45	905·20	
50·304	65	132·34	297·78	1204·76	904·46	
51·304	66	134·37	298·79	1205·07	903·73	
52·304	67	136·41	299·79	1205·38	903·01	
53·304	68	138·45	300·77	1205·68	902·30	
54·304	69	140·48	301·75	1205·97	901·60	
55·304	70	142·52	302·72	1206·27	900·90	
56·304	71	144·55	303·67	1206·56	900·21	
57·304	72	146·59	304·62	1206·85	899·53	
58·304	73	148·63	305·55	1207·13	898·85	
59·304	74	150·66	306·47	1207·42	898·19	
60·304	75	152·70	307·39	1207·69	897·53	
61·304	76	154·73	308·29	1207·97	896·88	
62·304	77	156·77	309·18	1208·24	896·2[illegible]	
63·304	78	158·81	310·07	1208·51	895·5[illegible]	
64·304	79	160·84	310·94	1208·78	894·[illegible]	
65·304	80	162·88	311·81	1209·04	894·[illegible]	
66·304	81	164·91	312·67	1209·30	893·[illegible]	
67·304	82	166·95	313·52	1209·56	89[illegible]	
68·304	83	168·99	314·36	1209·82	892[illegible]	
69·304	84	171·02	315·19	1210·07	891[illegible]	
70·304	85	173·06	316·02	1210·33	891[illegible]	
71·304	86	175·09	316·84	1210·58	89[illegible]	
72·304	87	177·13	317·65	1210·83	890[illegible]	
73·304	88	179·17	318·45	1211·07	88[illegible]	
74·304	89	181·20	319·25	1211·31	88[illegible]	
75·304	90	185·24	320·04	1211·55	8[illegible]	
76·304	91	185·27	320·82	1211·79	[illegible]	
77·304	92	187·31	321·58	1212·03	[illegible]	
78·304	93	189·35	322·36	1212·26	[illegible]	
79·304	94	191·38	323·13	1212·49		
80·304	95	193·42	323·88	1212·72		
81·304	96	195·45	324·63	1212·95		
82·304	97	197·49	325·38	1213·18	[illegible]	
83·304	*98*	*199·53*	326·11	1213·40		
84·304	*99*	*201·56*	326·84	1213·63		
85·304	*100*	*203·60*	327·57	1213·85		

100 lbs.
therefore
from an
ing

f 1180 units nearly, while at 100
t is only 1216 units.

When the pressure of the
ressure the following

			scharge per sq. in of orifice per min.
			Lbs.
		1	22.81
		1408	26.84
		1419	35.18
		1424	39.78
		1429	44.06
		1437	52.59
	9	1444	61.07
	91	1447	65.30
	895	1454	77.94
	898	1459	86.34
	902	1466	98.76
	906	1472	115.61
	910	1478	132.21
	912	1481	140.46
24	919	1493	181.58

es.—Mr. George H. Babcock, in "Steam," thod and tables by which can be determber of cubic feet per minute which can be ferent sized pipes for a given loss in pressure, ne loss of pressure owing to friction in different fferent rates of flow.

am through Pipes.—The approximate weight of h will flow one minute through any given pipe with r pressure may be found by the following formula:

$$W = 87\sqrt{\frac{D\,(p_1 - p_2)\,d^5}{L\left(1 + \frac{3.6}{d}\right)}}$$

Steam Pipes—Sizes.—For engines the average practio to have steam pass through the supply pipes at a velocit than 6000 feet per minute, and sizes run about as follows:

Diameter of pipe	2"	3"	4"	5"	6"	7"
Horse-power of engine	25	50	100	150	225	300

To calculate the mains the preceding table from "Stear be used. The upper part of the table above the diagona space refers to standard sizes or nominal inside diameters lower part is for actual inside diameters. The table tel many pipes of one size are equivalent to one pipe of anothe

Example of Use of Table.—Suppose we have 3 engin of 50 horse-power and two of 25 horse-power. What siz steam pipe shall we use? If the main were exceedingly l might have to calculate it by the preceding article on *Steam*; but for mains of ordinary length proceed as follow

Assume that the 50-horse-power engine has a 3" pipe 25 horse-power a 2" pipe. From the table one 3" pipe

SHOWING RADIATION DUE TO BARE AND COVERED PIPES
SAVING DUE TO COVERINGS.

KINDS OF COVERING.	B. T. U. Transmitted per Hour per Square Foot Pipe per Degree Difference in Temperature.	Lbs. Steam Condensed per Hour per Square Foot Pipe per Degree Difference in Temperature.	Lbs. Steam Saved per 100 Square Feet Pipe per Year.	
Bare Pipe	2.7059	.003107	——	—
Magnesia	.3838	.000432	635,801	$1
Rock Wool	.2556	.000285	670,666	1
Mineral Wool	.2846	.000311	662,957	1
Fire Felt	.5023	.000591	603,389	1
Manville Sectional	.3496	.000409	645,174	1
" Sectional and [illegible]	.2119	.000243	682,930	1
[illegible] ool Cement	.3448	.000410	646,488	1
[illegible] ineral Wool,	.3166	.000364	654,197	1
[illegible]	.4220	.000472	625,376	1
[illegible] t	.9531	.001089	479,960	
[illegible]	.8787	.001010	500,284	

3.05 2-inch pipes. The main needs to be equal to seven 2″ pipes. Looking again in the table opposite 2 we find that a 4″ pipe is equal to 6.47 2-inch pipes, and the size to use will be the next size larger, or 4½″.

Dimensions of steam pipe will be found in the chapter on materials. See index.

Loss by condensation in steam-pipes is very considerable unless coverings are employed. The preceding table, taken from Helios, shows the gain in using pipe coverings, assuming the cost of coal at $2.50 per ton, the cost of firing 12 cents per hour, and an evaporation of 7 pounds of water per pound of coal burned.

QUESTIONS.

What is the difference between heat and temperature?

How would you measure the number of heat units in a body?

What are the name and general principle of the instrument used for measuring temperature?

What is the difference between the Fahrenheit and the centigrade scales?

What is the difference between melting point and boiling point?

What is the absolute zero of temperature?

What is the mechanical equivalent of heat?

How many pounds of water will be raised 1 degree Fahrenheit by expending 1 horse-power on the water for the period of 1 hour?

What is latent heat?

What is the relation between total heat, latent heat of vaporization, and the heat of the liquid?

In what three ways is heat transferred?

Give the meaning of the term fuel.

Give the component parts of various kinds of fuel.

Give the comparative values of various kinds of wood for the *purpose of fuel as compared* with coal.

PART III.

BOILERS.

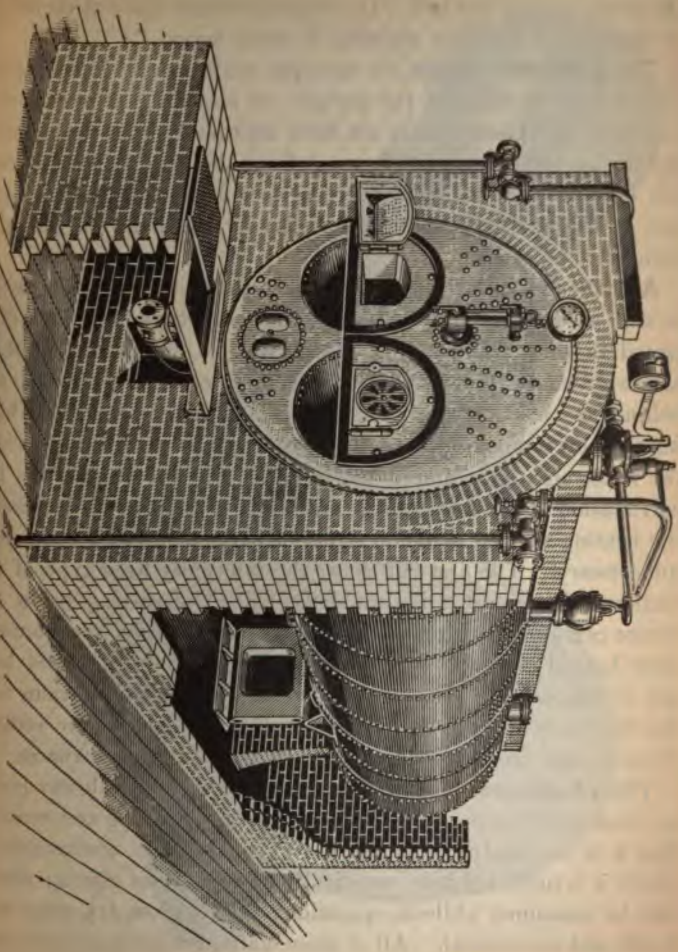
CHAPTER IX.

HISTORICAL AND DESCRIPTIVE.

Plain Cylindrical Boiler.—The first boilers consisted essentially of a plain cylinder of cast iron, set longitudinally in brickwork. The lower part of the cylinder contained the water, the upper part the steam. The ends were usually made hemispherical for increased strength, and the furnace was placed under the boiler at one end, consisting essentially of a series of grate bars set at a convenient distance from the boiler shell.

This type of boiler was in use for many years. It has, however, two great defects. In the first place, the heating surface, consisting of about one-half of the surface of the shell, is much too small compared to the bulk of the boiler, and consequently the gases pass from out of the stack at a very high temperature, wasting a large percentage of the heat of combustion. In the second place, the scale formed in the bottom of the boiler, right where the heat is most intense, makes a non-conducting stratum, which soon renders that portion of the heating surface practically useless, besides having a tendency to burn up the iron at that point. This latter defect has been partially remedied by placing a removable trough in the bottom of the boiler. The other defect, namely, insufficient heating surface, has been sufficient, however, to condemn this type of boiler, and there are very few in use at the present time.

***Cornish,* Lancashire, and Galloway Boilers.**—The next step in *the development* was the Cornish boiler, which consisted of a cyl-



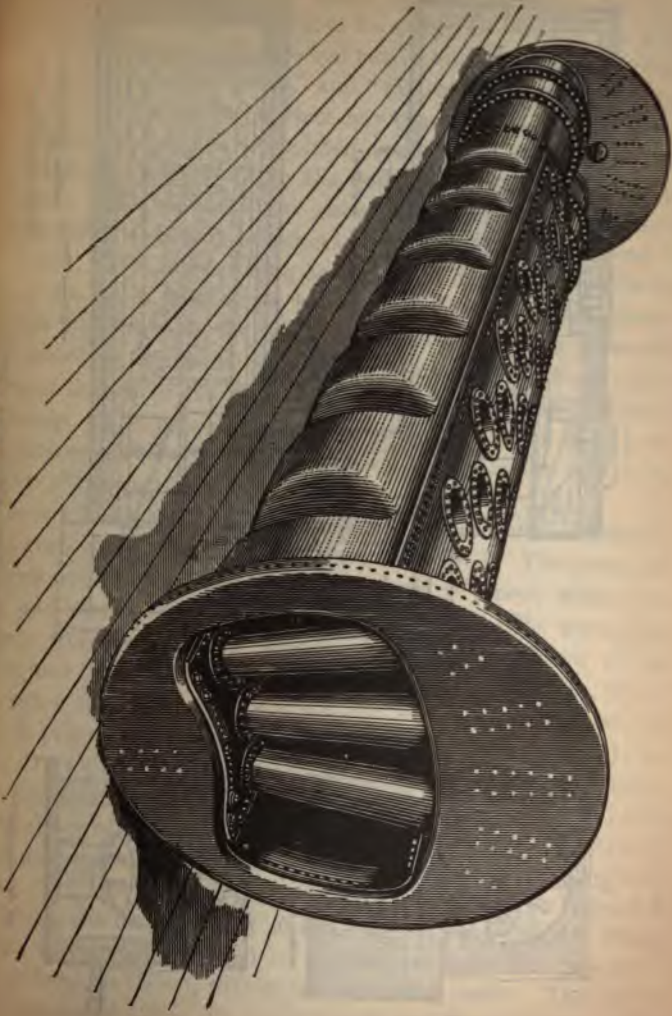
Galloway Boiler—Internally Fired Type.

lindrical shell with one internal cylindrical flue running th
ngth of the boiler. The furnace is contained in the flu
e grate bars at one end. In order to obviate some of the
f this type it has been modified in many ways.

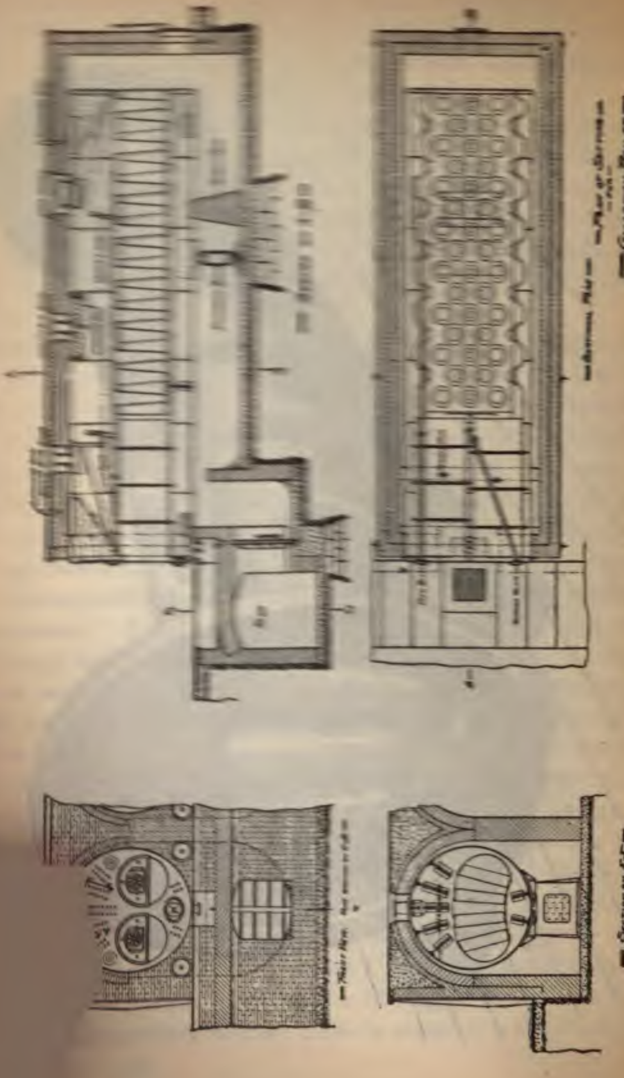
The Lancashire boiler, for example, contains two interna
rnaces side by side, for the purpose of attaining a more
ombustion. The furnaces are fired alternately, and consec
e smoke and unconsumed gases from the freshly fired f
re ignited in the common flue (the two flues usually mer
ne at the back of the bridge walls) by the heat of th
urnace.

A further modification of this type is the Galloway boiler
still used extensively. In the Galloway type, which i
ated in the accompanying cuts, it will be observed, tha
e two furnaces placed side by side, merging into a comm
ehind the bridge wall. The heating surface is increase
umber of conical tubes, called Galloway tubes, through
e water circulates, and by corrugating the flue as shown
rrugation of the flue and the Galloway tubes, besides inc
e heating surface, also add strength to the boiler and mak
nnecessary. The first cut shows the internally fired type
alloway boiler as it is ordinarily set. The casting bel
uire carries the weight of the boiler, and the brick pier in
ly behind it is added for safety, in case anything shoul
n to the casting. The second cut shows the corrugation
Galloway tubes, while the third is a plan of the s
ese boilers are also frequently made with external furnac

The advantages claimed by the makers of the Galloway
every portion is easily accessible for cleaning and re
o constructed that the expansion and contract
ubjected have practically no deleterious effects;
nined while in operation; that it gives dry stea
conomical. All of these claims are more or less
d practice, and the boiler is certainly a very suc
y ways.



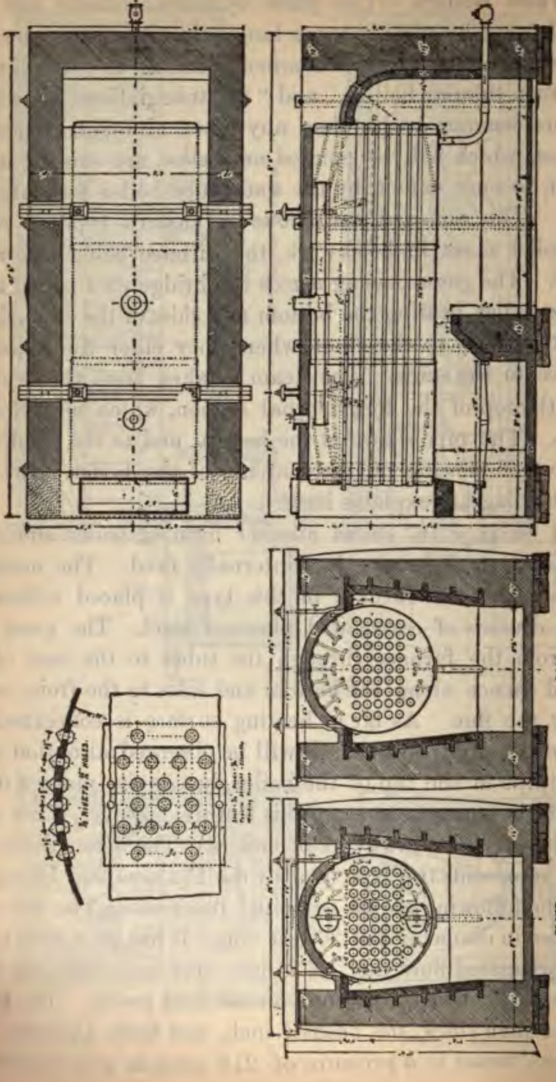
Galloway Boiler Flues.



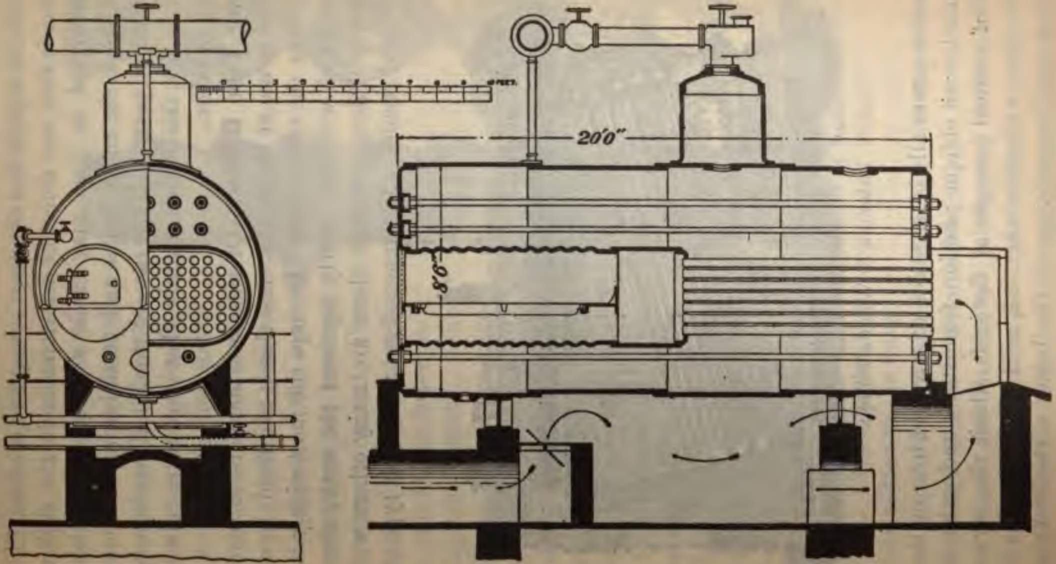
Setting Plan—Galloway Boiler.

Fire Tube Boilers.—The plain cylindrical boiler has been developed, also, by placing tubes longitudinally within the shell. This class of boilers, which is commonly known as "tubular boilers," "return tubular boilers," and "fire tube boilers," is without doubt more common to-day than any other, although certain disadvantages, which will be pointed out below, are causing its displacement, to some extent, by the water-tube boiler for stationary purposes. The annexed cut shows a modern type of return tubular boiler as set in brickwork, the furnace being external to the boiler. The gases passing across the bridge wall travel to the rear of the boiler, heating the bottom and sides of the shell, thence through the tubes to the front, where they enter the main flue and thence to the stack. The steam is taken from the *dry pipe*, shown at the top of the longitudinal section, which is perforated at the top. The pipe shown at the bottom and to the right is for the purpose of blowing off the contents of the boiler. In other respects the diagram explains itself.

The cut on page 167 shows another form of boiler similar in many respects to the above, but internally fired. The main differences are that the furnace in this type is placed within the shell and consists of corrugated plates of steel. The gases pass directly from the furnace through the tubes to the rear of the boiler, and thence along the bottom and sides to the front, where they enter the flue. As far as heating surface is concerned, the effect is practically the same. It will be observed, also, that there is no dry pipe in the top of the boiler, but in its place a dome, from which the steam is taken. This feature, however, is not peculiar to either of these two types of boilers. The boiler illustrated in this cut represents the type used by the Philadelphia Bureau of Water. The following are the principal dimensions: The boiler is 8 feet 6 inches in diameter and 20 feet long. It has 90, 4-inch tubes, 2 Fox's corrugated flues and 12, 2½-inch stay bolts that run from head to head, as shown, with nuts outside and inside. The boiler plates are ⅞-inch thick, the heads ⅝-inch, and flues 17/32-inch. The boilers are all tested to a pressure of 215 pounds per square inch.



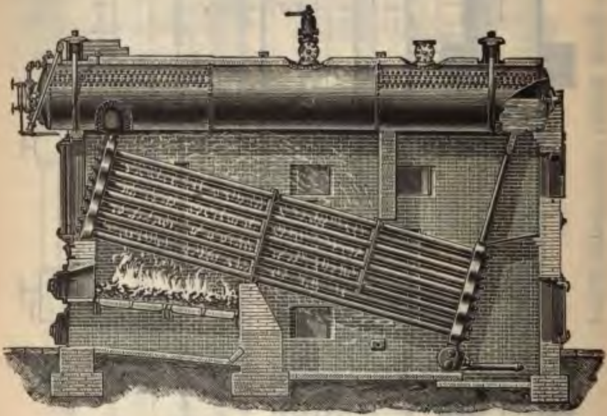
Horizontal Fire Tube Boiler and Setting.



Horizontal Fire Tube Boiler, Internally Fired.

Tubular boilers have many advantages. They are easily accessible for repairs and cleaning, strong and efficient. The great objection is that any defect or deterioration in the shell which is not discovered in time may cause a serious explosion, which would wreck the entire boiler and possibly produce fatal results to life and property. Many cases of this kind have been recorded, and it is for this reason, mainly, that the water tube boiler is growing in favor.

Water Tube Boilers.—Of this class there are so many different types in use at the present time that it is difficult to select one to represent the entire class. Perhaps the most widely used, and the one which will most nearly represent the entire class, is the Babcock & Wilcox, although there are many others which give equally good results. The annexed cut shows this type of boiler.



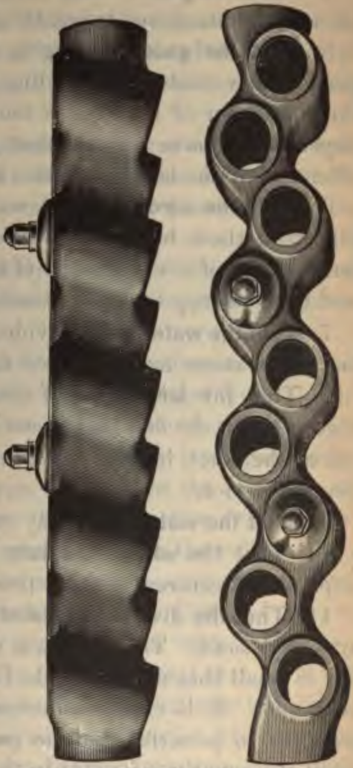
Babcock & Wilcox Boiler.

It consists essentially of a series of wrought-iron or steel tubes suspended in an oblique position from steam and water drums by means of vertical passages at the ends, which also serve to connect the tubes with each other. A mud drum connects the tubes the rear and lowest point of the boiler. The end connections

s in this type are in one piece for each vertical row of
latter being staggered as shown. The ends of the tubes
nded into the headers.
r therefore consists of
of vertical sections of
es, virtually independ-
h other, except for the
nections to the steam
drums. The first cut
early how the boilers
he course of the com-
ases, and the level at
water is carried. For
the plates are removed
ends of the tubes and
g tool inserted. The
steam drums are made
ht-iron or steel, while
rums are usually made
on.

lowing advantages are
or water-tube boilers:

t the portions of the
ich contain the water
nall in diameter that
rial used in the con-
can be made compar-
ght without impairing
th. Consequently the
ansmitted to the water
dily and the danger of burning the iron where it is ex-
the fire is greatly diminished.



Headers of Babcock & Wilcox Boiler.

t there are no riveted joints, and consequently no
icknesses of *metal exposed to* the fire.

the draught area, being much larger than in fire-tube boilers, gives ample time for the absorption of the heat of the gases before their exit to the chimney.

4. **That the gases** being thoroughly mingled in their passage between the staggered tubes, the combustion is more complete.

5. **That the gases** impinging against the heating surface perpendicularly, instead of gliding along the same longitudinally, the absorption of the heat is more thorough. It is claimed that experiments have proven that a gain of 30 per cent. in the efficiency of the heating surface is effected.

6. **That the circulation** of water is rapid and all in the same direction, there being no conflicting currents. As a result the temperature of every portion of the boiler is practically the same, and the tendency to deposit scale is materially lessened.

7. **That the water** being divided into many small streams in thin envelopes, steam may be raised rapidly.

8. **That the large area** of disengaging surface in the drums, together with the fact that steam is delivered at one end and taken out at the other, insures dry steam without the aid of any superheating device.

9. **That the water level** may readily be kept steady.

10. **That the whole structure** is so flexible that the parts may expand and contract without producing strains.

11. **That the division of water** into small masses avoids destructive explosions. The diameters of the parts subjected to pressure are so small that even if made light their power to resist rupture is ample. It is claimed, moreover, that the circulation of the water is so powerful that no part will be uncovered to the fire until the quantity of water in the boiler is so far reduced that if overheating should occur no explosion could result.

12. **That the space** occupied by this type of boiler for a given power is much less than in fire-tube boilers.

13. **That, by a suitable arrangement** of hand and man holes, every part of the boiler is accessible for cleaning and repairs.

14. That the [illegible] **effect** from dust collecting on the top of *the tubes is f*[illegible] fire-tube boilers, where it collects o the interior. In the latter case there is no limit to the amount of dust which may collect, while in the former only a limited amount is retained.

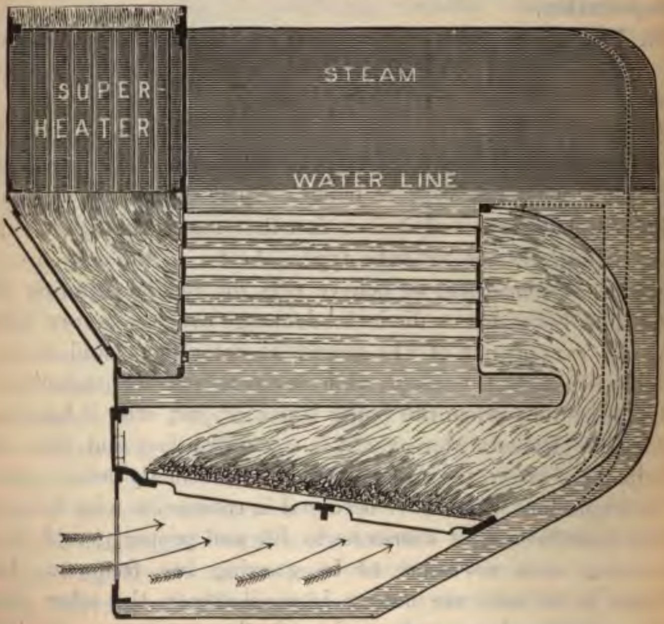
15. **That since no part of the boiler** above the water level is exposed to the fire, and because of the absence of deteriorating strains and of thick plates and joints in the fire, it is much more durable.

16. **That, being made in sections,** it is less cumbrous and much more easily transported. In fact, the parts for a boiler of very considerable capacity can be made small enough for mule transportation.

17. **That a new tube** may be easily inserted or almost any other repair made by an ordinary mechanic without any but ordinary tools.

Summary.—The advantages which have just been enumerated for water-tube boilers are all more or less borne out by practical experience with this type of boiler. They should not be overestimated, however, and it is a fact that many intelligent engineers still prefer the fire-tube type. As far as the economy of operation is concerned, we believe that for regular running the water-tube boiler has a distinct advantage over the return tubular. An evaporation of 11½ pounds of water per pound of combustible is not at all unusual, while in fire-tube boilers such results are attained only when the boiler is new or just after it has been thoroughly cleaned. Moreover, it is certainly a fact that, from the standpoint of safety, the water-tube boiler is distinctly better. Some of the explosions which have occurred in connection with fire-tube boilers have been most disastrous to life and property, and their occurrence does not seem to be growing less frequent. Explosions, to be sure, are not an impossibility in the other type, but, considering how many are in use, they are very rare, and, moreover, an explosion in a water-tube boiler, if properly set, seldom wrecks more than a single tube or a header. On the other hand, the water-tube boiler is a much more expensive apparatus than the fire-tube, especially for small capacities, and this feature alone will, without doubt, cause the latter to be retained in many cases, notably in the coal regions, where the cost of fuel is so low as to make economy in its use a secondary consideration.

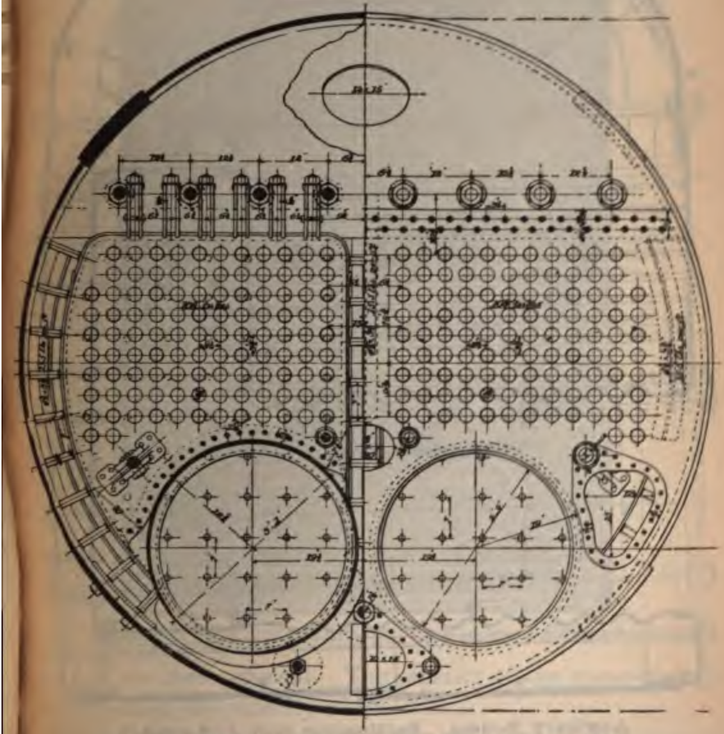
Marine Boilers.—For marine purposes many types, both fire and water tube, are used. The water tubular is fast disappearing, and is now rarely to be found except in the United States Navy, and in the navies of other countries. Its gradual disappearance arises from the fact that it is more expensive to build and to repair, is more complex, and requires extra care and management. If a tube splits or becomes leaky in the fire-tubular boiler, difficulty may be met by plugging, and the vessel can proceed way; but if the same accident occur in a water-tubular, it



Fire-Tubular Marine-Boiler.

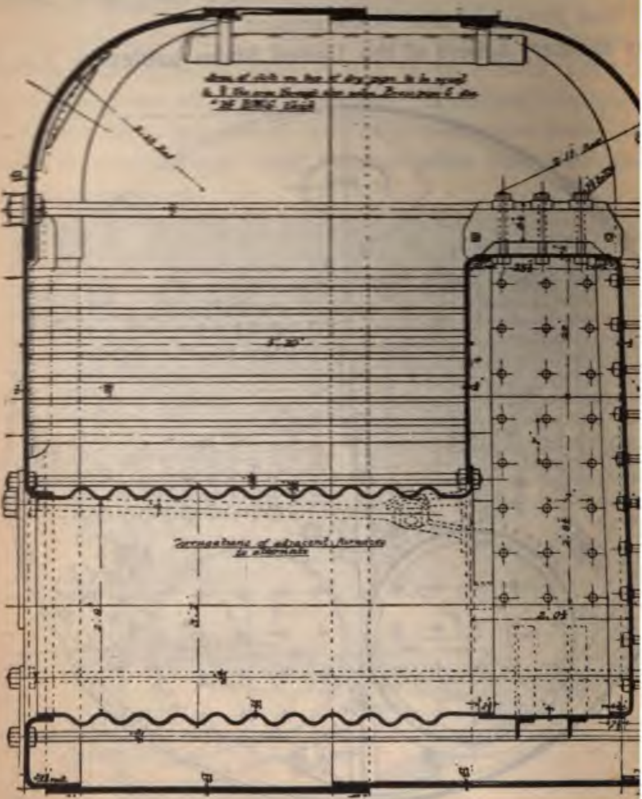
would be necessary to blow out the boiler. The same principle which was embodied in the Montgomery water-tubular marine-boiler was introduced into the Dimpfel locomotive-boiler, but soon fell into disuse in both cases. The fire-box, fire-tubular marine-boiler, with combustion chamber at the back end is the type of marine boiler most commonly used at the present time.

The auxiliary boilers of the United States battleship, Nos. 1, 2, and 3, the *construction of which* is clearly shown in the accompanying *cuts, illustrate* modern marine boiler practice.



Auxiliary Boilers. Battleships Nos. 1, 2, and 3.

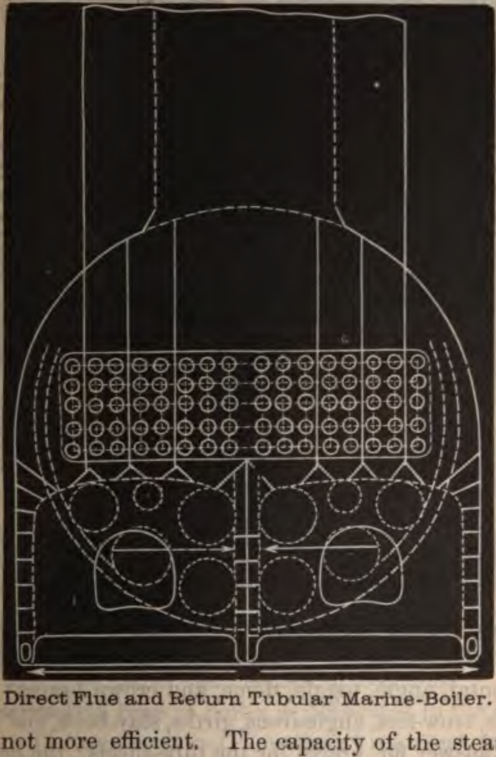
In this boiler it will be seen that there are two internal c
gated furnaces, which is the number usually employed wher
diameter of the boiler is from 9 to 13 feet. For diameters
13 feet three are often used, while the largest boilers, often ex
ing 15 feet in diameter, have four furnaces. Moreover, th
of boiler is frequently made double-ended, in which case th
furnaces at both ends, each furnace having a separate co



Auxiliary Boilers. Battleships Nos. 1, 2, and 3.

hamber, so that if a tube gives way in one chamber the other urnaces are not affected.

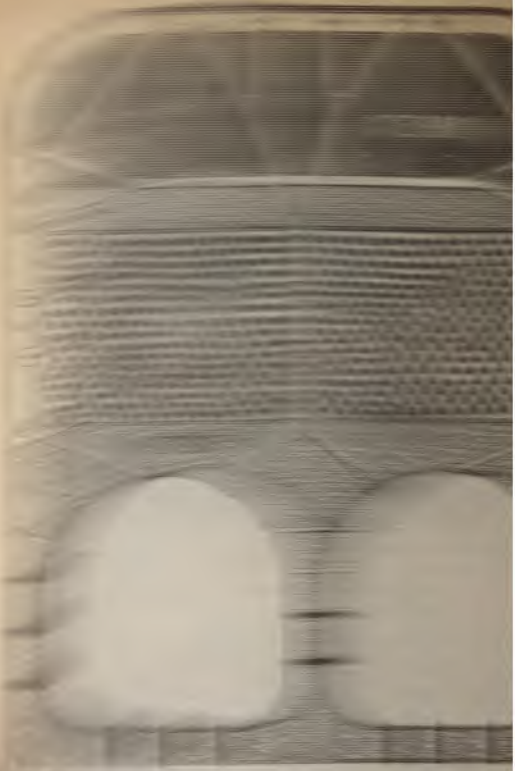
Martin's upright tubular boiler is sometimes used for marine urposes. Its only advantage is economy of space; its first cost more than that of the ordinary horizontal marine tubular boiler,



Direct Flue and Return Tubular Marine-Boiler.

it is not more efficient. The capacity of the steam-room is t one-third the capacity of the boiler.

his type of boiler is now but rarely used, and, in fact, none of ypes which have been tried from time to time have proved selves *superior to the cylindrical* return tubular type with *al furnaces.*



The above cut represents the arrangements cross [illegible] crown-bars and includin[illegible] crown brac[illegible] girths, stay-bolts, a[illegible] for the manufacturer. The[illegible] ed down, the proper strength for the fire[illegible] may be found by multiplying the number of[illegible] in the pressure of the steam by six times the[illegible] carried.

The principal dimensions of the boilers illustrated in the cuts on pages 173 and 174 are as follows: *

Diameter of boiler, outside		10′ $1\frac{25}{32}$″
Length " "		8′ 6″
Length of grate		5′ 10″
Heating surface:		
Tubes	824.66 sq. ft.	
Furnaces	60. "	
Comb. chamber	84. "	
Total	968.66 sq. ft.	
Grate area		32. sq. ft.
Ratio of heating to grate surface		30.3
Boiler pressure		160. lbs.
Number of tubes		216 { 58 stay. 158 ordinary.

Locomotive Boilers.—The duties which a locomotive boiler is called upon to perform have led to a development distinct, in many respects, from other types of boilers. A boiler which is to be used on a locomotive must have the following properties:

The size and weight are limited, because the boiler must be carried along at a high rate of speed. For the same reason and also on account of the jarring to which a locomotive is subjected, brick setting cannot be considered. Consequently the boiler must be internally fired. Additionally, it is necessary to evaporate a very considerable amount of water in a short time and to carry it at a high pressure. In other words, the conditions are such that the development of this class of boilers has been in the direction of rapid steaming rather than in that of economy.

The locomotive type of boiler is illustrated in the accompanying cuts. The two sectional elevations † represent two different types, the "Crown Bar" and "Radial Stay," so called after the

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* From the "Report of the Chief of the Bureau of Steam Engineering," Washington, D. C., 1890.

† From "Illustrated *Catalogue of* Narrow Gauge Locomotives," Baldwin *ocomotive Works, Philadelphia,* 1897.

[illegible] as is clearly [illegible]
[illegible] boiler proper, 2 the
[illegible] pipe, 9 is the throttle
[illegible] 30 is the fire-door,
[illegible] bars and stay bolts.

[illegible] made of copper
[illegible] rectangular, strength
[illegible] comparatively thick and it is in
[illegible] from the furnace readily
[illegible] pass through a
[illegible] stack which is
[illegible] by the exhaust
[illegible] from a nozzle (not
[illegible]

[illegible] is used quite
[illegible] setting is
[illegible] the boiler is to be
[illegible] importance than
[illegible] built by
[illegible] does not
[illegible]

[illegible] in the
[illegible] the same
[illegible] and
[illegible] which it is
[illegible]
[illegible] into
[illegible] The shell of
[illegible] the firebox, etc.
[illegible] can be seen in
[illegible] pressure.

Bellpaire Fire-box Boiler.

CHAPTER X.

BOILERS—DESIGN AND CONSTRUCTION.

Horse-power.—The horse-power of boilers is now usually determined by what is known as the Centennial Rating, which was adopted in 1876 by the committee of judges of the Centennial Exhibition. According to this, a horse-power is 30 pounds of water evaporated into dry steam per hour from feed water at 100° F., and under a pressure of 70 pounds per square inch above the atmosphere. A boiler rated at any stated number of horse-power should be capable of developing that power with easy firing, moderate draught, ordinary fuel, and good economy; and further, the boiler should be capable of developing at least one-third more than its rated power to meet emergencies at times when maximum economy is not the most important consideration.

The quantity of steam that can be generated in any boiler in a given time is dependent on a great variety of circumstances, such as the kind of boiler; its condition as to scale, dirt, etc.; the manner in which it is set and fired, the quality of fuel used, amount of grate-surface and heating surface, draught, etc., while the amount of water used will depend entirely on the engine, provided the steam is dry. The evaporation in tubular boilers,—stationary, locomotive, and marine,—under good conditions, is about 8 to 10 pounds of water to 1 pound of coal; water-tube, 10 to 12; but the [illegible] sult is about 25 per cent. below this. The nominal loss [illegible] ilers is rarely less than 30 per cent., and is frequently [illegible]).

[illegible] Grate Surface and Heating Surface.

[illegible] ***e surface required*** in different types of boilers is an [illegible] *variable* **quantity**, depending chiefly upon the quality of coal and the draught. If the quality of the coal is good, the percentage of ash being low, for a given draught, the grate may be smaller than for a poorer quality of coal. If the percentage of ash is high, the grate surface must be made proportionately larger. The following table, taken from Kent's "Mechanical Engineers' Pocket Book," gives approximately the grate surface required under different conditions. In general it may be said that in designing a new boiler, the grate surface should be made as large as possible without incurring other disadvantages in the design.

TABLE OF GRATE SURFACE PER HORSE-POWER.

	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 horse-power.								
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 and 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

Example.—With a poor quality of coal what should be the size of grate for a fifty-horse power boiler? What would be the consumption of coal, and how much water would be evaporated per pound of coal, the consumption of coal being 20 pounds per square foot of grate per hour?

From the table above:

Square feet of grate = 29 × 50 = 14.5.

Pounds *of water from and at 212°* = 6 pounds per pound of coal.

*Pounds of coal per horse-*power per hour = 5.75.

The ratio of heating surface to grate surface is dependent largely upon the quality of coal which is to be used. For good anthracite coal the practice, in stationary boilers, is to make this ratio from 30 to 40 square feet heating surface to 1 square foot grate surface. For bituminous coal the ratio is much higher, especially where the quantity of coal to be consumed per square foot of grate is large. In this case the ratio is sometimes as high as 60 to 1. There seems, however, to be a very considerable difference of opinion among engineers in this respect. While all generally agree that, in proportioning a marine boiler, for example, there should be sufficient grate-surface to consume the maximum quantity of coal required for the engine for which that boiler was intended to furnish steam, and that there should be sufficient heating surface to absorb the heat evolved by the fuel; yet, when it comes to laying down proportions, one engineer allows twice as many square feet of heating surface to one square foot of grate surface as another. Watt's proportions for land and marine boilers varied from 9.5 to 10 feet of heating surface to 1 square foot of grate surface. Maudsley and Miller allowed 10 square feet of heating surface to 1 square foot of grate surface in the boilers of the celebrated ocean steamer Great Western, and from 10 to 12 square feet of heating surface to 1 square foot of grate surface in other marine boilers that they constructed about the same time; so that neither they nor Watt seemed to have any fixed rule, nor did there appear to be any among naval constructors either in this country or in England.

This may be seen from the fact that the U. S. gun-boat Massachusetts had 34 feet of heating-surface to 1 square foot of grate-surface, while the Vixen, with the same-sized engine, had only 16 to 1. The merchant-steamer Constitution had 66 square feet of heating-surface to one square foot of grate-surface, while the Franklin, a steamship of nearly the same capacity, with engines of the same power, had only 28 to 1. The boilers of the celebrated steamships *the Collins Line*, which have made such fast time between *York and* Liverpool, had 33 square feet of heating-surface to 1 square foot of grate-surface, while in the boilers of the steamships of the Cunard Line the heating-surface varies from 18 to 37 square feet to 1 square foot of grate-surface. The Mary Powell, one of the fastest river-boats in American waters, has 17 square feet of heating-surface to 1 square foot of grate-surface. In proportioning the heating-surface to the cubic contents of the cylinder, the same variation seems to exist which shows there is no recognized proportion for either. The steamship Massachusetts, U. S. N., has 77 square feet of heating-surface to 1 cubic foot of cylinder, while the Powhatan has less than 15 square feet, and the San Jacinto has a trifle over 12. The merchant-steamer Union had one hundred and eighteen square feet of heating-surface to 1 cubic foot of cylinder, while the Isaac Newton had only 10 to 1. The steam-tug Rescue had 63 square feet of heating-surface to 1 cubic foot of cylinder, while the Anglo-Saxon had only 10 to 1.

The average proportion of heating-surface to grate-surface of 345 steamships, tugs, and ferry-boats examined was about 30 square feet of heating-surface to 1 square foot of grate-surface, while an examination of a great number of steamships, tug, and ferry-boats in this country, England, and France, showed that the average proportion of heating-surface to 1 cubic foot of cylinder was about 28. In stationary boilers the heating-surface varies from 12 to 30 to 1 square foot of grate-surface, while in some patented sectional boilers there are 60 to 70 square feet of heating-surface to one square foot of grate-surface, the average for locomotive-boilers being about 60 square feet of heating-surface to 1 square foot of grate-surface.

To proportion a marine-boiler understandingly, it is necessary to know the size of the engine and of the boat or ship, the load to be propelled, and the speed at which it is to move. The engineer can determine the pressure and volume of steam required, and decide on the degree of expansion, the quantity of grate- and heating-surface, and in relation to these two latter conditions, as shown in the *foregoing paragraphs*, the field has a very wide latitude. *But he must be sure that* the boiler possesses sufficient strength to resist in safety the maximum pressure to which it wil ever be exposed; that it contains sufficient grate-surface for the combustion of the necessary quantity of fuel under any circumstances; that it has sufficient heating-surface to evaporate the necessary quantity of water; that it is capable of containing a sufficient supply of water and steam to prevent undue fluctuation, and that it affords convenient facilities for the repair or renewal of any of its parts. After the foregoing conditions are determined on, another object of great importance to be considered is making the boiler as light and compact as possible. The term heating-surface, when applied to steam-boilers, means all that part of the fire-box, crown-sheet, tube-sheets, and flues with which the fire and flame come in contact in their escape from the furnace to the chimney.

Rules.

Rule *for finding the number of square feet of heating surface in a tube, or any number of tubes.*

Multiply the circumference of the tube in inches by its length in inches, and *divide by* 144; the quotient will be the number of square feet of heating surface. This *multiplied* by the whole number of tubes, will give the aggregate amount of heating surface.

Rule *for finding the heating-surface of fire-box boilers—locomotive, marine, or stationary.*

Multiply the length of the furnace-plates in inches by their height above the grate in inches; multiply the width of the ends in inches by their height in inches; multiply the length of the crown-sheet in inches by its width in inches; also the combined circumference of all the tubes in inches by their length in inches; from the sum of these four products subtract the combined area of all the tubes and the fire-door; divide the remainder by 144, and
otient will be the number of square feet of heating-surface.

r flue-boilers.—Multiply ⅔ of the circumference of the
ches by its length in inches; multiply the combined
ce of all the flues in inches by their length in inches;

the sum of these two products by 144, and the quotient e the number of square feet of heating-surface.

le for cylinder-boilers.—Multiply ⅔ of the circumference e shell in inches by its length in inches, divide by 144, and uotient will be the number of square feet of heating-surface.

le for externally-fired tubular boilers.—Multiply two-thirds circumference of the shell in inches by its length in inches; iply the combined circumference of all the tubes in inches eir length in inches. To the sum of these two products add hirds the area of both tube-sheets; from this sum subtract the ined area of all the tubes; divide the remainder by 144, and uotient will be the number of square feet of heating surface.

le *for finding the heating-surface of vertical tubular boilers, such e generally used for fire-engines.*—Multiply the circumference e fire-box in inches by its height above the grate in inches. iply the combined circumference of all the tubes in inches eir length in inches, and to these two products add the area e lower tube- or crown-sheet, and from this sum subtract the of all the tubes, and divide by 144. The quotient will be umber of square feet of heating-surface in the boiler.

Strength of Boilers.

le *for finding the pressure per square inch which will rupture indrical boiler.*

ultiply the thickness of the shell in inches by the tensile gth of the material and divide the product by one-half the eter of the boiler in inches.

ample.—Suppose the diameter to be 6 feet and the thickness e shell to be ½ inch, then if the tensile strength of the mate- s, say, 48,000 pounds per square inch, the bursting pressure be

$$\frac{\frac{1}{2}\times 48000}{\frac{1}{2}\times 72} = 666\tfrac{2}{3} \text{ pounds per square inch.}$$

the above it has been assumed that the shell of the boiler is *tinuous ring without joints* of any kind. In practice this is of these [illegible]. In all modern boilers the shell is bui of a number of plates riveted together.

Riveted seams weaken the shell and their effect is usually t into account in the calculations by assuming that the te strength of the material has been impaired to a certain ex depending on the nature of the joint. The following table derived from Unwin's "Elements of Machine Design," g approximately the extent to which the plate is weakened u different conditions. The figures apply to iron plates and rivets.

Thickness of plate.	Diameter of rivets.	Pitch of rivets.	Efficiency of joints.
SINGLE RIVETED JOINTS.			
[illegible]	[illegible]	[illegible]	.56
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	.53
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	.45
DOUBLE RIVETED JOINTS.			
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	.72
[illegible]	[illegible]	[illegible]	.71
[illegible]	[illegible]	[illegible]	.69
[illegible]	[illegible]	[illegible]	.64

In using this table the tensile strength of the material is multiplied by the efficiency of the joint.

Example.—If in the example given above the joint is do riveted, what would be the bursting pressure?

$$\frac{\frac{1}{2} \times 48000 \times .72}{\frac{1}{2} \times 6 \times 12} = 480 \text{ pounds per square inch.}$$

The result of this example does not mean that the boiler d at 480 pounds per square inch. To find the wor usual to assume a factor of safety, which mea ch the tensile strength is divided before it is ns.

fety used in boiler calculations differs

hat in different localities. For example, the number adopted
the British Board of Trade for marine boilers is 5, while the
rench government uses 3 for stationary boilers. Hence we have
e following

Rule *for finding the working pressure in cylindrical boilers.*

Multiply the thickness of the shell in inches by the tensile
rength of the material and the efficiency of the joint. Divide
e result thus obtained by the product of one-half the diameter
the boiler in inches and the factor of safety. The quotient will
the safe working pressure in pounds per square inch.

Example.—What is the safe working pressure in a cylindrical
iler with double riveted joints, if the diameter is 8 feet, the
ickness $\frac{3}{4}$ inch, the factor of safety 4, and the tensile strength of
e plate 50,000 pounds per square inch?

$$\frac{\frac{3}{4} \times 50000 \times .69}{\frac{1}{2} \times 12 \times 8 \times 4} = 136 \text{ pounds per square inch.}$$

Rule *for finding the proper thickness of cylindrical boiler shells to
fely carry a given pressure.*

Multiply the working pressure in pounds per square inch by the
ctor of safety and one-half the diameter of the boiler in inches.
ivide the result thus obtained by the product of the tensile
rength of the plate and the efficiency of the joint. The quotient
ill be the proper thickness in inches.

Example.—Required the proper thickness of shell of a cylindri-
al boiler with double riveted joints to safely carry a working pres-
ure of 125 pounds per square inch. Diameter, 65 inches; factor of
afety, 5; tensile strength, 45,000 pounds. As the proper thickness
ill be about $\frac{5}{8}''$, we will assume .71 as the efficiency of the joint

$$\frac{125 \times 5 \times 32.5}{45000 \times .71} = \frac{5}{8}'' \text{ approximately.}$$

Rule *for finding the safe external pressure on boiler flues.*

Multiply the square of the thickness in inches by the constant
umber, 89,600. Divide the product by the length of the flue in
eet and by its diameter in inches. The quotient will be the safe
orking pressure in pounds per square inch.

Boiler Materials.

Boiler making now holds an important place among the me ical arts. Its progress has been aided chiefly by the eno growth of the steam-engine as the prime mover, by the inc facilities afforded for procuring suitable materials, and by t provements made in working them. In the early days steam-engine, boilers of copper and cast-iron were used for ating steam, but they were seldom subjected to a pressure than that of the atmosphere; but when pressures of 3 to 4 o 7 atmospheres came into use, cast-iron was found to be unr and treacherous, for which reason it was discarded in fa *wrought iron*, which was not employed at first, in conseque the difficulty found in working it and in making steam-tight It has, however, of late years become the material employed almost entire exclusion of cast-iron and copper. Steel, also, i ing in favor and is now extensively used both for tubes and

The first quality to be sought for in boiler materials is st This does not necessarily imply the mere power to resist torn asunder by a dead weight, as in a testing-machine; b quality to withstand, without injury, the varying shoc strains to which boilers are exposed. An inferior quality o cannot be relied upon to bear the ordeal of heating and repeatedly, as they invariably warp and twist, showing de manufacture; more especially in the process of cold bendin minute fractures often occur on the outer surface of the pl stubborn or inferior qualities of iron.

The defect most commonly revealed in working boiler- want of lamination. This defect arises from the imperfect of the several layers which make up the thickness of the pl is usually caused by interposing sand or cinder, which n expelled by hammering or rolled out during the pr cture. This is more frequent in thick than in thin metimes very difficult to detect in cold plate, a ernible in the hot. It also often happens tha n passed as quite sound, on careful external exa ıd to be severely laminated when subjected to heating and ring, and prove totally unfit for use.

ers are of a similar nature, and arise from the same cause nation. Sometimes they appear as mere surface defects, of no consequence; but their appearance may be an in- of want of care or skill in the making of the plate, and always excite suspicion. It frequently happens that these pass undetected after the closest scrutiny and test by ham- but disclose themselves soon after the boiler is set to work, lly if the plates be exposed to sudden variations of tem- e. In the plates over the fire-grate of an externally fired such a blister may prove a very serious defect, and often ates the cutting out and replacement of the sheet. Infe- ınds of iron will rapidly show unmistakable signs of weak- en placed under the trying ordeal of bearing the alternate ement of a fierce flame and currents of cold air. The ariations of temperature caused by the sudden and frequent s of the furnace door, and passage of cold air through the ars, will soon tell on even the best iron, but more quickly of an inferior brand.

acteristics of boiler-iron when broken. On breaking a bar of wrought-iron, the fracture presents an appearance h the quality of the iron may, in some measure, be deter- The fracture is designated, on the one hand, as fibrous, silky, close-grained, etc., or, on the other hand, crystalline, open-grained, brittle, and cold-shut. When broken sud- the best qualities of plate and bar iron exhibit a fine, ained, uniform crystalline fracture, even silky, of a light olor; the appearance in the harder descriptions approach- that of steel. The appearance of indifferently refined and qualities is coarser, usually of a darker color, more or less , or open, exhibiting large facets, and approaching some tions of cast-iron. When broken gradually, good iron s a well drawn out, close fibre, of light greenish hue, whilst *qualities give a shorter,* more open, and darker fibre.

When good ductile iron is gradually torn asunder, it stretc to a considerable extent, causing a diminution of sectional are the fractured part, which should always be compared with original sectional area of the specimen in judging of the qual An inferior bar or plate may bear as great a tensile strain a similar specimen of superior quality; but on comparing their fr tured areas it will generally appear that the latter has been dra out considerably, while the inferior specimen, having stretch but little, has not sensibly diminished at the fracture. This owing to the fact that good ductile iron, when sudden strains occ will stretch, while badly refined will snap. Wrought-iron chan from fibrous to crystalline, after enduring long-continued c hammering, vibration, tension, jarring, and other strains, after l exposure to the influence of heat, or alternate expansion and c traction whenever it has been used for the plates of a boiler more. Even the very best plates, after from ten to twenty ye use in a boiler, have frequently been found to break withi stretching, at the same time displaying a crystalline fracture.

It has been said that this shows that a change has taken pl in the nature of the material, and that, from being fibrous a tough, it has, by some unexplained cause, become crystallized brittle, or that it has lost its nature in consequence of the tr ment it has undergone, whatever that may have been. Ther no doubt that the strains and other causes above mentioned h a tendency to make good iron become brittle and liable to sn suddenly under the same treatment that would originally h torn it gradually, and to this extent a change is produced in nature. This snapping, and not the fatigue of the metal, is direct cause of the crystalline fracture, which is but a necess consequence of the suddenness of the breaking, and not a pr erty of the iron itself. To say it snaps readily because it has come crystalline is to confound the cause with the effect. It erroneous to say the fibrous nature has passed out of the iron, its ductility can to some extent, at least, be restored, in m cases, by simply heating to a bright red, and slowly cooling, iron, or, failing that, by hammering or rolling it while hot. By heating to redness, and suddenly cooling, a piece of wrought-iron, it will become liable to snap, producing the same effect as cold hammering. The explanation of this is not clear, and it may be owing to the loosening of the crystals into which the composition of the material ultimately resolves itself. To this cause may also be attributed the same tendency to snap after long-continued jarring or alternate expansion and contraction.

It may be asserted, without fear of contradiction, that all boiler-plate worthy of the name is fibrous; whether its hardness makes it liable to snap, and, therefore, appear crystalline, depends on its original character and the treatment it has undergone. No fine iron can, however, by any treatment, except burning, be made to appear coarse, and the fibres of the poorest descriptions of iron cannot, without refining, be made to appear fine and close-grained. From a want of knowledge of the above facts, false opinions are often expressed respecting the qualities of boiler-plates.

It is no unusual thing to find intelligent mechanics and boiler-makers expressing their opinions, at coroners' inquests, on the quality of the iron in exploded boilers, without anything to base their opinions on except the load per square inch required to tear the plates asunder. They seem to forget, if the boiler be an old one, that the age, the position in the boiler in which the rent has taken place, the amount of strain to which it has been exposed, and all the circumstances connected with the occurrence, should be known in order to decide understandingly as to the quality of the iron. It has been shown, in numerous instances, that good ductile iron can be made to appear crystalline when pulled asunder in the testing-machine, by confining the minimum sectional area where fracture will occur to one point or to a very short length.

The general conclusions with regard to boiler material, which may be regarded as established from experiments, observations, and practice, thus far seem to be, 1st, That the laws of resistance of the parts of boilers to the internal pressure are sufficiently *well established; 2d, It is of* the utmost importance that the materials employed should be of the best quality as regards strength and durability; and as there are but few manufacturers of boiler-plates, the inspection of materials, especially boiler-plates, should be made by competent persons, appointed for that purpose, at the place of manufacture, which inspection should extend to the qualities of ores and the process of manufacture, the required brands, stamps, or certificates being put on or authorized by the inspectors in person. There is much greater certainty of securing the best materials by an inspection of the process of working, and of the raw materials employed, than by an inspection of plates after they have been sent to market, when, judging from all external appearances, good and bad plates are not easily distinguished.

Practical limits to the thickness of boiler-plates.— The proper strength of boilers, in order to enable them to withstand with safety the required pressure of the steam, is a matter of much importance as regards both life and property, and the responsibility of the proprietors and constructors of boilers is of so grave a character as to justify the devotion of a much larger space to this subject than is convenient in this work. The principles on which the strength of the material depends may be expressed in a very few words, — the strength being directly as the thickness of the metal, and, inversely, as the diameter of the boiler.

So long as the quality of boiler-iron remains as it is at present, the thickness of the plate may be practically determined within exceedingly narrow limits, as a good boiler must be constructed of plate ranging in thickness from $\frac{1}{4}$ to $\frac{3}{4}$ an inch, as anything less than the former cannot be properly caulked, and any thickness greater than the latter is difficult to rivet without the aid of machinery. A thickness of $\frac{3}{8}$ seems to have become the standard thickness for all diameters of boilers intended to sustain a high pressure. This, perhaps, arises from the fact that boiler-makers seem to be better acquainted with the practical limit to the strength of that thickness, because it has of late years been used more than any other; nevertheless, for steel, or some of the higher grades of American plate, a less thickness will suffice for the same pressure

iler Plates.—As already stated, the materials now commonly for the shells of boilers are wrought-iron and steel. The fications for this material vary somewhat in different locali- but the following, being that of the Board of Trade, is much : The material to have a tensile strength of from 54,000 to 0 pounds per square inch, to show an elongation at the point pture of not less than 18 per cent. in 10 inches, but should bout 25 per cent., and, if annealed, not less than 20 per cent. s 2 inches wide to stand bending until the sides are parallel distance from each other not greater than three times the ness of the plate. In some other requirements the contrac- of area is specified instead of the elongation, and in some nces both the elongation and contraction of area of cross on are specified.

tays.—For stays the Board of Trade requirements are that tensile strength shall lie between 54,000 and 60,000 pounds per re inch, with an elongation of not less than 20 per cent. in 10 es. Steel which has been welded or worked in the fire should be used.

ubes.—If wrought iron is used, it should have a tensile strength ot less than 45,000 pounds per square inch, and an elongation 5 per cent. in 8 inches. If steel is used, the elongation should ot less than 26 per cent. in 8 inches, and after tempering the bar should stand completely closing together. Experiments to indicate that, so far as leakage is concerned, iron is pre- ble because it is not subject to the same degree of expansion contraction as steel.

CHAPTER XI.

BOILERS: THEIR CARE AND MANAGEMENT.

GENERAL INSTRUCTIONS.

Water Level.

On taking charge of an engine and boiler, first ascertain if there is sufficient water in the boiler, and then trace out the pipes and connections between the engine, boiler, and pumps.

On first entering a boiler-room in the morning ascertain whether the water stands at the proper level or not.

Never fill a boiler with cold water while the shell, flues, or tubes are hot, as the contraction induced by the tube in cooling will have an injurious effect.

If the water should, from any unforeseen cause, become dangerously low, draw the fire, allow the boiler to cool down, and neither admit feed-water nor disturb the safety-valve.

In case the supply of water should be temporarily cut off, owing to the derangement of a pump, the bursting of a pipe, or any other cause, stop the engine, cover the fire with fresh coal, and shut the damper, so as to retain a sufficient quantity of water in the boiler to start on.

In all cases where it is possible, regulate the feed-water so as to send it into the boiler in a steady stream.

When fresh water is used in marine boilers it is best to use salt water for a short time when first put into use, in order to cover the parts with a thin coat of scale. This prevents them from being injured by the action of fresh water.

Do not rely entirely on the glass water gauge, but try the gauge *ks. If they do not* agree, ascertain the cause and remedy the *culty.*

The water gauges must be kept clean. They should be blown out frequently to prevent the passages from choking.

The water should not always be fed to the boiler by the same apparatus. It is always best to have two means of feeding the boiler. Use them alternately to make sure that both are in working condition. Examine the check valve while the boiler is feeding to satisfy yourself that it is working properly.

Firing.

Never start a fire under a boiler until you are satisfied there is a sufficient quantity of water in it.

Before starting a fire under a boiler, place a small quantity of coal on the grates, to prevent them from being warped by the extra heat of the new fire.

In starting a fresh fire under a boiler while it is cold, always allow it to burn gradually at first, in order to bring all the parts of the boiler to a uniform temperature.

Fire slowly and evenly. If the draft is weak or the coal poor, thin fires must be carried in order to supply the necessary amount of air. Medium thick fires are more economical with good draft and fuel.

Keep the grate covered with fuel and do not allow any holes in the fire, as the air passing through carries away heat, wasting fuel.

Do not clean the fires any oftener than is necessary.

The fires should not be disturbed while there is a bright light in the ashpit from the glowing coals in the furnace.

If there are several furnaces, they should be fired one at a time, as the unconsumed carbon which always tends to pass out of the stack when fresh coal is put on the fire, is ignited by the heat from the other furnaces. Besides the supply of steam is more uniform when the furnaces are fired alternately.

It is important that the fires should be fed frequently with a little coal rather than by heaping on a great deal at a time. By attending *to this the economy is* much greater and the supply of *steam more uniform.*

The best coal to use for steaming is that which is clean, bright, and free from slate and earthy matter. It is poor economy to buy cheap coal, as it requires constant cleaning of the fires and injures grates.

Steam Pressure.

Never carry a higher pressure of steam than is necessary, nor allow the water to rise above the second gauge-cock in the boiler when the engine is running.

Never open a steam-valve on a boiler under pressure quickly for the purpose of allowing steam to escape into the atmosphere, or into a boiler containing a less pressure, as it is attended with a certain amount of danger, and may possibly produce an explosion.

The steam gauge should stand at zero when the pressure is off. If it does not, the pointer should be adjusted.

The safety valve should be ample in size, and it should be tested at least once a day to make sure that it acts freely.

When the safety valve is blowing off the steam gauge should show the pressure at which the valve has been set. If it does not, find out which is wrong and correct the difficulty.

Cleaning and Blowing Off.

The heating surface should be kept clean, otherwise the heat of combustion will not be effective in raising steam. The boiler should at first be examined frequently to ascertain how much dust and scale has accumulated, and they should be removed at regular intervals.

Clean the flues or tubes of the boilers at least once a week, and never allow ashes or cinders to accumulate under the grates.

Boilers under which a forced draught is used require to be cleaned oftener than when the draught is natural.

When preparing to clean boilers allow them to cool down, and the water to remain in them until ready to commence cleaning.

If the feed water is muddy or salty blow off a portion *frequently and blow off* the boiler entirely, at least once a week.

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liable to spring the seams and cause fresh leakage in other parts of the boiler.

Scale Formation and Corrosion.

The tendency in all boilers is toward the formation of a non-conducting scale or incrustation on their heating surfaces, which lie between the iron and the water. It not only causes an increased consumption of coal, but allows the iron to become crystallized and burned. The evil effects of the scale are due to the fact that it is a non-conductor of heat. Its conducting power, compared with that of iron, is as 1 to 35.5. Consequently, more fuel is required to heat water in an incrusted boiler than in the same boiler if clean. A scale $\frac{1}{16}$ inch thick will require the expenditure of 15 per cent. more fuel; this ratio increases as the scale thickens. Thus, when it is $\frac{1}{4}$ inch thick, 60 per cent. more fuel is needed; $\frac{1}{2}$ inch thick, 150 per cent., and so on; consequently, to raise water in a boiler to any given temperature, the fire-surface of the boiler must be heated to a temperature corresponding to the thickness of the scale.

To raise steam to a pressure of ninety pounds, the water must be heated to about 320° Fah. In a clean boiler of $\frac{1}{4}$ inch iron, this may be done by heating the external surface of the shell to about 325°. If $\frac{1}{2}$ inch of scale intervenes between the shell and the water, such is its non-conducting power, that it will be necessary to heat the fire-surface to about 700°, almost red heat. Now, the higher the temperature at which iron is kept, the more rapidly it oxidizes, and at any heat above 600° it very soon becomes granular and brittle, and is liable to bulge, crack, or otherwise give way to the internal pressure. This condition predisposes the boiler to explosions, and makes necessary expensive repairs. Again, it is readily seen that the presence of scale renders slower and more difficult the raising, maintaining, and lowering of steam.

The minerals which constitute the basis of the scale whic *forms in steam-boilers* using fresh-water from wells, lakes, o *vers, are sulphate* of lime, phosphate of lime, carbonate of li magnesia, silica, and alumina, with small quantities of sesquioxide of iron, baryta, carbonic acid, organic matter, chlorine, sulphuric acid, potash, calcium, soda, phosphoric acid, magnesium, etc.

The principal ingredient in the scale which forms in marine boilers using sea water is sulphate of lime, but no very injurious effect will take place in boilers if the degree of saltness is not allowed to exceed $\frac{4}{32}$. In fact, a thin coat of scale is beneficial, as it protects the iron from corrosion and internal grooving.

An analysis of sea water shows the relative quantities of the ingredients it contains:

Water	964.745
Chloride of Sodium	27.059
Chloride of Potassium	0.766
Chloride of Magnesium	3.666
Bromide of Magnesium	0.029
Sulphate of Magnesia	2.296
Sulphate of Lime	1.406
Carbonate of Lime	0.033

The methods for preventing the formation of scale in steam boilers are innumerable. In general it may be said that where the quantity of scale-forming ingredients is small, say 12 grains per gallon, the trouble may be obviated by the use of chemicals or boiler compounds.

The composition of boiler compounds should be determined by the nature of the feed water, and a compound that is very effective in one case may be worse than useless in another. For example, if the impurity in the water consists largely of sulphate of lime, it may be prevented by adding the proper amount of carbonate of soda and introducing it into the boiler regularly with the feed water; but if the scale-forming ingredient is silica or alumina, say, the addition of carbonate of soda to the feed water will be ineffectual. The formation of scale is prevented by the use of boiler *compounds only* when their action is such as *to alter the chemical composition* of the ingredients, so that instead *of scale-forming salts they will* become soluble in hot water or of such a nature that they will be precipitated in the form of powder or grains.

It is evident, therefore, that no boiler compound can be effective in preventing the formation of scale in all cases. In order to determine the kind of preparation to use in any particular case it is necessary to have a complete chemical analysis of the feed water. There are many boiler compounds to be had in the market; while some of them, notably Lord's, are excellent for individual cases, it may safely be stated that any preparation which is sold as a preventive of scale or incrustation, no matter what the nature of the feed-water, is a fraudulent article.

The following substances may be used effectively to prevent the formation of scale: Carbonate of soda, if the ingredient which tends to produce scale is sulphate of lime, sodium phosphate for the sulphates of lime and magnesium, milk of lime for the carbonates of lime and magnesium, caustic soda and soda ash for the carbonate and sulphate of calcium and the sulphate of magnesium and tannate of soda for the suphate and carbonate of lime.

If the quantities of scale-forming ingredients are large, boiler compounds are of but little use. In such cases the source of water-supply should be changed, or else the water should be purified. The use of a feed-water heater is sometimes sufficient, while a condenser used in connection with the engine always insures pure water. If the water is absolutely free from salts, or if it is slightly acid, it should be neutralized by adding a small amount of lime. Rain water and condensed steam should be treated in this way, otherwise they will corrode the iron.

To remove hard scale from boilers it has been found well to add ¼ pound of caustic soda per horse-power and steam for a few hours. If this is done just before cleaning, the removal of scale will be greatly facilitated.

The term corrosion means wasting, pitting, or grooving of the material, and is generally referred to under two heads, namely, *ernal and external.*

ternal corrosion presents itself in different forms, and is due various causes, but principally to the minerals and acids contained in the feed water with which steam-boilers are supplied.

External corrosion is said to be due to the galvanic action of the minerals in the fuel and the gases in the atmosphere, and both causes are intimately associated with combustion, or stimulated by it; as the acids and minerals which are in solution in the water, and liberated by the heat, attack the boiler internally, while the sulphur which is liberated by the combustion of coal has a strong affinity for the iron of which boilers are constructed, and attacks it externally.

Corrosion in marine boilers is caused chiefly by the action of sea water and air while the boiler is under steam, and by the action of moisture and air when it is standing idle. Numerous devices have been employed to overcome this difficulty, the most effective of which are the formation of a thin layer of scale by steaming for a short time with sea water, painting the interior with Portland cement, or the use of metallic zinc suspended in the water and steam spaces. The two former methods reduce the efficiency of the heating surface somewhat, but aid materially in prolonging the life of the boiler. The action of the zinc is galvanic, and, while excellent results have been produced by its use in some cases, it has been found in others to produce a hard and tenacious scale.

Foaming.

Foaming in marine-boilers using jet-condensers is generally caused by changing the water from salt to fresh, or *vice versâ*, and is made evident by the boiling up of the water in the glass gauge. When foaming arises from this cause, the water in the boiler should be changed as soon as possible, which can be done by putting on a strong feed, and blowing out continuously, or at short intervals; it may even become necessary to throttle down the engine, cut off short, or even stop, in order to ascertain the level of the water in the boilers.

Violent foaming can be checked by opening the furnace-door, *closing the damper, and* covering the fire with fresh coal; but this means of relief should be used as little as possible, because it has a tendency to injure the boiler, owing to the sudden contraction of the parts most exposed to the fire. All the phenomena connected with foaming have not yet been satisfactorily explained; but, from whatever cause it may arise, it is always attended with a certain amount of danger. *Foaming* is sometimes confounded with *priming*, but they arise from different causes, and are productive of different results. *Foaming* is always made manifest by the violent agitation, the rising and falling of the water in the gauge, and the muddy appearance of the water.

Foaming is induced in stationary boilers by a filthy condition, particularly in those to which the feed-water is supplied through open heaters, in consequence of the oil or tallow employed for lubricating the cylinder being carried over with the exhaust-steam. The water in locomotive-boilers foams on some parts of the road, while on other sections this phenomenon never manifests itself, which may be attributed to the presence of alkali or saline matter in the water with which the boilers are supplied on certain parts of the road. Foaming is induced in all boilers by the want of proper proportion between the water-space, heating-surface, and steam-room of the boiler, and also from the absence of sufficient steam-room in the boiler to supply the cylinder.

Priming.

The term Priming is understood by engineers to mean the passage of water from the boiler to the steam-cylinder in the shape of spray instead of vapor. It may go on unseen, but it i generally made manifest by the white appearance of the steam as it issues from the exhaust-pipe as moist steam, which has a white appearance and descends in the shape of mist, while dry steam has a bluish color and floats away in the atmosphere. Priming also makes itself known by a clicking in the cylinder, which is caused by the piston striking the water against the cylinder head at each *end of the stroke.*

Priming is generally induced by a want of sufficient steam-roo in the boiler, the water being carried too high, or the steam-pipe being too small for the cylinder, which would cause the steam in the boiler to rush out so rapidly that, every time the valve opened, it would induce a disturbance, and cause the water to rush over into the cylinder with the steam.

Steam-Boiler Explosions.

The principal causes of explosions,* in fact, the only causes, are deficiency of strength in the shell or other parts of the boilers, *over-pressure* and *over-heating.* Deficiency of strength in steam-boilers may be due to original defects, bad workmanship, deterioration from use or mismanagement. Deficiency of strength arising from bad workmanship is the most difficult to discover, and not unfrequently escapes the closest scrutiny, more particularly in the case of flue, tubular, and locomotive boilers.

Over-pressure may be caused by the safety-valve being overweighted; by its sticking on its seat; by the inadequate size of the communication between the boiler and valve, or by an incorrect and worthless steam gauge. Overheating may be produced when there is a disproportion between the grate- and heating- surfaces, or where the heat from a large grate is concentrated on a small space. Under such circumstances, the heat is delivered with such intensity as to lift the water from the surface of the iron, thereby exposing it to the direct action of the fire.

Explosions occurring from excessive firing are in all cases the result of avarice, ignorance, or a want of skill in the care and management of the steam-boiler. Overheating may be caused by the accumulation of hard, solid incrustation adhering to the parts most exposed to the direct action of the fire, or it may be due to insufficiency of water, resulting from leakage of the valve or stop-cock, a failure in the supply-pipe, or a neglect to turn it on at the proper time or in sufficient quantity.

A steam-boiler may be well designed, of good material, and of

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* *See Roper's "Use* and Abuse of the Steam-Boiler."

first-class workmanship, and yet in a few months, after bei under steam, it may explode with terrible effect. On exa into the cause of the explosion, it may turn out that the used made a heavy deposit; that the boiler had not been c since it was put into use; that the fires had been fiercely and the water driven from the surface of the iron; as a the life had been entirely burned out of the sheets over and a the fire, thereby weakening the boiler, and putting it in gerous condition. That the sudden heating or cooling, and tion of the boiler, induce great deterioration of strengt been proved by experience. Defects in the material, as bl lamination arising from inferior material, or want of care manufacture, are other sources of weakness in steam-boilers

Upward of 300 boiler explosions occur annually in the U States, incurring the loss of over 300 lives and 450 injurie more or less serious character.

Technical Terms used in Connection with Boilers their Adjuncts.

Air-casing.—An arrangement attached to fire- and smok doors for the purpose of preventing radiation of heat.

Ash-pit.—The space below the grate, where the ashes mulate.

Blast-pipe.—A small pipe used to blow steam into the fu of locomotive and marine-boilers for the purpose of excitir draught in the furnace.

Blow-off cocks.—Cocks used for blowing the water o boilers.

-valve.—A valve used to retain the water in s nd relieve the feed apparatus from the pressure.

-chamber.—The chamber in which the check-

Connecting-pipes.— The pipes which connect check-valves with steam-boilers.

Crown-sheet. — That part of fire-box boilers (locomotive or marine) directly over the fire.

Crown-bars.—Bars placed on the upper side of crown-sheets, in the water-space, for the purpose of strengthening them.

Curvilinear Seams.—The curvilinear seams of a boiler are those around the circumference.

Crown-braces.—Braces attached to the crown-bars, and to the shells and domes of boilers, for the purpose of resisting the pressure exerted on the flat surfaces of crown-sheets.

Dashers. —Iron plates which are sometimes attached to the inside of steam-boilers to prevent the cold water, as it enters, from striking the tubes.

Dead-plate.—The solid iron plate which fills the space between the end of the grate-bars and the fire-door of boiler-furnaces.

Deflector.—An arrangement employed, in the furnaces of locomotives and marine-boilers, for the purpose of mixing the air and gases arising from the combustion of the fuel, and causing them to ignite.

Diaphragm-plate.—A perforated plate, used in the steam-domes of locomotives and marine-boilers, to prevent the water from being carried over into the cylinder with the steam.

Dome.—An elevated chamber on the top of steam-boilers, from which the steam is generally taken for the cylinders.

Dome-stays.—Stays employed, in the domes of locomotives and marine-boilers, for the purpose of strengthening them.

Dry Pipe.—*A perforated* pipe placed in the steam space, from

QUESTIONS.

THE ANSWERS TO WHICH MAY BE FOUND IN THE TEXT.

How were the first steam boilers constructed?

What were the reasons for abandoning the plain cylindrica boiler?

Describe and make sketches of the Cornish, Lancashire, an Galloway boilers.

What are the advantages of Galloway tubes?

Why are furnaces of boilers made corrugated?

What is meant by a tubular boiler?

What is the difference between a tubular boiler and a return tubular boiler? Make a rough sketch of each.

Make a sketch showing the method of setting a tubular boiler in brick-work.

What is the course of the combustion gases in a return tubular boiler?

What is the difference between an internally and an externally fired boiler? Make sketches showing the difference in the setting.

What different methods are employed in tubular boilers for taking off the steam?

What advantages have tubular boilers over other types?

Describe the Babcock and Wilcox type of steam boiler.

What are some other water-tube boilers?

Describe the Bellpaire fire-box boiler.

What advantages are claimed for water-tube over fire-tube boilers? Which of the two is the safer? Which is the cheaper to build?

Why is the fire-tube or tubular type of boiler preferable in some cases to the water-tube type?

What are the characteristics of marine boilers?

Why are the boilers used for marine purposes built differently from those used on land?

ake a sketch of a modern marine boiler, showing the shell, fur-
tubes, and method of staying. Indicate, by arrows, the
of the gases.

How many furnaces are used in marine boilers of different diameters?

Why do the furnaces in marine boilers have independent combustion chambers?

What conditions must be taken into consideration in designing locomotive boilers?

What are the principal features wherein locomotive boilers differ from stationary and marine boilers?

How is the draught produced in locomotive boilers?

What material is used in the construction of the fire-boxes of locomotive boilers? Why are they not made of the same material throughout?

Is the locomotive type of boiler used for any other purpose? What would be the object of using it for any other purpose?

Define horse-power of boilers. What is the Centennial rating?

How should boilers be rated?

What conditions affect the quantity of steam that can be generated in a boiler?

What amounts of water can be evaporated in fire-tube and water-tube boilers under good conditions? How much is usually evaporated in practice?

What percentage of the fuel is utilized in actually making steam? What becomes of the balance?

What considerations determine the surface of the grate? Is it, in general, an advantage to have a large grate surface?

In a 50-horse-power boiler, having a grate surface of fourteen square feet, how much coal would be consumed per hour, the quality of the coal and the condition of the boiler being good?

In the above boiler what would be the consumption of coal per horse-power per hour? How much water per pound of coal would be evaporated from and at 212°?

What is the average ratio of heating surface to grate surface in stationary boilers using anthracite coal? What is it where bituminous coal is used?

What is the heating surface in the tubes of a marine boiler aving 216 two-inch tubes?

What is the total heating surface of an externally fired boiler 6 feet in diameter, 10 feet long, having 100 thr tubes?

What pressure will burst a cast-iron cylindrical boi inches in diameter, the tensile strength of the material 18,000 pounds, and its thickness 1 inch?

What pressure can be safely carried in a cylindrical boil single-riveted joints, the diameter being 5 feet, thickness c ⅜ inch, tensile strength 55,000 pounds, and factor of safety

What should be the thickness of the shell of a stationary 6 feet in diameter, with double-riveted joints, to safely pressure of 200 pounds per square inch, using a factor of of 4?

What pressure can be carried with safety on a boiler flu in diameter, 10 feet long, and ¾ inch thick?

What different methods are used for staying boilers?

What materials are mostly used in the construction of boilers?

What qualities are most essential in a good boiler m What are the most common defects?

What are the characteristics of boiler iron when broken

What material is preferable for tubes? Why?

Explain the meaning of the technical terms applied to ferent adjuncts of steam boilers.

What course should an engineer or fireman pursue wh entering the boiler-room in the morning?

What precaution should be taken before starting a fire boiler?

What course should an engineer adopt on taking charg [illegible] boiler for the first time?

[illegible] should the fire be regulated when first started

[illegible] conditions should a boiler be blown out?

[illegible] condition of a boiler when it is to

[illegible]

[illegible]

What course should be adopted with boilers before cleaning?

How should boilers be treated when a *forced draught* is used?

How should the pressure in a boiler be regulated?

How should the kindling material be placed on the grate preparatory to starting a fire?

How often should steam-boilers be cleaned?

Should the cleaning of boilers be neglected, when solvents are used for the prevention and removal of scale?

What precautions should be taken before new boilers are put into service?

How often should the flues or tubes of boilers be cleaned?

What course should be adopted in case the water in a boiler becomes dangerously low?

What course should be pursued in case the water-supply becomes interrupted for any length of time?

What precaution should an engineer take in case it becomes necessary to blow out a certain quantity of water every day?

How should the supply of feed-water be regulated?

What advantages are gained by filling marine boilers with salt-water for the first time?

What is the meaning of the term "salting" when applied to marine-boilers?

What parts of any class of steam-boilers are most likely to suffer from the effects of heat?

What is the most practical method to adopt in case a boiler tube should become leaky?

What course should an engineer or fireman adopt in case a tube becomes split?

PART IV.

STEAM BOILER FITTINGS AND APPLIANCES.

CHAPTER XII.

VALVES, GAUGES, ETC.

Safety Valves.—It frequently happens in steam boilers that, through causes over which the fireman has no control, but more frequently through negligence on his part, the steam pressure rises above that which the boiler is designed to carry. Obviously, when this is the case there would be great danger of straining the boiler or even of its entire destruction, if it were not provided with some device for relieving the excess of pressure. Devices used for this purpose are called safety valves, and they consist essentially of a combination of a valve with weights or springs and levers, so arranged that when the pressure in the boiler exceeds that which it is intended to carry, the valve lifts and allows the pressure to be relieved.

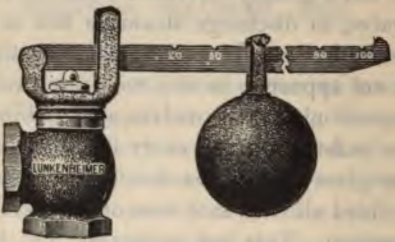
The lift of safety-valves, like all other puppet-valves, decreases as the pressure increases; but this seeming irregularity may be explained as follows: a cubic foot of water generated into steam at one pound pressure per square inch above the atmosphere will have a volume of about 1600 cubic feet. Steam at this pressure will flow into the atmosphere with a velocity of 482 feet per second. Now, suppose the steam was generated in five minutes, or in 300 seconds, and the area of an orifice to permit its escape as fast as it is generated be required, 1600 divided by 482 × 300 will give *the area of the orifice,* $1\frac{3}{5}$ square inches. If the same quantity of water be generated into steam, at a pressure of 50 pounds above the atmosphere, it will possess a volume of 440 cubic feet, and will flow into the atmosphere with a velocity of 1791 feet per second. The area of an orifice, to allow this steam to escape in the same time as in the first case, may be found by dividing 440 by 1791 × 300; the result will be $\frac{3}{25}$ square inches, or nearly $\frac{1}{8}$ of a square inch, the area required. It is evident from this that a much less lift of the same valve will suffice to discharge the same weight of steam under a high pressure than under a low one, because the steam, under a high pressure, not only possesses a reduced volume, but a greatly increased velocity; it is also obvious that a safety-valve, to discharge steam as fast as the boiler can generate it, should be proportioned for the lowest pressure.

There does not appear to be any recognized rule among boiler makers for proportioning safety-valves, since, while one allows one inch of area of safety-valve to every 66 square feet of heating-surface, another gives 1 inch area of safety-valve to every 4 horse-power, while a third allows 1 inch area of safety-valve to $1\frac{3}{4}$ square feet of grate-surface. This last proportion has been proved by experience to be capable of admitting of a free escape of steam, without allowing any greater increase of pressure than that for which the valve is loaded, providing that all the parts are in good working order. It is obvious, that no valve can act without a slight increase of pressure, as, in order to lift at all, the internal pressure must exceed that of the load. Doubtless, most safety-valves are larger than is actually required, and but few boiler explosions occur from want of safety-valve area. The most probable causes of accidents arising from safety-valves are that they are either overloaded or out of order. A badly proportioned safety-valve, whether too large or too small, is objectionable, and is always attended with a certain amount of danger.

Safety valves may be divided into three general classes, according to the manner in which they are loaded.

The simplest form of safety valve is that in which an ordinary puppet valve is loaded down with weights adjusted to the d blow-off pressure. This type is called the dead-weight valve, and it has the advantage that it is a difficult matt tamper with it, as any appreciable reduction in its loading be readily detected. On the other hand, it is bulky and uns and is now but little used.

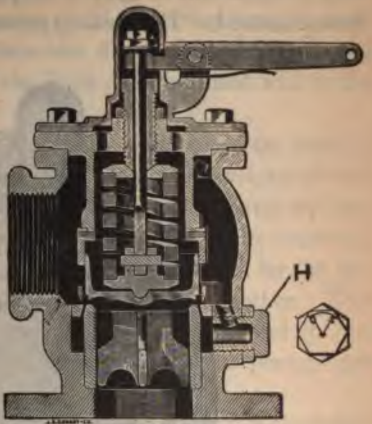
For stationary boilers, the type most commonly used co instead of a dead weight as described above, of a combinati weight and lever, the adjustment being made by shiftin



weight along the lever. This type of safety valve is shown i above cut, where the blowing-off pressure is regulated by sh the weight along the lever. The method of adjusting the w etc., will be found under "Rules" below. As already stated, the type of valve commonly used for stationary boilers. For motive and marine boilers it is obvious, however, that the ja would make the weight impracticable, and in such cases the is held down by a spring.

The spring-pop safety valve is the type used almost exclus for locomotive boilers. It is also largely used for marine, por and stationary boilers. A great many different makes o type are to be had in the market, and it is difficult to say wh e best. As a representative of this class of safety valv *strate the*

***hton* Lock-up Pop Safety Valve.**—As will be seen ectional cut, the valve seat is bevelled at an angle of 45°, this ngle being decided upon because it keeps tight and is easy to face off when necessary. The seat is made of composition metal or nickel, as may be desired. The spring is made of Jessop's steel, and is fitted with top and bottom pivoted discs in order to insure a true bearing on the valve. The device at the lower right hand is for the purpose of regulating the "pop" or difference between the opening and closing of the valve, and its method of operation will presently appear. The lock-up attachment consists of a casing which is secured to the trip lever by a padlock, which must be unlocked before the adjusting screw can be reached. The operation of the valve is simple. When the blow-off pressure is reached the valve rises from its seat and the steam escapes into the pop chamber, which is enclosed within the walls of the knife-edge lip and the top of the bushing and valve seat. The steam then passes into the discharge chamber. For larger sizes a supplemental pop chamber, consisting of the annular opening around the bushing, is used. This is connected to the primary pop chamber by a series of holes through the bushing and to the discharge chamber by means of the screw plug pop regulator *H*, which was referred to above. It will be evident hat by the adjustment of this plug, which may be done from the utside, the opening between the pop and discharge chambers nay be readily adjusted and consequently any desired pop may e *obtained.*



SECTIONAL VIEW.

The annexed cut shows an outside view of this valve, from which the position of this plug *H* will be clear. It is provided with a check nut to hold it in position after the desired pop has been obtained. The lock-up arrangement is also clearly shown in

Ashton Lock-up Pop Safety Valve.

this cut, and it will be seen that the padlock must be removed before the regulating screw can be reached. The trip lever is movable, and may be readily changed to stand in any desired position.

Rules.

Rule *for finding the weight necessary to put on a safety-valve lever, the area of valve, pressure, etc., are known.*—Multiply the ' *valve by the* pressure in pounds per square inch; multi- *product* by the distance of the valve from the fulcrum;

multiply the weight of the lever by one-half its length (or its centre of gravity); then multiply the weight of valve and stem by their distance from the fulcrum; add these last two products together; subtract their sum from the first product, and divide the remainder by the length of the lever; the quotient will be the weight required.

Rule *for finding the pressure per square inch when the area of valve, weight of ball, etc., are known.*—Multiply the weight of ball by the length of lever, and multiply the weight of lever by one-half its length (or the distance from the fulcrum to its centre of gravity); then multiply the weight of valve and stem by the distance from fulcrum. Add these three products together. This sum divided by the product of the area of the valve, and its distance from the fulcrum, will give the pressure in pounds per square inch.

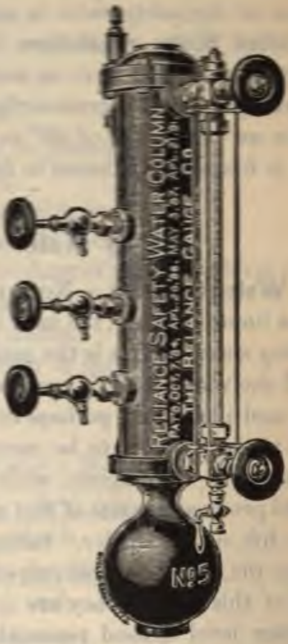
Rule *for finding the distance from the fulcrum at which the weight should be placed for a given blowing-off pressure.*—Multiply the area of the valve in square inches by the steam pressure per square inch and subtract the weight of the valve and stem in pounds. Multiply the difference by the distance from the valve to the fulcrum in inches, and to this product add the product of the weight of the lever by the distance of its centre of gravity from the fulcrum. This sum, divided by the weight of the ball in pounds, will give the required distance in inches.

Rule *for finding the distance of the centre of gravity of taper levers from the fulcrum.*—To the width of the small end of the lever add one-third of the difference between the large and the small end of the lever. Multiply the sum by the length of the lever and divide the product by the sum of the large and the small end of the lever, all in inches. The quotient will be the required distance in inches.

All of the preceding rules may be expressed by simple formulæ, as follows:

Let the diagram on page 222 represent the lever safety valve *hown on page 218 d,* and let

above the centre of the lower gauge cock and below the centre
the upper gauge cock, the bottom float presses upward by reas
of its buoyancy, while the top float presses downward by reas
of its weight and the two valves to the whistle remain clos



When, however, the water line passes the centres of either t
upper or lower gauge cocks, the reverse of the above takes pl
and the valve is opened, giving the desired alarm. The ba
shaped chamber at the bottom is for the purpose of collecting t
and is provided with a blow-off opening. The colum
l for standard fittings, so that any kind of water gau
cocks may be used. The annexed cut shows a nov
uge cock which may be used where the water level
nt the cocks could not be conveniently reached by t

endant. It differs from the usual type in this particular, that tead of pulling down the ndle to open the cock, the ight is lifted, and when sed it is held against the at merely by the weight the ball. This arrangeent has the advantage at the seat, not being aced next to the boiler, capes the cutting effect of the sediment.

Reliance Leakless Gauge Cock.

Steam Pressure Gauges.

About the year 1849 Eugene Bourdon, of France, discovered at the free end or ends of a flattened or elliptical metallic tube, ssessing sufficient elasticity for use as a spring, would move hen pressure was exerted in it through the medium of a uid applied externally or internally; that the motion was direct proportion to the pressure applied; and that when the ressure was removed they ould assume their former osition. From this circumstance, he conceived the idea f a new pressure gauge, in which the bent tube should be the main spring or means of motion. But, though it was generally conceded at that time that the hollow ube spring gauge, as invented by Bourdon, excelled in elicacy and sensitiveness ny previous mechanical ar*ngement employed for that*

Exterior View of Crosby's Steam Gauge.

purpose, nevertheless, it was demonstrated by experience th

Interior View of the Original Bourdon Steam Gauge.

a device, owing to its
liar construction, was no
adapted for all the purpo
which pressure gauges a
ployed, as, in consequen
being held only at one
would vibrate from a s
shock or slight change of
ure, thus causing the poi
oscillate on the dial-pla
ducing friction and wea
rendering the indicatio
the gauge uncertain and
sive. Besides, the dip o
a spring caused it to re
portion of the water condensed in it, thus rendering it li
burst in cold weather, to be strained by freezing, and lose its t

To overcome these defects, numerous devices have
suggested and tried, but they almost invariably embodied the same defects as those above mentioned, and were subject to the same errors, the gravest of which arose from the straightening or setting of the springs. Steam users are more indebted to George H. Crosby for remedying the foregoing defects in pressure gauges, and for the production of a perfectly reliable
am gauge, than to any one
ious to his time, as he dis-
red, *by observation* and ex-
nent, that only the horizontal motion of the free ends

Interior View of Crosb
Steam Gauge.

springs or tubes, while under varying pressure, had been used heretofore, and that they had a perpendicular or upward action, as well, when the springs were of proper length and shape, and that by uniting these motions by proper mechanism, it could all be transmitted to the pointer. In accomplishing this, he discovered that a firmer and stiffer spring than any heretofore used for the same pressure was an absolute necessity. And as a result, no pressure over that indicated by the pointer on the dial will affect their original elasticity, and vibration of the pointer under varying pressures is obviated; besides, in consequence of the spring being held at the lowest points, they have no dip, which arrangement admits of the water returning to the siphon, thus preventing freezing. Thus it would seem that, while the Crosby gauges embrace all the desirable points in the original Bourdon gauge, they also embody many others which have been demonstrated by experience to be absolute necessities in the construction of an accurate, reliable, and serviceable steam gauge.

Self-Testing Steam Gauges.—This class of gauges is of great importance, convenience, and utility, as the engineer in charge can always ascertain whether his gauge is correct or not by observing the following instructions: Set off all pressure that may be on the gauge, after which the pointer will fall to zero; then unscrew the plug on the left-hand side, which uncovers the hook. To this hook hang the first weight by the spindle. This is marked by a certain number, and the pointer should travel at once to the corresponding number on the dial, if correct at this point. *But if the pointer stands below or above this*

Crosby's Self-Testing Steam Gauge.

number, it will indicate just how much the gauge is "out,"

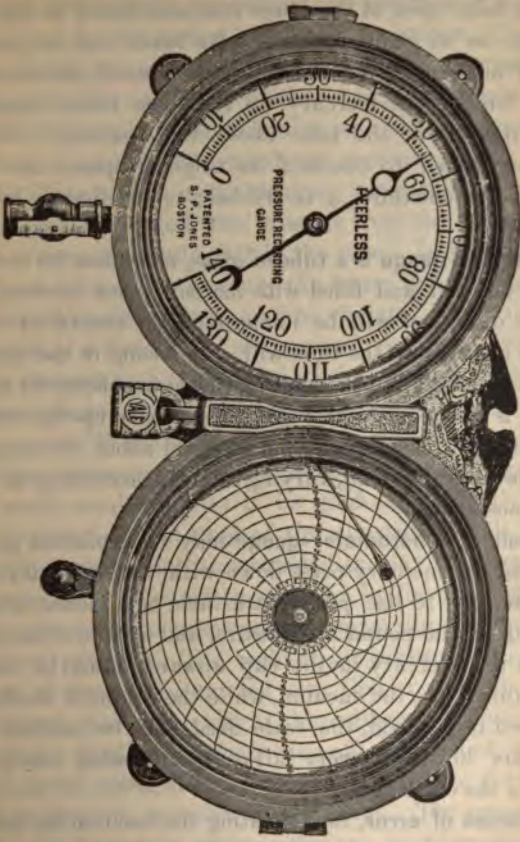
Crosby's Vacuum Gauge.

which direction. Proc
adding the next higher
tested weight, and conti
below.

Vacuum Gauges.—Th
ditions under which va
gauges act are the reve
steam gauges, as, in the
um gauge, the interior
tube is influenced by the
um, while its exterior
posed to the action of t
mosphere. The princip
covered by Bourdon is a
in most of the gauges now used, as it has been found applica
the various devices which are used in measuring pressur
vacuum.

Recording pressure gauges, though a comparatively
addition to the list of appliances which are to be found i
boiler room, are now used in every well-equipped plant.
first of these to be placed on the market was the Bristol R
ing Gauge, and the other makes are largely modifications o
type. The recording gauge consists essentially of a combi
of a clock mechanism with an ordinary steam gauge. Th
consists of a removable paper which is arranged to mak
complete revolution in twenty-four hours. The circles o
dial indicate the pressure, while the sinuous lines indicat
hour. By the combined motion of the pointer, which is act
by the steam pressure, and the dial, which is actuated b
rk, a record is made of the pressure which has bee
e boiler. The end of the pointer is filled with ink
an indelible record. The cut on page 229 shows o
es mounted with an ordinary gauge, which makes a
l appliance for the boiler room.

siphon-gauge is a bent tube, inverted, and partially filled mercury. The orifice of the short leg is connected with the r, and the long leg is open to the atmosphere. The steam sing upon the mercury in the short leg with greater force the weight of the atmosphere, causes the mercury in the other to rise, and indicates the excess of pressure above that of the *sphere. To the amount* shown by the gauge must be added



the pressure of the atmosphere. Thus, if a siphon-gauge shows 15 pounds pressure, the boiler-pressure is 30 pounds.

A mercurial gauge for high-pressure steam engines consists of a glass tube open at the lower end, and closed at the top, containing air in its ordinary state. Its lower end is placed in a cistern of mercury. When the cock is opened the steam passes through, forcing the mercury up the glass tube, thereby compressing the air in the tube above the mercury. When the air is compressed to one-half its original space, the pressure is doubled; to one-third, it is trebled; to one-fourth, it is quadrupled, etc.

A barometer-gauge is a tube of glass, more than 30 inches long, closed at one end, and filled with mercury, then inverted so that the lower open end will be immersed in a cistern of mercury, when the mercury in the tube will sink, rising in the basin until its weight balances the pressure of the atmosphere, which, by its elasticity, is endeavoring to force the mercury up the tube. The mercury in the tube will be found to stand about 30 inches higher than the level in the basin, varying slightly, according to the state of the atmosphere.

The scale of a barometer-gauge may be explained as follows: As 30 inches of mercury press down with the same force as the atmosphere, say 15 lbs. per square inch, two inches of mercury correspond to one pound of pressure, and a scale of inches measured from the mercury in the cup upwards must be fixed near the glass tube. As the vacuum, while the engine is working, may be supposed to be good, the scale need only be marked to a few inches below 30 inches, every fall of two denoting one pound of
sure in the condenser.

sources of error, in estimating the vacuum by this gauge,
n the following two facts: That the pressure of the at-
, or the mercury in the cup, is liable to change. That
ations on the scale are marked, on the supposition that
l of the mercury is stationary; because it is from this
nt the scale commences. Therefore a fixed scale must be

ous, on account of the sinking of the mercury in the cup
ses in the tube.

first source of error may be corrected by observing the
height of a weather barometer, and subtracting it from the
as shown by the gauge. This will be correct, if a tube of
dard diameter is used. This error may be corrected by a
gauge, similar to what a weather barometer would be if it
nclosed in a space, communicating with the condenser. In that
before a vacuum is created, the mercury would stand as
n the glass tube as in the weather barometer. On creating
uum, thus taking off the pressure from the mercury in the
n, the mercury would fall in the tube. In this instrument,
ss the height of the mercury the better the vacuum.

e second source of error may be obviated by having a mov-
instead of a fixed scale, so that its lower end might always
pt in contact with the surface of the mercury in the cup.

iphon-gauge, such as has been spoken of, may be used as a
um-gauge. When so used, it is necessary to connect the long
ith the condenser, placing a stick in the short leg. In this
he scale would require to be graduated directly contrary
at for steam. The state of the atmosphere will affect the
. The pressure in the steam-boiler may be ascertained by
emperature, by the safety-valve, or by the steam-gauge, but
not customary to measure the temperature in the boiler to
ain the pressure. The scale of all pressure gauges should,
time to time, be compared with that of a standard gauge,
any error that may exist in the caliberation should at once
medied. Similarly the blowing-off pressure of the safety
should be tested, and care be taken to see that the valve lifts
right pressure as shown by the gauge. The pressure gauge
he safety-valve are perhaps the two most important access-
of a steam boiler, as on these depend the safety of the entire
Hence, those in charge cannot be too careful to see that
are always in proper working order.

[illegible]

The Salinometer.

[illegible] pressure in boiler [illegible] may assum regular temperature under the pre of the atmosphere, because stean different pressures has different peratures, and a difference in temp ture will alter the indications of hydrometer.

The amount of salt in the wat a boiler may be ascertained by ob ing the degree of the boiling-poin means of a thermometer. To do quantity of the water in the boiler should be d copper vessel, and brought to the boiling-point. thermometer. For every pound of salt containe ter, the temperature rises one degree. Thus, i

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* See page 257.

r contains $\frac{1}{32}$ of salt, it will boil at 213°; if $\frac{2}{32}$, at 214°; if $\frac{3}{32}$, 15·5°, and $\frac{4}{32}$, at 216·6°.

alt-water, at the usual density, contains $\frac{1}{32}$ of its weight of salt; equently, if one pound of salt enters the boiler with every 32 lbs. ater, and 16 lbs. of that water be evaporated, the one pound of remains in the proportion of 1 : 16. Again, if $\frac{1}{2}$ of the 16 lbs. of er remains to be evaporated, the one pound remains in the 8 lbs. ater. Now, if these 8 lbs. of water were blown out of the boiler, salt would go with it; and so long as that proportion is carried out, saturation cannot exceed $\frac{4}{32}$; from which it is clear that, to keep er at $\frac{4}{32}$, one-fourth must be blown out; one-third at $\frac{3}{32}$, and at ne-half of the water used for feed must be blown out.

he errors in the hydrometer may be corrected in the following nner: Every 10° difference in temperature will vary the indions $\frac{1}{8}$ of $\frac{1}{32}$, 200° Fah. being the standard. Then, if the water 0° over 200° Fah., it will show $\frac{1}{8}$ of $\frac{1}{32}$ less than its true density; if 10° below 200° Fah., it will indicate $\frac{1}{8}$ of $\frac{1}{32}$ more. Moreover, e grade be 200° Fah., the thermometer shows 210°, and the hyneter indicates a density of $\frac{2}{32}$, the true density will be $2\frac{1}{8}$; if the temperature be 190°, it will be $1\frac{7}{8}$.

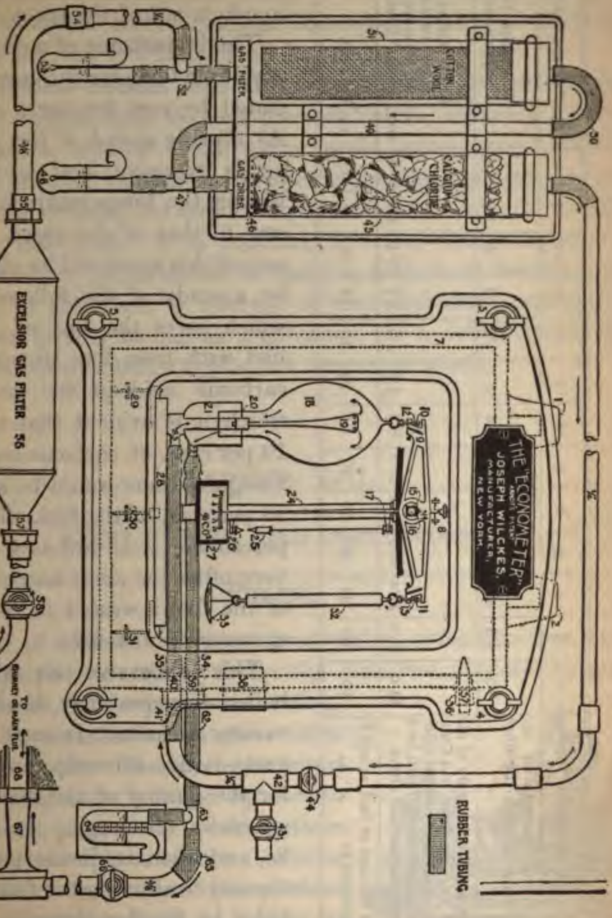
Salinometer may be constructed by taking a long glass tube, inserting in it sufficient shot to sink it in fresh water, marking point at which the water stands in the tube. Then immerse tube in water containing $\frac{1}{32}$ part of salt, when the point at ch the water stands will be the sea-water mark. Similarly erse in water containing $\frac{2}{32}$, $\frac{3}{32}$, etc., up to $\frac{12}{32}$ of its weight lt, marking off the respective points at which the water stands. nsfer these marks to a scale, and paste it inside the bottle in ctly the same position as the marks on the bottle, and the result good salt-gauge. The temperature must always be the same hen the hydrometer was graduated.

low to use a Salinometer.—Draw off some water from the ers, and when the ebullition has ceased, try its temperature with ermometer. If the temperature exceeds that marked on the ometer, let it cool till it reaches that degree; and if the tem-

The Econometer.

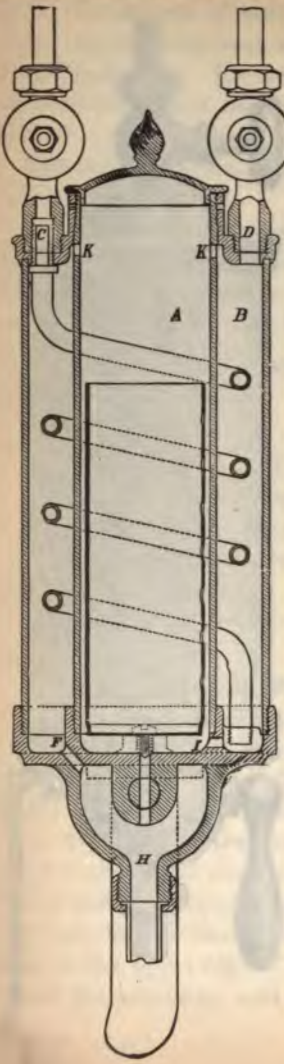
In order to insure economy in firing, one of the n
tant considerations is that the supply of air to the furna
sufficient for complete combustion of the fuel, but not
excess of this amount, because if too much air is adm
tain portion of the heat of combustion will be used t
temperature of the excess and will thus be wasted.
determine this point it has been the custom to mak
analyses of the flue gases from time to time, and from t
age of carbonic acid contained in them to decide whet
the amount of air admitted was the most advantageo
of this kind necessitated the drawing off of a sample
keeping it in a sealed tube, and making a chemical a
the Hempel or Orsatt apparatus, which is a somewh
operation.

The Econometer is an apparatus invented by Dr. Arn
many, whose object it was to have a gauge that wou
continuously and automatically the percentage of carbo
the flue gases. The device, which is illustrated in the a
ing cut, consists essentially of a glass bulb and a balanc
used for weighing, continuously, the combustion gases a
through the bulb. Referring to the cut, 61 is the con
the boiler flue, where the gases enter the apparatus.
pass successively through the three filters 55, 51, and 4
to remove all dust and moisture, and then enter the i
proper at the point 41. The gases issue from the funn
being heavier than the surrounding air, and also on a
the draught in the chimney, they descend and leave
through tube 22. Continuing through this tube th
[illegible] through the aspirator, 67, to the chimney. The b
[illegible] ised by the glass rod, 32, and the instrument i
[illegible] of iron filings until the pointer stands at zero
[illegible] through the bulb. The scale is graduated s
[illegible] read directly the percentage of carbonic a



"The Econometer" (ARNDT'S PATENT)

will be sufficient to reduce the temperature of the water p



through the coil. A hole is dril the back of the large pot, nea top, which allows the water to e in case it should accidentally b full. The cold water is supplied pipe connected by a globe-valve t pipe or valve below the water-lin plying cold water, and led to th nometer. If it should be desi place the salinometer above th side water-level, the cold water c supplied by some of the pumps.

In erecting these salinometers may be secured to the boilers or head, but when there are two or boilers, a very neat and conv arrangement may be made by them close together on a plain ca plate fastened down with tap-bol with the pipe for the cold water just above them, with a T co and branch to each one, the plate secured with tap-bolts in any c ient place in the engine-roo salinometer may be attached to boiler, and all of them supplie cold water from the same pipe, may be connected with two or boilers.

It is preferable to have on nected with each boiler, as in th the density of the water may served in any boiler independ the others. To put the salinom correct position of the damper. In any case, the defect should be remedied, and, in order to do this, it must first be located, and this is the function of the econometer. The instrument has been thoroughly tested and its readings correspond with the results of chemical analysis to a fraction of 1 per cent.

The smaller devices used in the boiler room, and in connection with boilers, such as back-pressure valves, reducing valves, check valves, blow-off cocks, gauge cocks, water gauges, steam whistles, pressure regulators, damper regulators, etc., etc., are all of great importance, but they are too numerous to mention, specifically, in this book. It is essential, however, that everyone in charge of steam plants should be familiar with these devices, and the user of this book is referred to manufacturers' catalogues, which can usually be had on application, for a detailed description of the various boiler appliances mentioned above.

CHAPTER XIII.

FEED PUMPS AND INJECTORS.

Pumps.

Pumps, of whatever design or construction, or for whatever purpose employed, are simply hydraulic machines attached to one end of a tube, for the purpose of raising, forcing, or transferring water, or other liquids or fluids. The idea entertained by many that water is raised by suction is erroneous, as, properly speaking, there is no such principle as suction. Atmospheric "lift" or "suction" pumps cause the water to raise itself by having its surface relieved of the column of air *resting upon it. If, therefore,* one end of a pipe or tube be lowered

[illegible]
the water i
side of it, propo
pressure of th
the pressure c
square inch wi
water will be forced u
inch of wate
be pound in
the pressure
per square i
an unequ
that outsid
feet in
that inside and
outside water
pressure upon
acting upon ea
same plane, bu
feet high
making a

ıat will weigh 15 pounds per square inch of area at the ascertain how far a suction-pump will cause the water to must be understood, that the distance varies with the bove sea level, and also with the pressure of the atmos- At our level of the sea, the column of water that the ere will support is about 33 feet in height, and a pump ıw water" (as it is called) this distance; but the force ıds the water into the pump at this height is so dimin- to be almost balanced by its own weight; hence a lifting- ll deliver water very slowly, drawing it this distance.

reliable, the cylinder and piston should be in good order, oints perfectly air-tight, a check-valve be placed in the l of the suction-pipe; and even then the pumps should a high speed. Pumps will give more satisfactory results lift is from 22 to 25 feet. There is hardly any limit to ıce a pump will draw water through a horizontal suction- ided the pipe is perfectly tight, and everything is so pro- as not to cause undue friction.

ıpacity of any pump may be determined by multiplying of the piston in inches by its stroke in inches, giving the f cubic inches per single stroke; this divided by 231 (the f cubic inches in a standard gallon) will give the number s per single stroke; but it must be remembered that all ırow less water than their capacity, the deficiency rang- 20 to 40 per cent., according to the quality of the pump. arises from the lift and fall of the valves, from inaccuracy akage, and in many cases from there being too much space he valves and piston, or plunger. The higher the valves ımp have to lift to give the necessary opening, the less he pump will be.

ıwer required to raise a given quantity of water a certain ıay be computed by the following rule: Multiply the f water in gallons to be raised per minute by 8·35 lbs. ht of a gallon of water), and this product by the height, in *discharge from the* point of suction; divide the result by

33,000, which will give the theoretical horse-power required to raise the amount of water to a certain distance. The actual horse-power which would be required to do this work is always considerably in excess of the theoretical, because there are many sources of loss in pumping water. These losses are due to various causes. In the first place, there are the losses in the pump itself, incurred in the friction of the moving parts, lifting the valves, etc. These are greater, in proportion, for small pumps than for large ones, and in small boiler feed pumps are often as high as 50 per cent. of the total power required. The other principal source of loss of power lies in the friction of the water in the piping, and this loss is proportional to the square of the velocity of the flow. Hence, the velocity of the water should be kept as low as possible by making the pipes of ample diameter. Bends in the piping, fittings, valves, and other obstructions should also be avoided in order to make the losses of power in the pipes as [illegible]. A table of power will be found on page 145.

[illegible] of a pump to feed a given boiler [illegible] much water the boiler is capable of [illegible] the Centennial Rating (see p. 182) [illegible] boiler capacity corresponds to an evaporation [illegible] of water per hour. The pump, however, should [illegible] supplying all of the water when the boiler is forced; [illegible] better to operate a pump slowly and con[illegible] and for these reasons the pump running at its normal [illegible] should be capable of supplying about twice as much water [illegible] boiler evaporates under usual conditions. In determining nsions of the pump, the velocity of the water in it should 500 feet per minute.

d pumps belong to that class of pumping machines e pumps; that is, those which force water against an sure at the point of delivery, as distinguished from hich lift the water and deliver it under atmospheric *They may* be classified as follows, according to the *ployed* in driving them:

(*a*) Power pumps.
(*b*) Electric pumps.
(*c*) Steam pumps, { Direct acting,
Fly wheel,
Duplex.

r pumps are those in which the power used to drive them
lied from some external source and is transmitted to the
roper by means of pulleys and belts, toothed gearing,
clutches, or other device for transmitting power. This
pumps is not much used for boiler feed purposes.

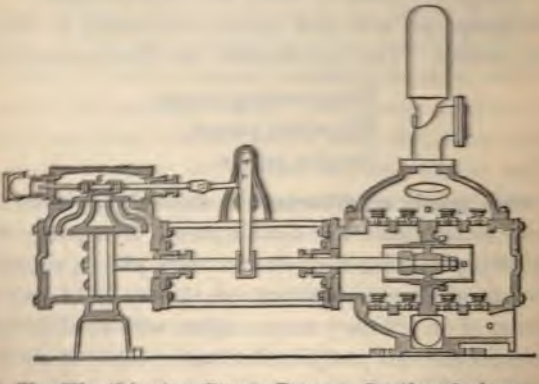
ric pumps are those which are geared or directly con-
to electric motors. Like power pumps, these are not
sed to feed boilers, because in transforming the energy
team first into mechanical power, then into electrical, and
ack again into mechanical power, additional and unneces-
ses are incurred. Electric pumps are used mainly where
l energy only is available, or where it is not desirable to
unsightly system of steam and exhaust pipes.

n pumps are now used almost universally for the purpose
ng boilers. They are divided into three general classes:

Direct acting pumps,
Fly-wheel pumps,
Duplex pumps.

main points of difference in these three classes lie in the
of getting past the dead centre. If a pump were con-
simply by using two cylinders with pistons attached to the
ends of a common piston rod, the one end being used like
nder of an ordinary steam engine, with its slide valve, etc.,
other end for pumping the water, there being no rotary
of any kind in the mechanism, it is evident that the
e would come to rest at the end of each stroke unless some
l method were employed for helping it over its dead centre.
course, could be easily done by simply adding a crank-
d a flywheel of sufficient weight to carry the engine over

the dead points. This is exactly what is done in flywheel pu
but, inasmuch as no rotary motion is required for driving
pump, except to carry it over the dead points, it has occurre
builders of pumps that some simpler method might be devi
These considerations have led to the invention of the direct ac
pump, which consists essentially of the two cylinders and pis
as described above, with a suitable slide valve for distribu
steam, and in addition an auxiliary valve or valves operated b
suitable mechanism to admit steam behind the piston when
on what would ordinarily be the dead centre. Many diffe
designs of this type have been placed on the market, notably
"Knowles," "Blake," "Deane," "Cameron," and others, all
which operate successfully without crank shaft or flywheel.
only objection to pumps of this kind is that they are necess
somewhat complicated, and while their operation has proved v
satisfactory, they are not used as extensively as the last-na
type, the duplex pump, which is much simpler in its action.



The Worthington Steam Pump. Sectional view.

The duplex steam pump is virtually a combination of
ps so coupled that the slide valve of the one is oper
the piston-rod of the other, and vice versa. In this

there is no dead centre, and furthermore, no auxiliary valves or mechanism of any kind are required to accomplish this end. The sectional and perspective views illustrate the Worthington pump, which is perhaps the most widely used make of the duplex type of pump. It will be seen from these cuts that the valve is a plain (*D*) slide valve operated by a vibrating arm, *E*, which swings through the whole length of the stroke. The one piston acts to admit steam to the other, after which it completes its stroke and then remains at rest until its valve is acted upon by the other piston, before beginning its next stroke. As one or the other of the two valves is always admitting steam, there can be no dead point, and the pump may therefore be started in any position by simply opening the throttle valve. The plunger, *B*, is double-acting; that is, when water is taken in on one side it is discharged on the other. *C* is the suction and *D* the discharge chamber.

The Worthington Boiler Feed Pump.

When hot water passes through the pump certain conditions arise which must be met by special devices. It has been found that hot water cannot be lifted successfully, *because as the plunger moves forward and creates a vacuum in the suction pipe, the pressure being relieved, to a sufficient extent, the water will* [illegible] about twenty times as great as that of a jet [illegible] from the boiler at the same pressure, and this hig [illegible] concentrated on a jet of very small cross section. It i [illegible] fore, that it possesses a large margin of energy over [illegible] that necessary to force it into the boiler, and this sur- [illegible] to the water which has been drawn in through the [illegible] pipe. Of course, the proportions between the vol- [illegible] and water must be correctly chosen, because if [illegible] enough water to condense the steam the action just [illegible] take place, while if there is too much water the [illegible] condensed steam jet will not be sufficient to give the [illegible] requisite velocity. For this reason the propor- [illegible] of the various parts of an injector are of the [illegible] Much experimentation and study have been [illegible] both in this country and abroad, and of [illegible] in this connection, that of Strick- [illegible] attention. The user of [illegible] "Practice and Theory of [illegible] himself more thoroughly

[illegible] injectors **to work** may be due to a variety of [illegible] common of these is the presence of air in the [illegible] to leaks in the joints or improper packing of [illegible] suction pipe must be made air-tight and the [illegible] must be submerged in water, otherwise air will b [illegible] the injector will not work. Sediment and scale i [illegible] other causes of injectors failing to work, and thi [illegible] be looked after from time to time. When th [illegible] get water there may be a leak in the supply pipe [illegible] may be cut off, the strainer may be clogged u [illegible] be too hot, or the pressure may be too low for th [illegible] If it gets water, but fails to force it into the boile [illegible] supply is probably not properly adjusted to the stea [illegible] it may be due to an obstruction in the check valve, th [illegible] pipe, or the delivery tube of the injector. If it sta ed water to the boiler, but *breaks*, the fault may lie in any one e above causes, or it may be that a globe valve in the supply has a loose disc which partly closes the valve after the tor is started. This may be remedied by reversing the e.

jectors may be classified as follows:*

ngle jet injector, one in which a single set of combining and ery tubes is used.

ouble jet injector, one containing two sets of steam jet ratus, of which the first or lifting set receives the feed-r from the source of supply and delivers it to the second orcing set, from which it receives sufficient impulse to enter boiler.

itomatic or re-starting injector, one that is able to re-estab- automatically the continuity of the jet, after a temporary ruption in the steam or water supply.

elf-adjusting injector, one in which the supply of water is matically adjusted to suit the steam supply without waste at overflow.

pen overflow injector, which has one or more apertures in the oining tube, opening into one or more overflow chambers, that be closed against the admission of air by the use of light k valves opening outward.

osed overflow injector, which can only start by means of an ing or vent placed beyond the delivery tube, which must be d in order to divert the jet into the boiler.

om a practical standpoint they may be classified as:

fting injectors, in which there is a partial vacuum formed in eed-pipe preliminary to starting.

on-lifting injectors, which require a pressure in the water ly.

he injector was first introduced in this country by William rs & Co., Incorporated, of Philadelphia, who have done much

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* *Strickland L. Kneass, Practice and Theory of the Injector.*

Section of William Sellers & Co.'s Lifting Injector.

the lower end of the combining-tube slides in a cylindrical guide formed in the upper end of the delivery-tube.

The rod *B* is connected to a cross-head which is fitted over the guide-rod, *J*, and a lever, *H*, is secured to the cross-head. A rod, *L*, attached to a lever on the top end of the screw waste-valve passes through an eye that is secured to the lever *H*; and stops, *T*, *Q*, control the motion of this rod, so that the waste-valve is closed when the lever *H* has its extreme outward throw, and is opened when the lever is thrown in, so as to close the steam-valve, *X*, while the lever can be moved between the positions of the stops, *P*, *Q*, without affecting the waste-valve. A latch, *V*, is thrown into action with teeth cut in the upper side of the guide-rod, *J*, when the lever *H* is drawn out to its full extent, and then moved back; and this click is raised out of action as soon as it has been moved in far enough to pass the last tooth on the rod *J*. An air-vessel is arranged in the body of the instrument, as shown in the figure, for the purpose of securing a continuous jet when the injector and its connections are exposed to shocks, especially such as occur in the use of the instrument on locomotives.

The manipulation required to start the injector is exceedingly simple,— much more so in practice, indeed, than it can be rendered in description. Moving the lever *H* until contact takes place between valve *X*, and stop on hollow spindle, which can be felt by the hand upon the lever, steam is admitted to the centre of the spindle, and, expanding as it passes into the delivery-tube *D*, and waste-orifice *P*, lifts the water through the supply-pipe into the combining-tube around the hollow spindle, acting after the manner of an ejector or steam-siphon. As soon as solid water issues through the waste-orifice *P*, the handle *H* may be drawn out to its full extent, opening the steam-valve *X* and closing the waste-valve, when the action of the injector will be continuous as long as steam and water are supplied to it.

To regulate the amount of water delivered, move in the lever *H* until the click engages any of the teeth on the rod J, thus *diminishing the steam-supply*, as the water-supply is self-regulating. If too much water is delivered, some of it will escape through *O* into *C*, and, pressing on the piston *N N*, will move the combining-tube away from the delivery-tube, thus throttling the water-supply; and if sufficient water is not admitted, a partial vacuum will be formed in *C*, and the unbalanced pressure on the upper side of the piston, *N N*, will move the combining-tube towards the delivery-tube, thus enlarging the orifice for the admission of water. The injector, once started, will continue to work without any further adjustment, delivering all its water to the boiler, the waste-valve being kept shut. By placing the hand on the starting-lever, it is easy to tell whether or not the injector is working; and if desired, the waste-valve can be opened momentarily by pushing the rod *L*, a knob on the end being provided for the purpose.

TABLE

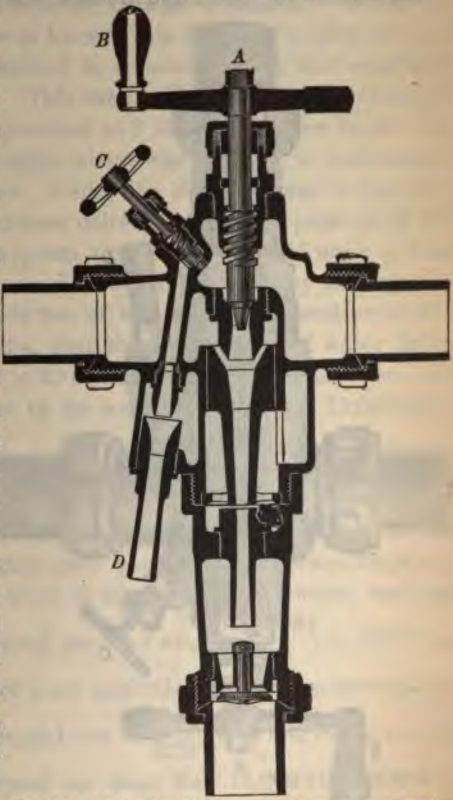
SHOWING STEAM-PRESSURE REQUIRED TO LIFT AND DELIVER WATER WITH SELLERS' FIXED-NOZZLE LIFTING INJECTOR.

HEIGHT WATER IS LIFTED.		STEAM-PRESSURE REQUIRED TO LIFT AND DELIVER WATER.	HEIGHT WATER IS LIFTED.		STEAM-PRESSURE REQUIRED TO LIFT AND DE LIVER WATER
Feet.	Inches.	Lbs. per Sq. In.	Feet.	Inches.	Lbs. per Sq. In
3	0	25	21	3	52
5	0	30	22	10	60
11	6	40			70
15	0	49			100

Sellers' Non-Adjusting Fixed-Nozzle Injector with Lifting Attachment, for Stationary Boilers.

The cut on page 259 represents Sellers' Non-Adjustable Injector with fixed-nozzle and lifting attachment. As will be observed, a steam-ejector or siphon is attached to the side of this instrument, which draws the water, when lifted by the admission *of the steam,* through the combining-tube, and discharges it *through the orifice* of the lifting attachment, through which, also

water or overflow escapes. This injector has a check-
nected to it, also a steam stop-valve, which can be opened
ıalf a revolution of the lever on the stem. In connecting
or, since it has fixed nozzles, a water-supply valve must
led, and, as al-
marked, a sec-
k-valve in the
pipe and an-
am-stop valve
able.
ting this injec-
ı is first admit-
e lifting-nozzle,
r-supply valve
justed so as to
bout the max-
nount of water
ıding to the
essure; and as
solid water is-
m the lifting-
he steam-valve
opened slightly
e jet is estab-
vhen the full
essure is to be
, and the valve
its steam to the
ozzle is to be
little dexterity
ed to start the
for a maximum lift, but the manipulation is readily ac-
vhile for all ordinary *lifts* no special care is required. As
ity of steam escaping from an orifice varies greatly with



Section of Sellers' Non-Adjustable Fixed-Nozzle Lifting Injector.

The term range is frequently used in connection with injecto and means the difference between the maximum and minimu delivery.

TABLE

SHOWING THE MAXIMUM AND MINIMUM DELIVERY OF SELLERS' SEL ADJUSTING, 1876, INJECTOR NO. 6; TEMPERATURE OF DELIVERE WATER; PRESSURE AGAINST WHICH INJECTOR DELIVERS WATER, AN HIGHEST TEMPERATURE OF FEED ADMISSIBLE; WATER FLOWING T INJECTOR UNDER 15 INCHES HEAD; WASTE-VALVES SHUT.

Pressure of Steam Supplied to Injector, and Pressure against which Water is Delivered. *Lbs. per Sq. In.*	Delivery in Cubic Feet per Hour.			Temperature Fahrenheit Degrees.			Pressure of Steam Required to Deliver Water against Pressure in Column 1.	Highest Temperature admissible of Feed-Water, Fahrenheit Degrees.
					Delivered Water.			
	Maximum.	Minimum.	Ratio of Minimum to Maximum Delivery.	Feed-Water.	At Maximum Delivery.	At Minimum Delivery.		
1	2	3	4	5	6	7	8	9
10	75·3	63·6	0·845	66	100	94	3	132
20	82·4	61·2	0·743	66	108	104	9	134
30	94·2	56·5	0·600	66	114	116	16	134
40	100·1	60·0	0·599	66	120	123	22	132
50	108·3	64·7	0·597	66	124	125	27	131
60	116·5	63·6	0·546	66	127	133	34	130
70	124·8	63·6	0·510	67	130	142	40	130
80	133·0	67·1	0·505	66	134	144	46	131
90	141·3	69·5	0·492	67	136	148	52	132
100	147·2	64·7	0·456	66	140	159	58	132
110	153·0	67·1	0·439	67	144	162	63	132
120	156·6	73·0	0·466	67	148	162	69	134
130	161·2	74·2	0·460	66	150	165	75	130
140	166·0	78·9	0·476	66	153	166	81	126
150	170·7	70·6	0·414	66	157	167	88	121

The table of capacities shows the maximum delivery, but th *injector can be regulated* so as to reduce the amount about 60 p *cent.*

OF CAPACITIES OF SELLERS' INJECTORS.

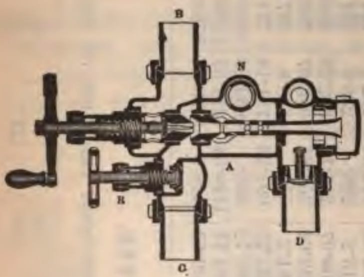
Size of Injector.	Size of Pipe for Connections.	Pressure of Steam in Pounds.									
		10	20	30	40	50	60	70	80	90	100
		Cubic Feet of Water Discharged per Hour.									
No. 2	½ in.	8·3	·9	9·7	10·4	11·1	11·8	12·5	13·2	13·9	14·6
" 3	¾ "	19·27	21·04	22·81	24·58	26·35	28·12	29·89	31·66	33·43	35·2
" 4	1 "	36·66	39·6	42·74	45·88	49·02	52·16	55·3	58·44	61·58	64·72
" 5	1¼ "	57·58	62·5	67·42	72·34	77·26	82·18	87·1	92·02	96·94	101·86
" 6	1¼ "	83·48	90·6	97·72	104·84	111·97	119·09	126·21	133·33	140·45	147·57
" 7	1½ "	114·03	123·75	133·48	143·2	152·93	162·65	172·38	182·1	191·83	201·55
" 8	2 "	149·2	162·	174·8	187·6	200·4	213·2	226·	238·8	251·6	264·4
" 9	2 "	189·2	205·35	221·51	237·66	253·82	269·97	286·13	302·28	318·44	334·59
" 10	2 "	233·84	253·8	273·76	293·72	313·68	333·64	353·61	373·57	393·53	413·49
" 12	2½ "	337·2	366·	394·8	423·6	452·4	481·2	510·	538·8	567·6	596·4
" 14	2½ "	451·49	491·45	531·41	571·36	611·32	651·27	691·23	731·18	771·14	811·09
" 16	3 "	600·32	651·6	702·88	784·16	805·44	856·72	908·	959·28	1010·56	1061·84
" 18	3 "	760·07	825·	889·93	954·86	1019·78	1084·71	1149·64	1214·57	1279·5	1344·42
" 20	3½ "	938·84	1019·	1099·16	1179·32	1259·48	1339·64	1419·8	1499·96	1580·12	1660·28

TEMPERATURE OF FEED-WATER.

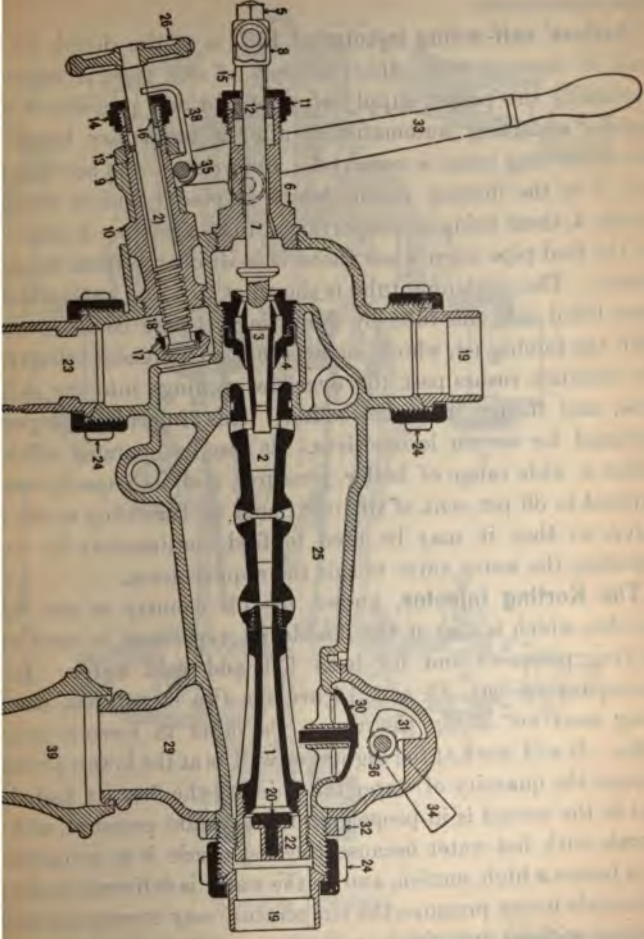
MAXIMUM TEMPERATURE OF FEED-WATER ADMISSIBLE AT DIFFERENT PRESSURES OF STEAM.

Pressure of Steam Pounds per Square Inch.........	10	20	30	40	50	100
Temperature of Feed-water, Fahrenheit.............	148°	138°	130°	124°	120°	110°

Sellers' fixed nozzle injector of 1885 is illustrated, in section, by the accompanying cut. It is a lifting injector—that is, it will receive water under pressure, or it will lift it to a considerable height before delivering to the boiler. Moreover, it is automatic and restarting—that is, if the water and steam are turned on, it will start itself, and, should the jet be broken, it will re-establish itself as soon as the disturbing cause is removed. The automatic action is complete when the water enters the injector under pressure, and also when lifting to a height of eighteen feet with ordinary steam pressures, the amount of water delivered being regulated by a valve contained in the injector or by the adjustment of both the water-valve and steam-plug, as may be preferred. If the supply of water is too much reduced, steam will escape at the overflow, but the jet will not break.



When required to lift, the injector, at say 60 pounds steam pressure, will raise the feed water 23 feet. As a non-lifter it will take water at 137° Fahr. with the overflow-valve open, and at 150° Fahr. with the overflow closed. By reference to the sectional view it will be seen that the instrument is quite simple in its construction, notwithstanding its applicability to varied conditions of service: *A* is the body or case of the injector; *B* is the steam connection leading from the steam-space in the boiler; *C* is the water-supply connection, in which is situated the water-regulating valve *R*; *D* is the water delivery connection, containing a check-valve, and leading to the boiler. The overflow-valve *N* may be shifted to either side of the injector body and turned radially, so that the injector may be placed in any position that will per*mit it to discharge* the overflow vertically downward. Another *important* and exceeding ent feature of the constructio



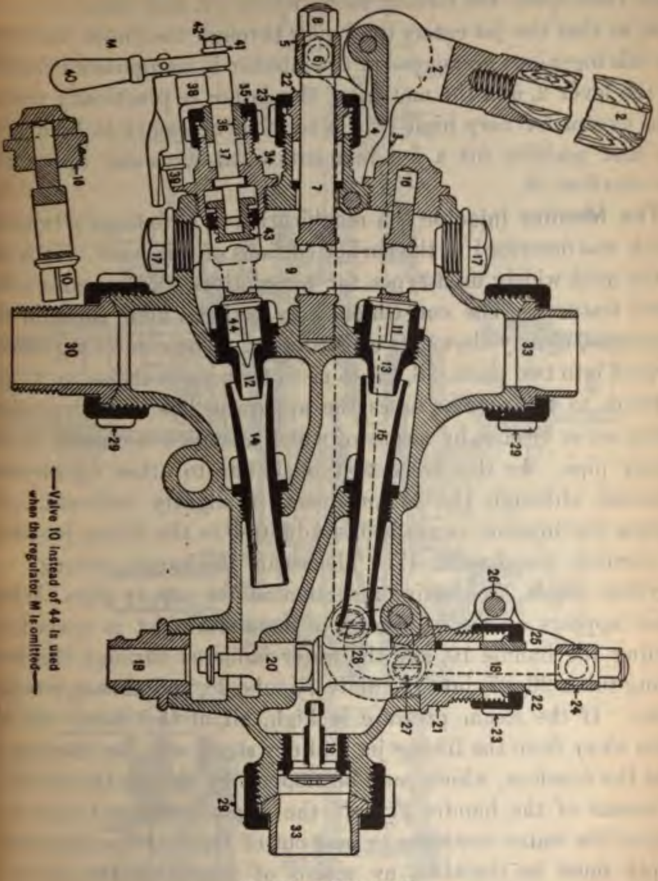
Sellers' Injector, 1887.

is, that by simply removing the end caps, all of the tubes ca
removed, for examination or for cleaning, without disturbing
pipe connections.

Sellers' self-acting injector of 1887 is of the double jet t
and, in common with other injectors of this type, it adjusts
maintains the proper supply of water for any pressure of ste
besides restarting automatically after a temporary break w
the disturbing cause is removed. Referring to the accompany
cut, 3 is the forcing nozzle, which is placed within the lif
nozzle 4, these being so proportioned that a suction is maintai
in the feed pipe even when there is a discharge from the for
nozzle. The combining tube is shown at 2. The water which
been lifted into this tube by the lifting jet here comes in con
with the forcing jet, which imparts to it an increased velocity,
the mixture rushes past the overflow openings into the deliv
tube, and thence into the boiler. This injector is especi
designed for use on locomotives. It may be operated efficie
under a wide range of boiler pressures, and its capacity may
reduced to 36 per cent. of the maximum by throttling at the f
valve, so that it may be used to feed continuously by sim
adjusting the water valve to suit the requirements.

The Korting Injector, known in this country as the *Sch*
Injector, which is also of the double jet type, may be used u
varying pressures and for both hot and cold water. In
accompanying cut, 15 and 14 are the two steam jets, the
being used for lifting the water, the other to force it into
boiler. It will work at the highest as well as at the lowest pressu
because the quantity of water taken in by the first jet and de
ered to the second is in proportion to the steam pressure, and
operate with hot water because the first nozzle is so proportio
as to insure a high suction, and as the water is delivered to the
nd nozzle under pressure, the temperature may correspond to t
re without interfering with the operation of the appara
ector has no overflows in either of the combining tu
ration is had by simply moving the lever 2 to the

The first motion of the lever opens the lifting steam nozzle 12, because the forcing valve 44, having a larger area, is kept closed



Korting Injector.

by the pressure of the steam upon it and acts as a fulcrum to the lever. The water is *now raised* and will appear at the waste-pipe 18. *The lever is now drawn further* to the left, which closes the of modern injectors, it will be evident that their differences li entirely in the details of construction, the principle being exactly the same in all. A description of other types would involve a great deal of repetition without any special benefit to the user of this book. The construction of the various types is clearly set forth in the catalogues of the makers, and the reader is referred to the following types, all of which are widely used, both for locomotive and stationary boilers: "Nathan, W. F.," "Belfield," "Rue" (Little Giant), "Metropolitan," "Gresham," "Manhattan," "Penberthy," "Eclipse," "National," "Hancock Inspirator," and many others.

In setting up injectors there are certain general rules which apply to all types. Upon the observance of these depends the successful operation of the apparatus, as much as upon its construction, and they should be carefully followed when the injector is first installed: All pipes, whether steam, water-supply, or delivery, must be of the same or greater internal diameter than the hole in the corresponding branch of each injector, and as short and straight as practicable. When floating particles of wood or other matter are liable to be in the supply-water, a strainer must be placed over the receiving end of the water-supply pipe. The holes in this strainer must be as small as the smallest opening in the delivery-tube, and the total area of all the holes must be much greater than the area of the water-supply pipe, to compensate for the closing of some of them by deposits. The steam should be taken from the highest part of the boiler, to avoid the carrying over of water with the steam. "Dry pipes" should always be used on locomotives to insure dry steam; wet steam cuts and grooves the steam spindle and steam-nozzle. The steam should not be taken from the steam-pipe leading to an engine, unless such pipe is large. Sudden variations in pressure may break the jet. After all the pipes are properly connected to
injector and to the boiler, and before steam and water are ad-
d through them to the injector, they should be disconnected
ll washed out by blowing steam or running water through

vash out all red lead, scale, or other solids that may be in

Finally, in setting injectors it is important to place them possible, since their capacity is reduced and the prompt- eliability of their action diminished as the height of lift is

The Ejector or Lifter.

nexed cut represents the ejector or lifter, which is prac- e lifter side of the inspirator,* with a reduced steam-jet ged lifter combining-tube. It is suitable for breweries, bleacheries, etc.; for trans- rge volumes of water, lye, acid, r liquids. It will deliver more any kind at a low lift, with a ssure of steam, than either the or inspirator; but it is not as or as well adapted to the dif- rposes for which these instru- e used, as either of them. It very good purpose when cellars ooded in consequence of heavy high tides, or overflowing of and requires no very intelligent ent. Its action is based on the nciple as that of the injector, ore simple, as it has no adjust- ovable parts.

d of starting the ejector.—All cessary to start the ejector is to the steam, after which it will long as the water-supply and ssure continue; and it is imma- at lift it is started on, as the pply may be gradually reduced

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spirator is the name given by John Hancock of Boston to the *njector.*

to meet the requirements of the quantity of water to be d charged.

Pumps vs. Injectors.

Since the injector was first introduced in this country in 18 it has rapidly grown in favor. It has the distinct advantage over pump that it feeds a continuous stream of water into the boiler, b sides being more compact and having no moving parts subject wear and tear. So far as economy in the use of steam is concern it cannot be said that it is more economical than a pump under conditions, but where the temperature of the feed water is low is the more economical device of the two, and it may be said, general, that the efficiency of the injector increases as the te perature of the feed water diminishes. The following table, c culated by Professor D. S. Jacobus, gives the relative value pumps and injectors under different conditions.

Method of Supplying Feed Water to Boiler. Temperature of feed water as delivered to the pump or to the injector, 60° Fah. Rate of evaporation of boiler, 10 pounds of water per pound of coal from and at 212° Fah.	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 ct.
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 "

CHAPTER XIV.

ED-WATER HEATERS, ECONOMIZERS, SEPARATORS, AND TRAPS.

ating the feed water before it enters the boiler has three
ct advantages. In the first place, if the water enters the
at ordinary temperatures, which range from 70° in summer
° in winter, the cold water, coming in contact with the hot
and tubes, causes strains in the boiler which will impair its
ery materially. This may be avoided almost entirely by
ng the water to a temperature of about 210° before it enters
oiler. Secondly, it has been found that the corrosive effect
t water is much less than that of cold water; besides, the heat-
f bad water to a high temperature removes a large propor-
f the impurities, depositing them in the heater, where they
f less importance and where they may be easily removed,
d of allowing them to be carried into the boiler, where a
it of scale is dangerous unless frequently removed. Lastly,
y material gain in economy is effected by heating the feed
. If, for example, the normal temperature of the feed-
supply is, say, 50°, and the boiler is used for making steam at,
0 pounds pressure it will require in all about 1162 heat units
aporate each pound of water. Suppose the boiler has a
ity of fifty horse-power, which means that about 1500 pounds
ater are evaporated, requiring $1162 \times 1500 = 1{,}743{,}000$ heat
per hour. Under the best conditions this would mean a
mption of about 175 pounds of coal per hour, assuming that
l the heat contained in each pound of coal 10,000 units are
able for making steam. Now suppose the feed water enters
boiler at 210°. It will then require only 1002 heat units to
orate a *pound of water, and* consequently there will be used
$1002 \times 1500 \div 10{,}000 = 150$ pounds of coal per hour under

Percentage of Saving in Fuel by Heating Feed-Water. Steam at 70 Pounds Gauge Pressure.

Initial Temperature Feed.	TEMPERATURE TO WHICH FEED IS HEATED														
	100°	110°	120°	130°	140°	150°	160°	170°	180°	190°	200°	210°	220°	240°	300°
35°	5.53	6.38	7.24	8.09	8.95	9.80	10.66	11.52	12.38	13.24	14.09	14.95	15.81	19.40	29.31
40°	5.12	5.97	6.84	7.69	8.56	9.42	10.28	11.14	12.00	12.87	13.73	14.59	15.45	18.89	28.76
45°	4.71	5.57	6.44	7.30	8.16	9.03	9.90	10.76	11.62	12.49	13.35	14.22	15.09	18.37	28.22
50°	4.30	5.16	6.03	6.89	7.76	8.64	9.51	10.38	11.24	12.11	12.98	13.85	14.72	17.87	27.67
55°	3.89	4.75	5.63	6.49	7.37	8.24	9.11	9.99	10.85	11.73	12.60	13.48	14.35	17.36	27.13
60°	3.47	4.34	5.21	6.08	6.96	7.84	8.72	9.60	10.47	11.34	12.22	13.10	13.98	16.86	26.58
65°	3.05	3.92	4.80	5.67	6.56	7.44	8.32	9.20	10.08	10.96	11.84	12.72	13.60	16.35	26.02
70°	2.62	3.50	4.38	5.26	6.15	7.03	7.92	8.80	9.68	10.57	11.45	12.34	13.22	15.84	25.47
75°	2.19	3.07	3.96	4.84	5.73	6.62	7.51	8.40	9.28	10.17	11.06	11.95	12.84	15.33	24.93
80°	1.76	2.65	3.54	4.42	5.32	6.21	7.11	8.00	8.88	9.78	10.67	11.57	12.46	14.83	24.37
85°	1.30	2.22	3.11	4.00	4.90	5.80	6.70	7.59	8.48	9.38	10.28	11.18	12.07	14.32	23.83
90°	0.89	1.78	2.68	3.58	4.48	5.38	6.28	7.18	8.07	8.98	9.88	10.78	11.68	13.81	23.27
95°	0.45	1.34	2.25	3.15	4.05	4.96	5.86	6.77	7.66	8.57	9.47	10.38	11.29	13.31	22.73
100°	0.00	0.90	1.81	2.71	3.62	4.53	5.44	6.35	7.25	8.16	9.07	9.98	10.88	12.80	22.18

lar conditions. In other words, the heating of the feed water saved 25 pounds, or about 15 per cent. of the fuel consumed. his way it may be shown that about 1 per cent. of the fuel is d for every ten degrees the temperature of the feed water is ed. The preceding table is calculated to show the exact saving uel for different temperatures when the steam pressure is 70 nds.

he methods of heating feed water generally used are three umber, viz.:

eed-water heaters, consisting of an arrangement whereby the aust steam* from the engines, pumps, etc., is brought in con- with a fresh supply of feed water, either directly or through medium of a series of tubes, in such a way that the heat of the m is imparted to the feed water until the temperature of the er is raised to from 200 to 212 degrees. After passing through heater the steam, if not condensed in the heater, passes either the atmosphere or into a condenser.

conomizers, consisting of an arrangement of tubes placed ally at the point where the boiler flues enter the stack. The water is pumped through the tubes into the boiler, and in its sage absorbs the heat of the escaping gases, which would other- e be wasted. An economizer is essentially a water tube boiler, as such should always be equipped with a suitable safety ve.

ondensers, being essentially the same as feed-water heaters their mode of operation, except that there is a considerable ess of water used above that required in the boiler, the in object being the condensation of the exhaust steam rather n the heating of the feed water. (See also Condensers, page .)

eed-water heaters may be divided into two principal classes: sed heaters and open heaters.

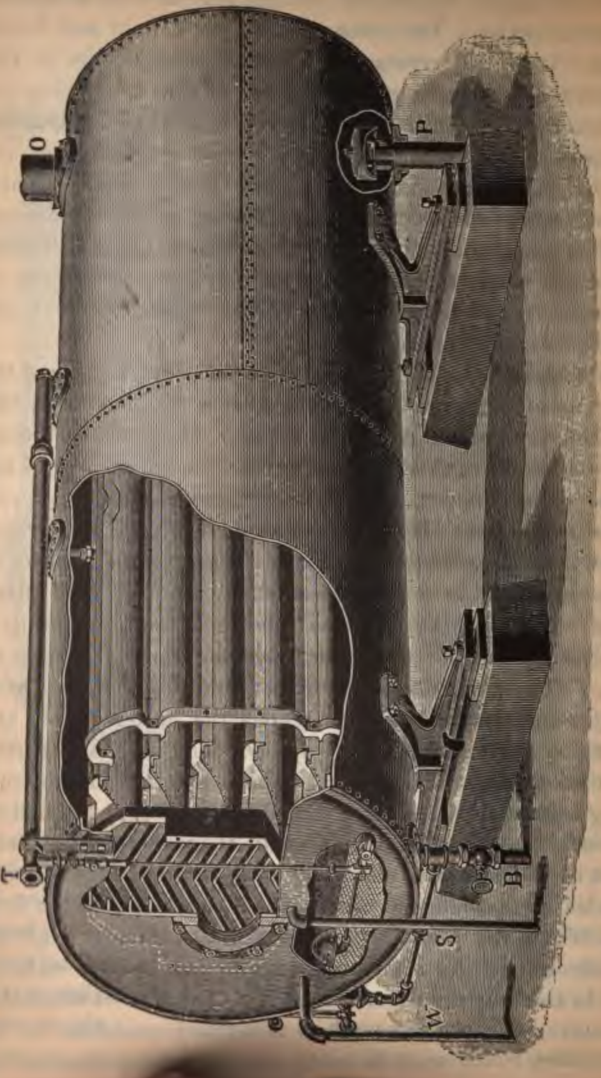
losed feed-water heaters consist of an arrangement of tubes

In some cases where the water contains a large percentage of solid *r in solution, live-steam feed-water* heaters are also used.

through which the feed water is forced into the boiler,
being surrounded by the exha
from the engine. They have t
tage over open heaters in this
water passes through the pump
pump being placed between the
supply and the heater. There
more or less difficulty in pun
water, and if the heater cannot
higher than the pump the close
preferable. On the other har
properly constructed, closed he
cause a back pressure on th
which will lose more power
gained by raising the temperat
water. Besides this, many of
which are in common use are
cult to clean. This is an impo
sideration in the selection of a
cause there is always a precip
lime if any is present in the
the removal of this and othe
should be provided for. Th
panying cut illustrates the Go
of heater, which belongs to
The tubes are expanded into t
at either end of the heater.
pressure is within the tubes, there is little danger of
lapsing, and they are made of brass in order that they
ily conduct the heat from the steam to the water. T
has the great advantage over many others of the same
the tubes are easily accessible for cleaning, it being me
sary to remove the head. The cross section of the stea
is from eight to sixteen times as great as that of the ex
that no back pressure can ensue from its use. Refe

e top or bottom side opening may be used as the ex-
outlet. The water enters at the bottom and leaves
n the Berryman heater, which also belongs to this
es are ∩ shaped, both ends of the tube being ex-
he same tube sheet. By this method of construction
ay be made much shorter and the tubes are not
xpansion and contraction. The National Heater
spiral coil or coils of brass tubing enclosed in an iron
has the advantage that there are no joints to become
e whole arrangement is exempt from strains due to
d contraction. Both of these types, however, are
ore difficult to clean.

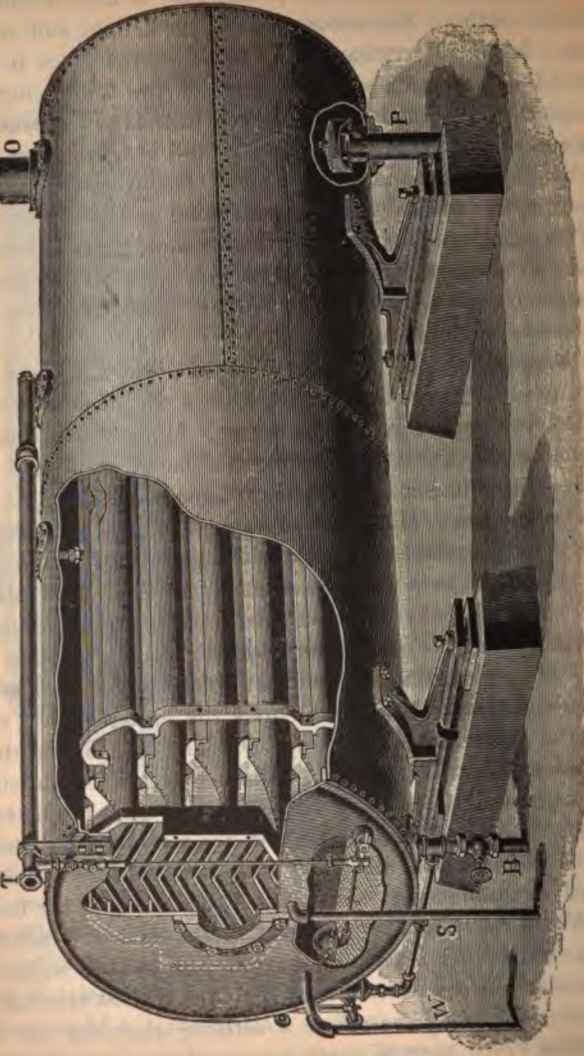
ters:—In the open type of feed-water heaters the
must be under pressure, as it is not possible in this
the water through the heater. Moreover, the heater
ed above the pump, otherwise the hot water will not
mp plunger, as already explained. The cut repre-
ell-known Hoppes feed-water heater and purifier,
of the oldest of this class. It consists of a series of
nclosed in a cylindrical shell made of steel plate,
ther end by cast-iron plates. The front head is
permit the pans to be taken out for the purpose of
he exhaust steam enters at the back end, and after
ugh an oil catcher it enters the heater proper and
e front through the pipe *O*. The pipe *S* is a drip
catcher. The water is admitted at the top, the sup-
ulated by the valve *T* and float shown at the bottom
. After filling the top pan the water overflows and
the next pan, and so on until it reaches the bottom,
es through the pipe *P*, which connects with the feed-
en the plant is in operation the pans are always
water and completely surrounded by the exhaust
his way the water is heated to the highest attainable
while the pans afford a settling chamber for the
ies, which may be easily removed from time to time.



Hoppes Feed-water Heater, showing Oil Catcher and Water Regulator.

The advantages and disadvantages of the two types of feed-ater heaters may be summarized as follows: With closed heats the water passes through the pump cold, and the water supply, ump, and heater may be placed in any convenient position relave to each other, while in open heaters the level of the source f water supply must be above that of the heater, and that of the eater above that of the pump. Further, the feed water entering he boiler where the closed heater is used is fresh water, and does ot contain any of the impurities absorbed in the passage of he steam through the engine. While it is claimed that these mpurities are removed in open heaters by the use of oil separators, etc., yet there is a strong probability that a sufficient quantity remains to injure the boiler plates to some extent. On the other hand, the back pressure on the engine in the case of open heaters s practically nothing, while in closed heaters it is often quite appreciable, the purification of the water is more complete in the open type, and the efficiency—that is, the temperature to which the water is raised—is usually higher. Besides, the open heater is not required to operate under pressure; it is consequently cheaper to build and is less liable to accident.

Economizers, though not used as extensively as feed-water eaters, without doubt frequently add to the economy of operation n large plants, while in small ones their first cost is generally too reat. The sectional views illustrate one of the oldest and most idely used types of this apparatus, known as Green's Economizer. consists of a series of cast-iron tubes about four inches in ameter and nine feet long, connected at the top and bottom by aders similar to those used in some types of water-tube boilers. e headers are also connected by two branch pipes running gthwise outside of the brickwork. The feed water enters the paratus through the connection shown at the bottom, which is the end of the lower branch pipe nearest the point of exit of the es, and leaves it through the connection shown at the top, ch is in the end of the *upper* branch pipe nearest the point *re the gases enter. In order* to keep the exterior surfaces of



Hoppes Feed-water Heater, showing Oil Catcher and Water Regulator.

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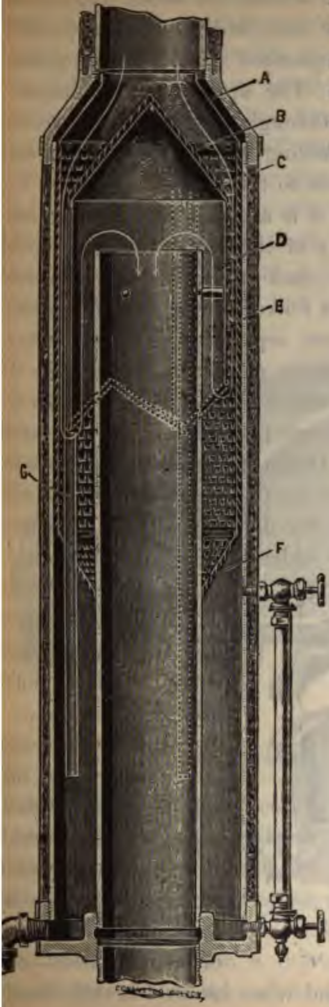
Economizers, though not used as extensively as feed-water heaters, without doubt frequently add to the economy of operation in large plants, while in small ones their first cost is generally too great. The sectional views illustrate one of the oldest and most widely used types of this apparatus, known as Green's Economizer. It consists of a series of cast-iron tubes about four inches in diameter and nine feet long, connected at the top and bottom by headers similar to those used in some types of water-tube boilers. The headers are also connected by two branch pipes running lengthwise outside of the brickwork. The feed water enters the apparatus through the connection shown at the bottom, which is in the end of the lower branch pipe nearest the point of exit of the gases, and leaves it through the connection shown at the top, *which is in the end of the upper* branch pipe nearest the point *here the gases enter. In order* to keep the exterior surfaces of is intended mainly to remove the entrained water from the steam, while a separator placed in the exhaust piping when the exhaust steam is to be condensed and used again in the boilers, is intended to remove the grease which it has accumulated in its passage through the engine. The use of dry steam in engines is important not only because an accumulation of water in the cylinder is a menace to its safety, but also because entrained water involves a very considerable reduction in the economy of operation. The water carried into the steam cylinder not only carries away heat from the boiler which is incapable of doing any work in the engine, but it also materially increases the initial condensation, one of the most important losses of power in the engine. Hence there should be provided some device which will insure dry steam.

The principles upon which the action of steam separators should be based are now fairly well understood. In the first place, they should be constructed in such a way that the momentum which has been acquired by the liquids and solids is destroyed. This is accomplished by baffle or deflecting plates, which alter or reverse the direction of flow of the steam, or by allowing it to expand and give the heavier particles time to fall by the action of gravity. After this has been accomplished it is important to prevent the separated water from being again picked up and carried along by the purified gases. Finally, care must be taken that an ample and easy passage is afforded to the current of steam, so that there will be no loss of energy from friction.

The cuts on p. 283 represent in section two well-known types of separators in which these principles are embodied, Sweet's and Cochrane's. The former is for use in a vertical pipe and is usually placed directly over the engine cylinder, while the latter is for use in a horizontal steam main, but both can be slightly modified so as to be applicable to either horizontal or vertical pipes. Referring to the illustration of Sweet's separator, the course of the steam in its passage through the apparatus is indicated by the *whi* [illegible] ncipal points of merit are that the water once se [illegible] come in contact with and hence cannot be picked up by the current of steam and the so-called "whip-snapping" action or sudden reversal of direction of flow of the steam, by which the rest of the moisture is shaken out, as it were. In Cochrane's separator the separation is effected by a

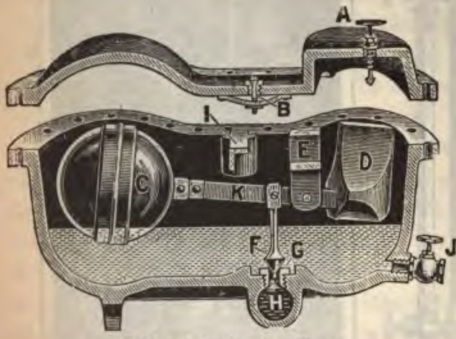


Sweet's Separator.

Cochrane's Separator.

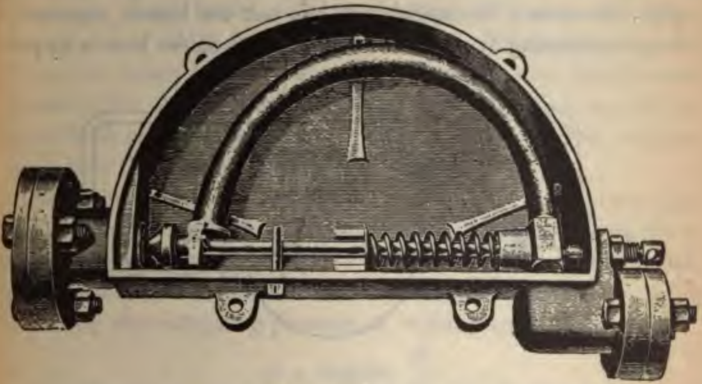
ribbed baffle plate placed between the steam inlet and outlet. The sides of the separator converge toward the centre and lead to the reservoir, the mouth of which is protected, so that the purified steam will not again pick up the separated particles during their descent or after reaching the well. The apparatus is so designed that the area of the steam passage through it greatly exceeds the area of the steam pipe, thus minimizing the loss in friction and giving the heavier particles a chance to fall to the bottom.

Steam traps are used wherever it is necessary to carry off condensed steam without allowing any of the steam itself to escape with it. There is hardly a steam plant in existence which does not contain one or more steam traps for collecting and discharging the condensation in the steam pipes, separators, etc., and it may safely be said that the steam trap is one of the most important of the accessory devices in a modern steam plant. The number of different types of traps which the market offers and the difference in their mode of action are so great that it would be impossible here to attempt to describe them all, but the two cuts given below will illustrate, in a general way, how the desired result is attained. The McDaniel trap is one of the oldest and most widely used types in existence. The cut illustrates the trap in longitudinal section, with the cover removed. It consists of a cast-iron casing into the top of which leads a pipe (not shown) from the system which is to be drained. The water of condensation col- ts in the bottom of the casing, and when its level is sufficiently i, it acts upon the copper float C, which, with the aid of a



McDaniel Steam Trap.

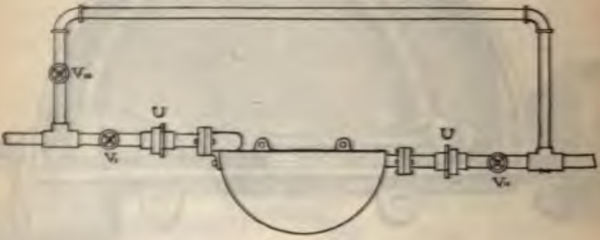
system of levers, *K*, and a counterpoise *D*, actuates the plug valve *F*, lifting it from its seat *G*, when the water in the trap is high, and closing it when the water is low. As will be seen from the cut, the cover is removable, so that the trap is accessible for cleaning and repairs. There is also provided a blow-off pipe *J*, which may be connected to the waste pipe. The set screw *A* in the cover is for the purpose of adjusting the rate of discharge. It is claimed for the McDaniel trap that it will discharge continuously and without allowing any steam to escape with the condensation. When properly adjusted there is no reason why it should not substantiate these claims, and it has been found a very satisfactory trap for both high and low pressures. The Heintz steam trap,



Heintz Steam Trap.

illustrated in the other cut, is entirely different in its action, but accomplishes the same object, viz., the continuous discharge of the condensation without wasting steam. It consists of an outer casing with removable cover, a curved tube spring of elliptical cross section, a plug valve, and a spiral spring. The tube spring is partially filled with a liquid which, heated by the condensed water surrounding it, completely fills the tube when the temperature reaches 197° F. The action is similar to that in the Bourdon pressure gauge, for as the temperature of the water rises, pressure is exerted within the tube, causing it to straighten out and thus close the plug valve. When the temperature has reached 212° the valve is forced tightly against its seat, remaining so until enough condensation has accumulated to lower the temperature one degree, when the valve opens sufficiently to pass off the condensed steam, but closes again as soon as the water is discharged. The opening and closing are accomplished so quickly that there is practically a continuous flow of water from the outlet.

By-Passes.—All of the appliances which have been described in this chapter should be provided with by-passes—that is, they should be connected with the piping in such a way that either the steam or the water can be made to pass through an auxiliary pipe whenever it is desirable to cut out the heater, separator, or trap for cleaning or repairs. The diagram shows how a by-pass is usually arranged. It consists of a pipe passing around the appliance to which it is connected, and three valves $V_{\prime}$, $V_{\prime\prime}$, and $V_{\prime\prime\prime}$. Under ordinary conditions the valves $V_{\prime}$ and $V_{\prime\prime}$ remain open and $V_{\prime\prime\prime}$ is closed. But if the by-pass is to be used, the valve $V_{\prime\prime\prime}$ is opened and $V_{\prime}$ and $V_{\prime\prime}$ are closed. The heater or other appliance may then be disconnected by means of the unions U, without interfering in any way with the continuity of operation.



CHAPTER XV.

FURNACES, GRATES, CHIMNEYS, ETC.

rnaces and Flues.—The rules which apply to the strength e cylinder subjected to a pressure from within, such as cylin- l boilers, do not apply to furnaces and flues, where the ure is exerted from without. The thickness of a cylinder cted to a given pressure from within depends only upon the eter of the cylinder, the pressure, and the strength of the rial. The tendency of the internal pressure is to keep the idrical shape intact, so that rupture will occur only when naterial of which it is made gives way. When, however, the sure is exerted from without the case is more complicated, use unless the cylinder is mathematically perfect, any devia- will be exaggerated by the pressure, so that it will collapse before the crushing strength is reached.

he experiments of Fairbairn, made some forty years ago, ved that the strength of cylinders subjected to external press- varies directly as the square of the thickness of the metal, inversely as the diameter and the length. Rankine's formula finding the collapsing pressure of boiler flues is:

$$P = 806000 \frac{t^2}{l\,d}$$

re $P =$ collapsing pressure in pounds per square inch.
$t =$ thickness of the iron in inches.
$d =$ diameter of the flue in inches.
$l =$ length " " feet.

nce, to find the collapsing pressure of a boiler flue, we have following:

ule.—*Multiply the square of the thickness of the iron in* *es by the constant number* 806000, *and divide this produ* *he product of the diameter of the flue in inches and*

Morrison's Suspension Furnace.

length in feet. The quotient
be the collapsing pressur
pounds per square inch.

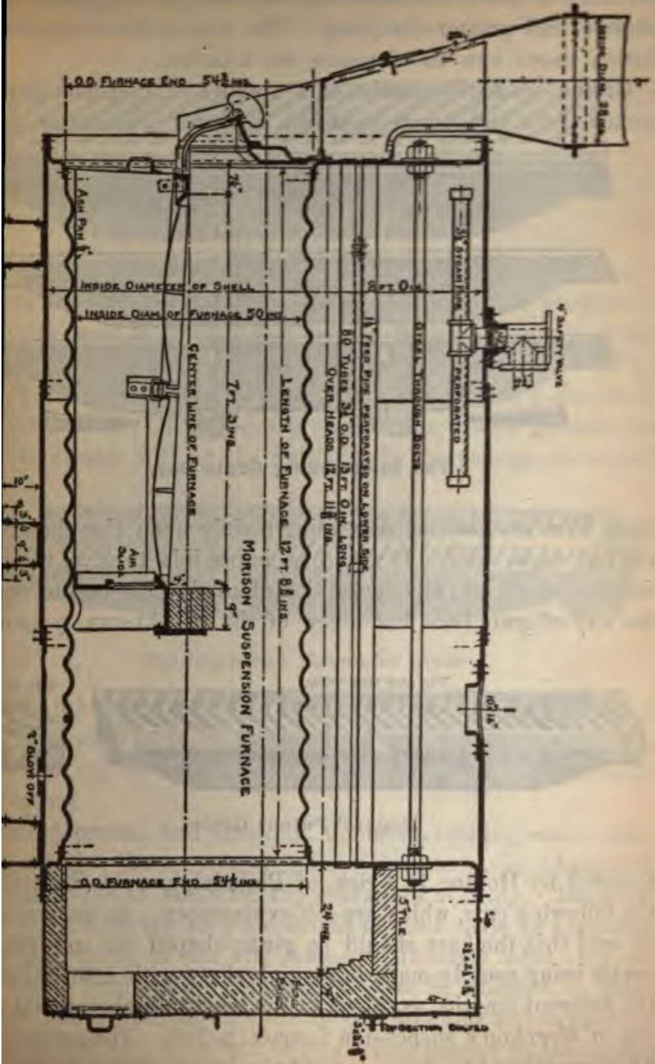
Example.—What pressure
square inch will cause a b
flue 24 inches in diameter an
feet long to collapse, if the m
is ⅜ of an inch thick?

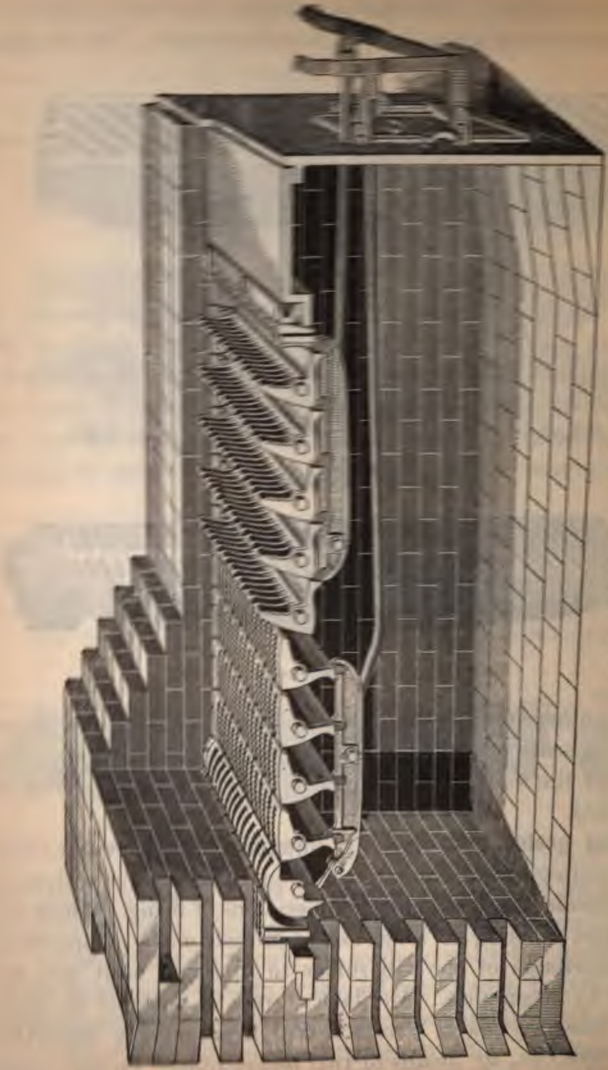
Collapsing pressure

$$=\frac{806000\times.375\times.375}{24\times20}$$

$= 236$ pounds.

Various methods have
employed for strengthening
flues, such as angles and tees
eted around the inner or o
surface at intervals. In such
the strength is to be calculate
the above rule, but the leng
taken as the distance between
stiffening rings. Galloway t
(see Galloway Boiler, p. 162)
also been employed to increas
strength of flues. The most
cessful plan, however, is tha
vised by Mr. Samson Fox
Leeds, England, which co
of corrugating the flue, as s
in the perspective and sect
views of Morrison's suspe
furnace. This plan of corrug
the furnaces and flues is no
most universally used with
nally fired boilers. Beside
strength of this type of furnaces over plain cylin


O.D. FURNACE END 54½ INS.
INSIDE DIAM. 28 INS.
ASH PAN 6"
INSIDE DIAMETER OF SHELL 8 FT. 0 IN.
INSIDE DIAM. OF FURNACE 50 INS.
CENTER LINE OF FURNACE
7 FT. 3 INS.
LENGTH OF FURNACE 12 FT. 8⅝ INS.
MORISON SUSPENSION FURNACE
1½" FEED PIPE PERFORATED ON LOWER SIDE
60 TUBES 3½" O.D. 13 FT. 0 IN. LONG
OVER HEADS 12 FT. 11⅛ INS.
STEEL THROUGH BOLTS
3½" STEAM PIPE PERFORATED
4" SAFETY VALVE
AIR SLIDE
2" BLOW OFF
10" x 16"
O.D. FURNACE END 54½ INS.
24 INS.
5" TILE
TOP OF SECTION GROUTED



McClave's Improved Grate.

ribution of fuel. The spacing of grate bars depends entirely n the nature of the coal which is to be burned. The air space

Obtuse Angle.

en the bars should be subdivided as much as possible, so every part of the fire will receive its proper supply of air. ituminous coal the spaces between the bars should be $\frac{1}{2}$-$\frac{5}{8}$ but for anthracite, especially the finer grades, it should be ver $\frac{3}{8}$ inch. Of course, the smaller the spaces between the the greater will be the resistance to the passage of air, and

The Improved Keystone Grate.

ne anthracite fuel it is frequently necessary to use forced ght in order to make the combustion sufficiently rapid. The ce of the top of the grates from the ashpit varies from 24 inches.

aking grates, and crushing, dumping, rocking, water circu-, rotating grates, etc., are names given to various designs of s intended to facilitate the operations of firing. There are types, differing to some extent in their mode of operation, description of one will suffice to illustrate what they are ded to accomplish. McClave's grate is intended to shake re, remove clinkers from soft-coal fires and fine ashes from *coal fires, etc., by means of* two levers placed on the outside, coal may be used. The labor of firing is cut down very materially, there being no cleaning of fires and no manual labor whatever, except, perhaps, in bringing the coal into the hoppers in front of the boilers, which can also be accomplished by the aid of suitable machinery. Finally, where mechanical stoking is employed, the whole boiler plant is very much cleaner, and the man in charge can keep it so with as little labor as an engineer can the engine-room.

One of the most successful systems of mechanical stoking which has thus far been designed is the Wilkinson system, built by the Wilkinson Manufacturing Company, of Bridgeport, Pa. There are many other* systems which have also proved successful, but a description of the Wilkinson Device will suffice to show in a general way how mechanical firing is accomplished.

The Wilkinson Automatic Stoker, as used at the Baldwin Locomotive Works, and the method of handling the coal and ashes, are illustrated in the following cuts.

The first illustration represents the interior of the boiler room on the second floor, showing the fronts of the Babcock & Wilcox water tube boilers equipped with automatic stoking apparatus (Wilkinson system). There are four batteries of two boilers each, aggregating 2000 horse-power.

The second illustration shows the exterior of the power house. It will be seen that the siding has a number of holes between the tracks provided with cover plates. These holes are the entrances into the coal vaults under the boiler house. During the operation of the boilers an endless chain with buckets passes along the front of the coal bins, up through a cylinder at one end of the building, then over the top of the hoppers shown above the front of the boilers, where, by a simple device, the buckets are tilted so they can be emptied into any one of the hoppers. After discharging their contents the buckets pass down a similar cylinder

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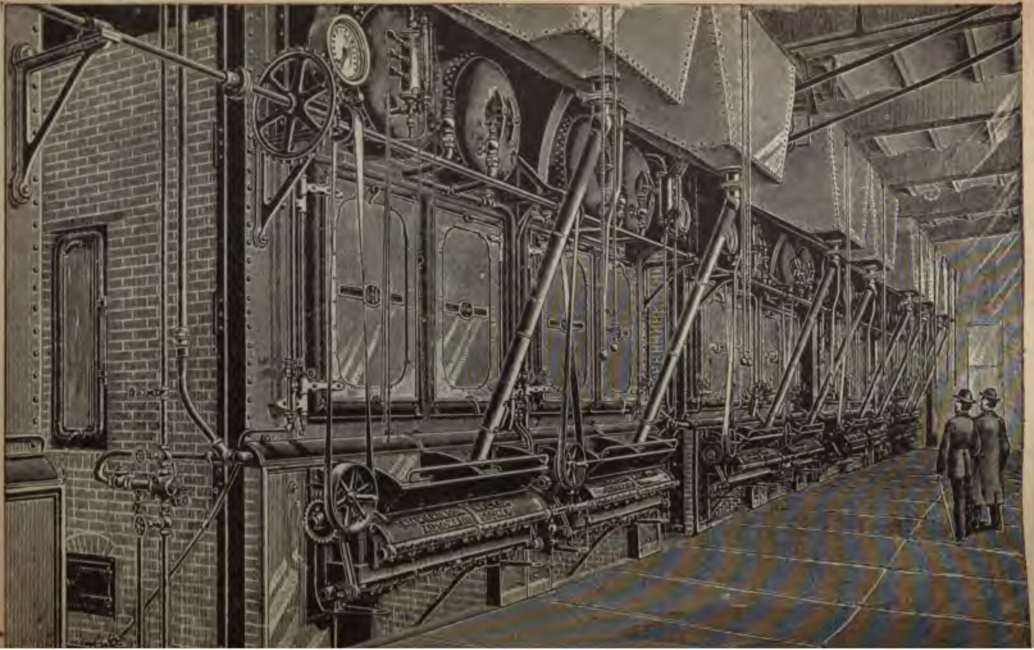
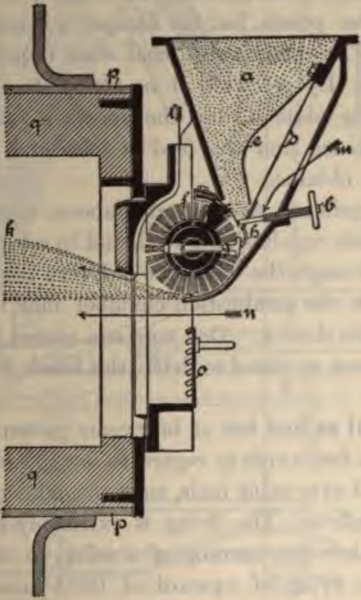
* Among the other American systems of mechanical firing the following *may be menti*[redacted]ey, Babcock & Wilcox, Murphy, American, Jones, *etc.*



forth motion of the grate bars maintains a uniform thickness of fire, while the coal gradually descends to the bottom of the grate, when it falls on the stationary grate shown in the furnace view. The ashes are pushed from the stationary grate by the motion of the grate bars, and descend through chutes under the boiler floor to the cars on the siding, as shown in the exterior view of the boiler house. A steam blast is used to induce a current of air through the grate, the intensity of the current being regulated by a suitable valve. The amount of steam required for this purpose is about 10 per cent. of that generated by the boilers. It is claimed that, as the steam is decomposed by the heat of the fire, the combustion chamber is filled with burning gases, resulting in a more uniform distribution of the heating surface of the boiler. A further object of the steam blast is to preserve the grate bars.

Coal-dust firing is another one of the inventions of the past decade which will doubtless play an important part in the advancement of industrial enterprise. It is hardly necessary here to point out the advantages of a system of firing by which coal dust, or particles too fine for use with any form of grate, can be economically used as fuel. Several systems for utilizing coal dust in boiler furnaces have been devised, and of these the *Schwartzkopf System* has been most successful in consuming this grade of fuel, not only economically, but also with an entire absence of smoke. The cut below represents this system. The apparatus consists of a hopper, *a*, filled with coal dust. The hopper is closed at the bottom by an elastic plate, *c*, which can be adjusted by means of a set screw, *b*, and by a shaking lid, *d*. A stationary plate, *e*, relieves the lid, *a*, of the pressure of the coal dust; *f* is a round brush made of flat steel wires. Attached to it is a hammer, *g*, which at each revolution strikes the piece *h*, fastened to the shaking lid *d*. Each stroke of the hammer throws the plate *d* back a certain distance, the range of which can be regulated, and permits a fixed quantity of coal dust to fall through *the slot thus opened.* This slot, which extends the whole width *of the revolving* brush, allows the coal to fall within reach of the les, which throw it with some force into the combustion *k*. As soon as the hammer *g* has passed the piece *h*, the prings back by its own tension and closes the aperture which the coal fell, thus checking the feed. As the rrying the hammer *g* revolves rapidly, it causes a con- nd uniform feeding of the coal dust, which can, however,



ted by the screw *b*. Even damp coal and larger parti- h may have gotten into the hopper by accident are fed and thrown into the combustion chamber, a feature not possessed by any other system of dust firing.

mbustion chamber *k* may be made in the flue of a boiler it for a distance of five or ten feet with firebricks.

t the coal-dust fire it is necessary to build a small wood burn some greasy waste in the combustion chamber.

draught for the consumption of a certain quantity of
given time, but such formulæ have more frequently failed,
eeded, in giving satisfactory results, which is due prob-
he want of knowledge of the requirements in each in-
case, and of the location and surroundings. Attempts
any instances, made to produce a good draught by carry-
imney above all surrounding objects and buildings, but it
y occurs that shorter chimneys of the same area and
dimensions have a better draught. It is claimed by some
that chimneys ought to increase in area from bottom to
e capable of producing a good draught, while others assert
reverse, and claim that they ought to decrease from bottom
It has been found by experiment that both arrangements
l a good draught under some circumstances, but neither
under all circumstances. The area of any chimney should
slightly from bottom to top, in order to provide for the
l volume of the heated air and gases resulting from their
n. It has been found that round flues produced a better
as a general thing, than either square or oval ones of the
a and height. This doubtless arises from the fact that
ing through or up a flue or funnel, has a tendency to as-
form of a screw, which is due probably to some natural

se currents and capping winds frequently interfere with the
in short chimneys, but the same effect is frequently pro-
tall ones during some kinds of weather and at certain
f the year; certain it is, that very tall stacks do not pro-
orresponding draught in proportion to the height, and it
demonstrated by observation that there is nothing to be
y raising chimneys very high. It often occurs that chim-
apparently sufficient height are incapable of producing
draught. This, in many instances, arises from the fact
quantity of fuel consumed in the furnace will not produce
heat in the flue to rarefy the air and cause draught
other chimneys of ample height and area, in consequen

of the air and heated gases having to pass through a long, cold flue between the boiler and chimney, the draught is sluggish and unsatisfactory.

The theory which underlies the proportioning of chimneys may be briefly explained as follows: Each pound of coal consumed in the furnace requires about 24 pounds of air for its complete combustion, and as a pound of air has a volume of $12\frac{1}{2}$ cubic feet at 32°, and the volume of the products of combustion is practically the same as that of the air supplied, the total volume of furnace gases at 32° will be $24 \times 12\frac{1}{2} = 300$ cubic feet. At any other temperature the volume is increased in the proportion of the absolute temperatures. Thus, if the temperature in the furnace is 2000°, the volume of the gases will be

$$300 \times \frac{2000 + 460}{32 + 460} = 1495 \text{ cubic feet.*}$$

The draught of the chimney depends only upon the difference between the weight of a column of outside air having a height equal to that of the chimney above the grate and that of the column of hot air within the chimney. It is proportional nearly to the product of the height of the chimney into the difference of temperature of the outside and inside temperatures. For example, the weight of a column of gas 1 foot square and 150 feet high at 32° would be:

$$\frac{1 \times 150}{12.5} = 12 \text{ pounds,}$$

while if the temperature is 500°, the weight of an equal column will be

$$\frac{12\,(32 + 460)}{500 + 460} = 6.15 \text{ pounds.}$$

Hence, if the temperature of the outside air is 32° and that within the chimney 500°, the difference in weight of two equal columns of gas 1 foot square and 150 feet high, at those temperatures, is

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* *The absolute temperature* is obtained by adding 460 to the Fahrenheit, *or 273 to the Centigrade* temperature.

15 = 5.85 pounds, which is equal to the draught per square chimney area. The height of a column of gas at the tem-e within the chimney equal to this difference in weight is he head of the chimney, because it is this difference which es the draught or flow of air, just as the difference of level l produces the flow of water.

for finding the head of chimneys.—Multiply the weight of foot of air at the temperature of the outside air by the of the chimney and divide the product by the weight of ic foot of air at the temperature in the chimney. From otient subtract the height of the chimney. The result will head in feet.

nple.—If the temperature of the air is 32°, that in the y 500°, and the height of the chimney 150 feet, the weight bic foot of the outside air will be

$$\frac{1}{12.5} = .08 \text{ pound},$$

he weight of a cubic foot of air at the temperature of the y will be

$$\frac{.08\ (32 + 460)}{500 + 460} = .041 \text{ pound}.$$

nce the head

$$\frac{.08 \times 150}{.041} - 150 = 143 \text{ feet}.$$

ere were no obstruction to the passage of the gases, the y of flow of air would be equal to the square root of the t of the head and the constant number 64.4. However, the greatly impeded by the resistance opposed by the grate and l, and by the friction of the sides of flues, tubes, and the f the chimney. Hence, the actual flow is very much less his; how much less, depends upon the kind of grate and e thickness of fire, the condition of the flue walls, etc. It ent, therefore, that any rules which may be laid down for ting the size of chimneys will be largely the results of *nce.*

[illegible]

[illegible] constan

[illegible] stack in

[illegible] per

[illegible] square

[illegible] the are

[illegible] consumed p

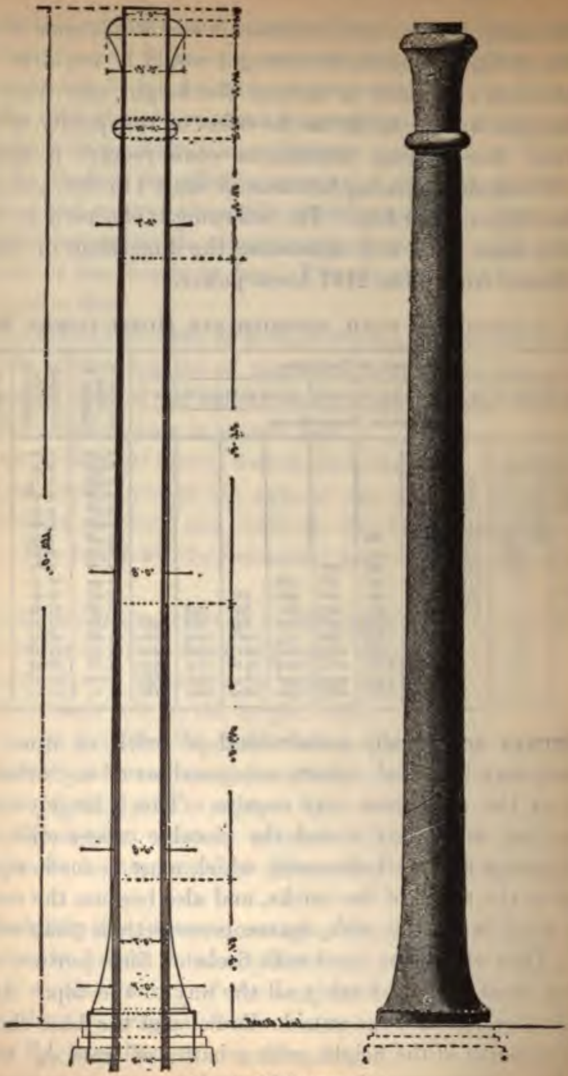
[illegible] square the

›t, and partly, also, because if the wind came from the n of higher objects the draught would be impaired. Conly it is customary to assume the height, and from this to :e the area. As far as the effect of the quality of coal is ed, free-burning bituminous coals require a height of 5 feet, slow-burning bituminous coals 115 feet, and anthram 125 to 150 feet. The following table, used in connec:h these data, will determine the dimensions of chimneys ers of from 23 to 2167 horse-power.

OF CHIMNEYS WITH APPROPRIATE HORSE-POWER BOILER.

HEIGHT OF CHIMNEYS.										Effective Area, square ft.	Actual Area, square ft.	Side of square of approximate area. Inches.
60 ft	70 ft	80 ft.	90 ft.	100 ft.	110 ft.	125 ft.	150 ft.	175 ft.	200 ft.			
Commercial Horse-Power.												
25	27									0.97	1.77	16
38	41									1.47	2.41	19
54	58	62								2.08	3.14	22
72	78	83								2.78	3.98	24
92	100	107	113							3.58	4.91	27
115	125	133	141							4.47	5.94	30
141	152	163	173	182						5.47	7.07	32
	183	196	208	219						6.57	8.30	35
	216	231	245	258	271					7.76	9.62	38
		311	330	348	365	389				10.44	12.57	43
		363	427	449	472	503	551			13.51	15.90	48
		505	539	565	593	632	692	748		16.98	19.64	54
			658	694	728	776	849	918	981	20.83	23.76	59
			792	835	876	934	1023	1105	1181	25.08	28.27	64
				995	1038	1107	1212	1310	1400	29.73	33.18	70
				1163	1214	1294	1418	1531	1637	34.76	38.48	75
				1344	1415	1496	1639	1770	1893	40.19	44.18	80
				1537	1616	1720	1876	2027	2167	46.01	50.27	86

nneys are usually constructed of brick or iron. Brick :ys may be round, square, octagonal, or of any other crossas the conditions may require. This is largely a matter ε, but, as already stated, the circular cross-section is preexcept for small chimneys, which must be made square on t of the shape of the bricks, and also because the resistance wind is greater with square cross-sections than with any They should be lined with firebrick for a portion of their at least, and preferably all the way to the top. As far as h is concerned, the outside diameter at the base should be one-tenth of the height, with a batter of from $\frac{1}{16}''$ to $\frac{1}{4}''$ per *The thickness at the top* should be not less than one brick



Iron Chimney.

or 9 inches) for a distance of 25 feet. If the height exceeds feet, it should be a brick and a half, and it should increase in ckness one-half brick for each length of 25 feet to the bottom. arched opening at the bottom should be provided to permit access for cleaning and repairs, as well as a ladder either inside outside to permit of access at the top.

Iron stacks are preferable in some cases to brick, because they much cheaper, and, besides, their efficiency is somewhat higher. irthermore, they are better able to withstand changes in nperature, which often cause brick chimneys to crack. Iron cks are frequently built with firebrick linings. They should be mly bolted down to a substantial brick foundation, and if not fficiently heavy to withstand the pressure of the wind, they ould be additionally stayed by guys to surrounding objects. ey should be well painted, preferably with red lead, to prevent sting, and should be provided with a ladder to permit of access any part of the stack. The opening at the bottom is usually aced in the brick supporting-base, arched and provided with an n door. The cut on page 308 shows an iron stack 170 feet high ed with firebrick.

QUESTIONS.

What is the function of a safety valve? How does it act?

What relation exists between the lift of a safety valve and the essure? Explain the reason.

Name and describe the three principal kinds of safety valves, d explain the use of each.

Why is a lever safety valve with a weight at the end not fit for e on locomotive or marine boilers?

Describe the Lock-up Pop safety valve.

If the area of a lever safety valve is one square inch, the distance of the valve from the fulcrum 2 inches, the weight of the er 2 pounds, and the distance of its centre of gravity from the *crum 5 inches, the weight* of the valve and stem ½ pound, and

INDICATED HORSE-POWER OF SINGLE CYLINDER ENGINES AT DIFFERENT SPEEDS AND PRESSURES.

Cutting off Steam ¼ Stroke, 40, 45, and 50 Pounds Mean Effective.

Size of Engine.	Revolutions per minute.	Initial Steam Pressure.		
		80	90	100
6 x 8	350	16.00	18.00	20.00
	400	18.15	20.60	22.90
	450	20.50	23.20	25.75
6 x 10	300	17.13	19.27	21.41
	330	18.84	21.20	23.55
	350	19.98	22.48	24.98
7 x 8	350	21.90	24.50	27.20
	400	24.90	28.05	31.05
	450	28.00	31.50	35.00
7 x 10	300	23.32	26.23	29.15
	330	25.64	28.86	32.07
	350	27.20	30.61	34.01
8 x 8	350	28.40	32.00	35.50
	400	32.50	36.56	40.60
	450	36.50	41.10	45.70
8 x 10	300	30.46	34.27	38.08
	330	33.50	37.69	41.88
	350	35.53	39.98	44.42
8½ x 10	300	34.30	38.75	43.00
	330	37.75	41.50	47.20
	350	40.10	45.00	50.10
9½ x 10	300	42.95	48.32	53.69
	330	47.25	53.16	59.06
	350	50.13	56.38	62.64
9 x 12	250	38.52	43.34	48.19
	280	43.15	48.20	53.97
	300	46.24	51.44	57.83
10 x 10	300	47.70	53.50	59.60
	330	52.40	59.00	65.50
	350	55.60	62.60	69.50
[illegible]	250	47.60	53.55	59.50
	280	53.31	59.98	66.64
	300	57.12	64.26	71.40
[illegible]	250	57.59	64.79	71.99
	280	64.50	72.56	80.63
	300	69.11	77.75	86.39

IORSE-POWER OF SINGLE CYLINDER ENGINES AT DIFFERENT SPEEDS AND PRESSURES.

f Steam ¼ Stroke, 40, 45, and 50 Pounds Mean Effective.

e.	Revolutions per Minute.	Initial Steam Pressure.		
		80	90	100
	250	68.52	77.08	85.65
	280	76.75	86.34	95.94
	300	82.24	92.52	102.80
	250	80.44	90.50	100.55
	280	90.09	101.36	112.62
	300	96.53	108.60	120.66
	250	93.29	104.95	116.61
	280	104.48	117.54	130.60
	300	111.94	125.94	139.93
	245	122.44	137.75	153.06
	265	132.44	149.00	165.55
	275	137.50	155.00	171.50
	245	139.50	156.30	174.20
	265	151.00	169.50	187.50
	275	156.00	176.50	195.00
	200	114.24	128.52	142.80
	230	131.16	147.55	163.95
	240	137.08	154.21	171.35
	200	130.00	146.25	165.50
	230	148.24	166.77	185.30
	240	155.96	175.45	194.95
	200	136.75	165.50	183.25
	230	167.50	188.00	209.00
	240	176.00	198.00	220.00
	200	164.46	185.01	205.57
	230	189.13	212.77	236.41
	240	197.35	222.02	246.69
	200	206.18	231.95	257.72
	210	216.51	243.57	270.64
	220	226.82	255.17	283.53
	200	228.43	256.99	285.54
	210	239.90	269.89	299.88
	220	251.30	282.74	314.16
	200	267.00	311.00	345.50
	210	290.00	327.00	262.50
	220	304.50	342.50	380.00

What is the object of a steam separator? What are the important points which should be observed in its design?

Explain why traps are essential in all steam plants. What should an efficient steam trap accomplish?

What is meant by a by-pass? Make a sketch showing how a feed-water heater would be piped with a by-pass for both steam and water.

In what respect does a cylinder, subjected to pressure from without, differ from one where the pressure acts from within?

What do the experiments of Fairbairn prove in regard to the strength of boiler flues?

Describe the different methods which are employed to strengthen boiler flues.

What pressure would cause a boiler flue 3 feet in diameter, 20 feet long, and ½ inch thick, to collapse if it were strengthened with a tee in the middle?

How are the furnaces of internally fired boilers usually made? Make a sketch showing how they are supported.

What determines the shape of grate bars and the width of spaces between them?

Why are grate bars often set at an angle instead of horizontal?

In what respect does a grate intended to burn bituminous coal differ from one intended for fine anthracite?

Explain the object of using shaking grates.

What are the advantages to be derived from the use of mechanical stokers?

What are the advantages to be derived from using coal dust as fuel?

What are the advantages to be derived from using oil as fuel?

Explain the causes which produce draught.

What is the best shape to give a chimney?

What are the causes which interfere with the satisfactory action of chimneys?

plain the theory which underlies the proportioning of chim-

What is meant by the term *head* as applied to chimneys?

If the height of a chimney is 125 feet, the temperature of the gases in it 600°, and that of the surrounding atmosphere 60°, what would be the head of the chimney?

Why is the draught of a chimney not equal to that which the head is capable of producing?

Why is the effective area of a chimney less than the actual area?

Calculate the effective area of a stack designed for 500 horse-power, the height being 150 feet.

Explain how to go about designing a chimney for a given horse-power, taking into account the surrounding conditions.

What shapes are given to chimneys of brick? What determines these?

Give the rules for determining the outside dimensions of brick stacks at different heights.

In what respects are iron stacks preferable to brick?

What are the principal points to be observed about iron stacks?

shaft. The caps are bolted down as shown and provided with a means of taking up the wear.

These are the essential parts of a steam engine, but there are various devices such as keys, gibs, lubricators, throttle valves, packing, etc., used in connection with it. These are here omitted, because they are merely details in the construction of the engine.

Power of Steam Engines.

The power which a steam engine can furnish is generally expressed in "horse-power," the "nominal horse-power" being admitted to be a force capable of raising a weight of 33,000 pounds one foot high* in one minute, or 150 pounds 220 feet high in the same length of time. If an engine is rated at 25 horse-power, it is recognized as being capable of raising 33,000 pounds one foot high twenty-five times in each minute. The question will naturally arise, How are these 33,000 pounds to be raised? The answer to which would be, by *belts, pulleys, cog-gearing, cables, paddle wheels, screw-propellers,* or *whatever mechanical arrangement* is most practicable and convenient.

There are several terms employed to express the power of engines, such as the "nominal," "indicated," "actual or net," "dynamo-metrical," and "commercial" horse-power. The *indicated horse-power* is obtained by multiplying together the mean effective pressure in the cylinder as shown by the diagram, the area of the piston in square inches, and the speed in feet per minute, and dividing the product by 33,000. The *actual* or *net horse-power* is the total available power, and is equal to the indicated horse-power less the amount necessary to overcome the friction. The *dynamo-metrical* or *brake horse-power* is the horse-power of the engine as measured at the driving pulley by means of a dynamometer or brake, and is equal to the net horse-power. Whenever orse-power is used in reference to steam engines it

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* Foot-pounds.

e indicated horse-power. The method of ascertaining l horse-power will be explained under "The Steam ndicator."

orse-power of a steam engine is determined by four iz.:

mean effective or average pressure,*
length of stroke,
diameter of cylinder,
number of revolutions of crank.

d the horse-power of any engine:

—Multiply the mean effective pressure* on the piston in er square inch by the area of the piston in square inches; this product by twice the product of the length of the feet and the number of revolutions per minute; divide product by 33,000, and the quotient will be the horse- the engine.

ole.—What is the horse-power of an engine under the conditions:

Mean effective pressure, 40 lbs. per sq. in.
Diameter of cylinder, 18″.
Stroke, 24″.
Speed, 200 revolutions per minute.

rea of the piston is:

$$.7854 \times 18 \times 18 = 254 \text{ square inches,}$$

he stroke in feet, $\frac{24}{12} = 2$ feet,

ce the horse-power by the above rule is:

$$\frac{40 \times 254 \times 2 \times 2 \times 200}{33,000} = 246 \text{ horse-power.}$$

d the diameter of a steam cylinder to develop a given wer under a given mean effective pressure and at a given eed:

—Multiply the horse-power by 33,000 and divide this by the product of the piston speed in feet per minute, the

---

**See mean effective* pressure, page 327 and tables.

All steam engines must belong to at least one of the above classes, and many belong to several. For example, an engine may be a compound, condensing, high speed, automatic cut-off, double-acting, stationary engine, and, in fact, there are many such in use. The classification might have been carried considerably further by recognizing differences in the details of construction as constituting different classes, but this would lead us too far and the classification adopted will be quite sufficient to bring out the essential points in which steam engines differ as to construction and method of operation.

High-speed and Slow-speed Engines.

The term high-speed engines, though sometimes used to include only engines which run at a high speed of rotation, means in reality engines with high piston speeds. The ideas of engine builders in regard to what is a high piston speed have changed very materially during the last quarter of a century, so much so that engines which in 1870 were considered as high-speed would now be classed as extremely slow-speed engines. At the International Exposition in Vienna, in 1873, the average piston speed of the engines there exhibited was about 350 feet per minute, and the maximum about 420 feet per minute, while the same makers exhibited in 1888 at the Vienna Industrial Exhibition engines whose average piston speed was about 480 feet per minute, and a maximum of nearly 700 feet per minute. At the International Exposition in Paris, in 1889, piston speeds of 780 feet had been attained, and at the Electrical Exposition in Frankfurt, in 1891, the maximum was 875 feet per minute. In large engines to-day 900 feet per minute is not considered extraordinary, and we find even in small electric lighting engines of the type known as high-speed engines, meaning high rotary speed, that between 600 and 800 feet per minute is the ordinary piston velocity.

The advantages of high-speed over slow-speed engines may

fly stated as follows:—

For a given steam pressure and cut-off the power of

varies directly as its speed. There are four factors which
ine the power of an engine, viz.:

The mean effective pressure on the piston.
The length of the stroke.
he area of the piston.
he speed.

er words, an engine of a given diameter and *length of*
cting under a given mean effective pressure, will *develop*
proportion to its speed, and if the speed is *doubled the*
ll also be doubled, and so to obtain a *given power under*
mean effective pressure we need make an *engine only*
rge if we double its speed. Hence we have as the first
for high speeds, economy both in first cost and in space.

ly.—In most cases where power is supplied by a steam
must be transmitted to other shafting, which usually
much higher speed. Now whether this transmission is
y toothed wheels, or by friction gearing, it can be per-
ore efficiently if the ratio of the speeds is *not too great.*
cases, where the power is transmitted by belting the
peeds is too great to admit of transmission in a single
e the arc of contact on the driven pulley would be too
revent serious slippage of the belt. In such cases it is
to use an intermediate shaft, which performs no other
to make the reduction more gradual, and thus to insure
tory running of the belt. By increasing the speed of
e this is done away with in many cases. In fact, in the
dynamo machines, which, until recently, were nearly
riven through an intermediate or counter shaft, it is now
practice to couple the shafts of engine and dynamo
thout any belting whatever. In spite of all that may be
nst this practice, it cannot be denied that it often saves a
iderable amount of valuable space.

—It is claimed for high-speed steam engines that the
in the use of steam far exceeds that of the older forms
re is no doubt a great deal of justice

in this claim, because one of the main losses in the eng
the cooling of the cylinder walls and passages during
and re-evaporation is greatly reduced. The disadva
admitting steam by the same channels through which it
is clearly demonstrated in the increased economy of th
type of engine, where this is not the case.

As far as re-evaporation is concerned, it is of course
that the cylinder walls are chilled very considerably du
process, and the more steam is passed through the eng
given space of time the less will be the re-evaporation.
the increased economy of the high-speed engine.

Finally.—It is a fact that the uniformity and smootl
running are much better in high-speed engines than
speed engines. This is due partly to the fact that the i
of the fly-wheel is greatly enhanced and partly to the s
influence of the reciprocating parts. It is a well-known
the steadying action of a fly-wheel is proportional to th
of its speed, which means that if one engine runs twice
another of the same design and same weight of fly-whee
run four times as steady.

The influence of the reciprocating parts on the runni
engine, in order to be thoroughly understood, requires
more consideration. In a steam engine revolving with a
velocity all the parts which move to and fro—the recip
parts—come to rest at the beginning and end of each
The reciprocating parts consist of the

piston,
piston rod,
cross head, and
connecting rod.

When the stroke is reversed they are gradually set in
slowly at first, and faster until the middle of the strok
they are moving with the same velocity as the crank-p

at their motion is retarded until the end of the stroke, when ey again come to rest and the same action is repeated. Now, order to set a body in motion it is necessary to apply force to , and the amount of force depends on its mass or weight and the elocity of motion. A body once set in motion no longer requires ny force to keep it moving uniformly; but so long as its motion s increasing, so long must force be applied to it, the amount that must be applied being in proportion to the rate of increase of velocity. The reverse of this is also true. If a body is moving with a certain velocity and this is decreased, the body exerts a force on whatever is tending to stop it, and here too the amount of force which it exerts is in proportion to the rate of decrease of its velocity. This is a familiar fact in mechanics, and is often illustrated in text-books by the case of a railroad train, which requires a certain force to get it up to speed. After it has attained this it requires no more energy to keep it in motion, but all that is supplied to it in the shape of steam is used up in overcoming the friction. Just so it is with the reciprocating parts. At the beginning of the stroke they require a comparatively great force to start them from rest, which becomes less and less until the middle, when it requires none at all, for they are now up to the speed—that is, moving with the same velocity as the crank-pin. After this their motion is gradually retarded until the end of the stroke, when they come to rest completely. Now in every steam engine the pressure is a maximum at the beginning of the stroke, decreasing as the stroke advances until the end, when it is a minimum; hence it is evident that the action of the reciprocating parts, which is to absorb or store a portion of the pressure during the first half of the stroke and restore it during the second half, has the effect of tending to keep the pressure on the crank uniform during the entire stroke, or, in other words, to steady the running of the engine.

High-speed engines must be high-pressure engines—that is, *the steam pressure at the* beginning of the stroke must be suf*ficient always to set the* reciprocating parts in motion, and the

The back pressure in the condenser, which represents the difference between the indications of the vacuum-gauge and a perfect vacuum, must be deducted; but as a perfect vacuum is not attainable, the back pressure varies from 2 to 5 pounds, according to the condition of the engine and the quantity of uncondensed steam remaining in the condenser.

Advantages of the Condensing over the Non-condensing Engine.—When the resistance of the atmosphere is removed from the piston the steam may be cut off earlier and further expanded in the cylinder. This reduces the draught on the boiler and admits of a slower combustion of the fuel. In this way economy is promoted by condensation of the exhaust steam and by the vacuum formed in the cylinder. A vacuum equal to 14 pounds means roughly 35 per cent. saving in fuel, or the same increase in power; but this saving undergoes a great reduction in consequence of the cylinder being open alternately to the lower temperature in the condenser, which varies with the degree of expansion employed, being least when the steam follows full stroke, which is very seldom the case. The practical gain, therefore, in the condensing engine is from 20 to 30 per cent., varying with the conditions above named, as shown in the working of condensing engines, both stationary and marine. The economy of the condensing engine might be increased, if advantage could be taken (as in the case of the injector and steam-jet) of the velocity with which the exhaust steam escapes from the cylinder to the condenser. On entering the condenser, the power due to its energy is entirely destroyed by the cold water injection, or by being brought in contact with refrigerating surfaces.

The difference in effect between the condensing and non-condensing engine, with equal pressure of steam and expansion, is solely that the condensing engine has the advantage of the effect produced by the vacuum, or the amount of atmospheric pressure removed. Their difference in operation is, that in the condensing engine, the steam, after having performed its duty in the cylinder, is condensed by the admission of a spray of cold water, or being ught in contact with cooling surfaces, thus producing a vacuum *minus* pressure, which varies, according to the perfection of the chinery, from 10 to 13 lbs. per square in.; while in the non-con- ısing engine, the steam, after having performed its duty, is charged into the atmosphere. Thus, the advantages of the cuum are lost; some of the waste heat, however, is utilized by ıding the exhaust steam through a heater, for the purpose of ating the feed-water. For this reason small simple engines are rely run as condensing engines. The slight gain in economy ɪm the use of a condenser is usually more than balanced by the creased first cost and the disadvantage of feeding cold or impure ter to the boilers. Condensers are frequently added, however, r the purpose of increasing the power of existing engines. There no essential difference in the design of condensing and non- ndensing engines.

Simple and Multiple Expansion Engines.

Simple engines are those in which the steam is used for per- rming work only once. It makes no difference how many cyl- ders an engine has or how many sets of valve gears, it is a nple engine so long as the steam, after passing through any one the cylinders, is not again used in the engine. To this class long most small stationary engines, and, with a few exceptions, comotives and all engines which take their steam directly from e boiler, and, after one expansion, exhaust it into the atmosphere into a condenser. The great advantage of this type over multiple pansion engines is, as their name implies, extreme simplicity ıd consequently, also, low first cost. On the other hand, they e less economical as far as steam consumption is concerned, and nce large stationary and marine engines, where economy in the e of steam is an important factor, are usually compound, triple pansion, or even quadruple expansion engines. The reasons hy the latter are superior in this respect will presently appear, *hile the actual difference in* steam consumption will be found *ler "Steam Engine Economy."*

pressure must never be reduced by means of the throttle val
otherwise the engine will be subjected to strains which will imp
its life. For the same reason the governor should change
cut-off and not the steam pressure. The reciprocating pa
should be made as light as is consistent with strength, a
hence they should be made of steel. The steam ports shou
be carefully considered in the design; the higher the speed t
larger the steam passages, otherwise the pressure will be reduc
before entering the cylinder. The steam should be cut off earl
and there should be a moderate amount of compression—that i
the exhaust should be closed before the end of the stroke, in ord
to provide a cushion for bringing the reciprocating parts to res
In other respects there is no difference between high-speed an
slow-speed engines. Their design is essentially alike, and cons
quently it will not be necessary here to describe engines of thes
two classes, as the only apparent difference would be that th
regulation of the speed or governing of the one would be by mean
of a device for changing the cut-off, and in the other by mean
of a device for changing the initial steam pressure. In oth
respects the difference between the two types is merely a diffe
ence of degree and not of kind. (For descriptions of differe
kinds of governors, see page [illegible].)

Non-condensing and Condensing Engines.

In the non-condensing engine the steam, after acting on th
piston, escapes into the open air; therefore the pressure of th
outgoing steam must exceed atmospheric pressure, or 14.7 pound
to the square inch. Thus, if steam at 45 pounds average pres
ure above vacuum be admitted to the piston of a high-pressur
it will exert a force equal to its pressure; but 14.7 pound
re inch of that pressure will not be converted into wor
be lost in overcoming the pressure of the atmosphere
y be illustrated by the following example:

Diameter of cylinder, 12 in.; area, 113·09 in.
Average steam pressure per square inch, 45 lbs.
Total steam pressure, 5089·05 lbs.

As before, area, 113·09 sq. in.
Atmospheric pressure, 14·7 lbs.
Total atmospheric pressure, 1662·423 lbs.

5089·050
Loss due to atmospheric pressure, 1662·423
Effective steam pressure on piston, 3426·627 lbs.

foregoing example shows the resistance to be overcome at troke of the piston before the steam acting against it can ce any useful effect. Thus it will be seen that the piston igh-pressure steam-engine is exposed to the action of two res, namely, the pressure of the steam from the boiler on le, and that due to the atmosphere and the steam remaining cylinder after exhaust takes place on the other. The re utilized or converted into work will be the difference en the two.

he condensing engine the steam, after acting against the , escapes into a condenser, where it is condensed into water vacuum is formed, thus rendering not only a considerable n of the steam pressure in the boiler, but also the 14.7 s per square inch required in the non-condensing engine to me the pressure of the air available as an effective force t the piston, which may be explained as follows:

Diameter of cylinder, 12 in.; area, 113.09 sq. in.
Average steam pressure per sq. in., 45 pounds.
Total steam pressure, 5089.05 lbs.

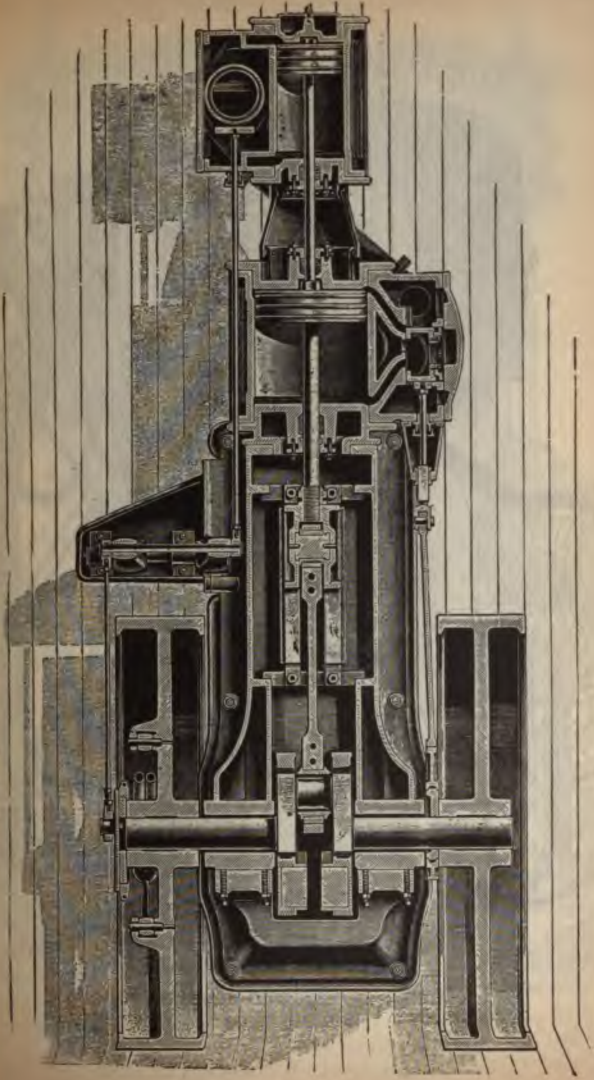
As before, area, 113.09 sq. in.
Pressure in condenser, at best, 2 lbs.
Total back pressure, 226.18 lbs.

5089.05
226.18
Effective pressure on piston, 4862.87

[illegible] steam, [illegible] called hi [illegible] or set o [illegible] further expan [illegible] usually so p [illegible] the high-pres [illegible] ways of arrangi [illegible] crank i [illegible] the engi [illegible] form, [illegible] compou [illegible] rods an [illegible] cha [illegible] valves [illegible] valve r [illegible] in the hig [illegible] steam. In [illegible] tandem compou [illegible] Pa., this is a [illegible] by separate [illegible]

It is frequently inconvenient to use the tandem arrang cylinders on account of the excessive amount of space oc the direction of the centre line of the cylinder. In such customary to place the cylinders side by side, with a crank for each cylinder. This arrangement is shown in of the Compound Marine Engine on pp. 342 and 343. I observed that the cranks, while acting on the same s placed at an angle relatively to each other—in this case 90 This arrangement of the cranks, which is necessary fo engines, where there is no fly-wheel to steady the motio [illegible] necessitates an important change in the constructi

In the tandem arrangement the steam when e [illegible] *high*-pressure cylinder is immediately admitte [illegible]*ure* cylinder, both pistons being at the end of th



Section View Tandem-compound Engine. Ball Type.

sion engines, and the arguments which have been used in favor of compound engines apply to all multiple expansion engines. In modern steamships steam pressures of 160 pounds and over are commonly used, which means a difference of temperature, if condensing, of about 250° Fahrenheit. Such enormous differences in temperature would involve a very material loss of heat even in a compound engine, and therefore it has been found advantageous to use triple and quadruple expansion. The most common arrangement of multiple expansion engines is illustrated in the frontispiece,* which represents the type much used in the United States Navy (coast line battleships Nos. 1, 2, and 3). This engine is of the triple expansion type, with high-pressure cylinders, 34½″, intermediate cylinder, 48″, and low-pressure cylinder, 75″ in diameter, stroke 42″. The horse-power is 4500, and there are three cranks set 120 degrees apart. In some cases there are but two cranks, the high-pressure cylinder being placed over the intermediate, the two working on one crank, while the low-pressure cylinder drives a separate crank. Various other arrangements of cylinders have been adopted, but that illustrated in the frontispiece, where each operates a separate crank, is the most common, because it gives the most uniform turning moment on the shaft.

Throttling and Automatic Cut-off Engines.

An automatic cut-off engine is any steam engine in which the distribution of steam is so controlled by the governor as to cut off the steam at any point from zero to three-quarters stroke—the cut-off taking place earlier or later to accommodate the varying load on the engine and the pressure in the boiler, the object being to obtain full boiler pressure at the commencement of each stroke, and maintain it to the point of cut-off, leaving the balance of the stroke to be completed by expansion, the speed of the engine being controlled by the cut-off and not by throttling. In engines

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n *the Report* of the Chief of the Bureau of Steam Engineering, n, *D. C., 1890.*

the cylinder are also cooled, and consequently the next
steam is admitted it strikes the cold walls of the cylinder
artially condensed. This condensation, called *initial con-*
n, is an absolute waste, as no work whatever is performed
oss of heat. The trouble is partially remedied by the use
jackets, but even under the most favorable circumstances
ugh to materially impair the efficiency of the engine. Now
eam is expanded successively in two separate cylinders, it
at that each cylinder will be subjected to only one-half the
n in temperature, and hence the loss by initial condensa-
lso only about one-half as great. This is the reason why
nd engines are more economical than simple engines, and
lent that the gain is proportional to the difference between
perature of the live steam and that of the exhaust.

les the gain in economy, compound engines have certain
ical advantages over simple engines. There being two
in compound engines (except tandem), these may be set
desired angle, and thus the turning effect on the shaft
ore uniform; besides this the effect on the piston is very
If the entire expansion takes place in a single cylinder,
a great difference between the initial and mean pressure
iston, whereas in the case of a compound engine these are
ore nearly equal. As the engine parts have to be de-
o withstand the maximum pressure, it is evident that for
power these may be made lighter in the compound than
mple engine. A condenser should be used whenever pos-
h compound engines, because with a low-pressure cylinder
diameter the gain in economy is proportionally greater
loss due to initial condensation less.

e and Quadruple Expansion Engines.—When the steam
used is very high the advantages which are offered by
of two successive expansions of the steam in independent
s are to be had to an even greater degree by expanding
m successively in three or four independent cylinders.
gines are called respectively triple and quadruple expan-

automatic cut-off and throttling engines will be found under "Economy of Steam Engines."

Throttling engines are those in which the flow of steam from the boiler to the cylinder is regulated either by a throttle-valve, a kind of damper in the steam-pipe, which, as the speed of the engine increases, is turned, and stops off the supply of steam, or by the steam in its passage from the boiler to the cylinder going through the passage of some peculiar type of governor-valve. An engine controlled by any such device is in a condition somewhat like that of a horse restrained by a brake applied to the wheels of a wagon. Such relics of barbarism are fast giving place to the automatic cut-off arrangement, by which the brakes are removed from the wheels, and the bit placed in the horse's mouth, instead. Manufacturers of this class of engines claim that they give results equal to the automatic cut-off engines, which is untrue, both as to economy and close governing. With an early cut-off, which is absolutely necessary to good economy, it is simply impossible to govern the speed of throttling engines closely, with even a moderate change in load and pressure.

In the best types of throttling engines, in consequence of the peculiar construction of the governor-valve, and the tortuous passage through which the steam has to travel, the pressure in the cylinder is in many cases not more than one-half of the boiler pressure; the effect of which is, that when the work to be performed is varying in its nature, such engines increase their speed when any considerable load is thrown off, and decrease it when additional load is put on. Now, every stroke an engine makes above its regular speed is a waste of steam, and if the engine is large, or runs at a high speed, the volume of steam, and consequently of fuel, wasted will be enormous; likewise every stroke an engine makes below its ordinary speed, when work is thrown on, lessens production. The loss of one revolution in ten diminishes the productive capacity of every machine driven by the engine 10 per cent.; in short, the loss of one revolution in ten diminishes the ductive capacity of the whole factory 10 per cent.; while the of conducting the whole business, rent, wages, insurance, inues the same as if everything was in uniform motion. ion of one revolution in ten is quite common in throttling

Steam Engine Cut-offs.

of the engines which will be described in Chapter XX. the automatic cut-off type; in fact, this class of engines most of the stationary engines of to-day. Throttling re occasionally used for small powers and uniform loads, nt of their simplicity. The vertical engine described in ning of this chapter, which is one built by the New York team Power Company, is a good representative of the throttling engine, and any further description of other uld be simply a repetition.

ationary, Marine, and Locomotive Engines.

assification of steam engines into stationary, marine, and ve is rather an unsatisfactory one, because in many cases really no difference in the design of these engines. A narine or a locomotive engine could be used equally well purposes to which stationary engines are applied; in marine type of engines frequently is used in large power hile there is practically no difference between a locomone and a stationary hoisting engine except in the mounte parts. Nevertheless, marine and locomotive engines tain characteristics which distinguish them from ordiionary engines, and these will be briefly pointed out.

e Engine.—The term marine engine is in very common it has no definite meaning, as it may be either condensing ondensing, vertical, horizontal, or inclined, simple or d. The only reason that can be assigned for designating ine engine is that it was designed to be used on steam- *marine engine, properly* speaking, is an engine designed *a certain space* on a vessel, and be capable of developing motion in this engine and in most American locomotives consists of a pair of eccentrics and a link, actuating an ordinary flat slide valve for each engine, the cut-off being varied by means of the link. (For description see Valves and Valve Gears.) Locomotives are not provided with governors, for various reasons, the speed being variable and under constant control of the engineer. It may be varied either by the throttle or the cut-off, but preferably the latter, because more economical in the use of steam.

In estimating the power of a locomotive, the term horse-power is not generally used, as the difference between a stationary steam-engine and a locomotive is, that while the stationary engine raises its load, or overcomes any directly opposing resistance with an effect due to its capacity of cylinder, the load of a locomotive is drawn, and its resistance must be adapted to the simple adhesion of the engine, which is the measure of friction between the tires of the driving-wheels and the surface of the rails.

The power of the locomotive is estimated in the moving force at the tread of the tires. It is called the tractive force, and is equivalent to the load the locomotive could raise out of a pit by means of a rope passed over a pulley and attached to the draw-bar of the engine. The adhesive power of a locomotive is the power of the engine derived from the weight on its driving-wheels, and their friction or adhesion to the rails.

If the wheels of a locomotive were geared into toothed rails its power would be proportional to the force with which its wheels could be made to turn, or the force which, if applied at the rims of the wheels, would prevent them from turning. But if the wheels revolved on smooth rails and slipped in turning, a part of the power would be wasted, and the effective power of the engine limited by the friction or adhesion of its driving-wheels. Hence the terms "tractive power" and "adhesive power" mean re-
ively the revolving power and the progressive power of the

Single- and Double-acting Engines.

The difference between single- and double-acting steam engines hat the former admit steam to only one side of the piston, the er being open to the atmosphere, while in the latter both ends the cylinder are closed and steam is admitted at either end of piston. Obviously, of two engines, the one single- and the er double-acting, having the same diameter of cylinder and oke, working under the same boiler pressure and at the same ed, the double-acting engine will develop twice as much power the single-acting. Consequently it may be said at once that latter is the less economical as far as first cost is concerned. has the further disadvantage that, on the return stroke, ad- ntage cannot be taken of the cushioning action of the steam for nging the reciprocating parts to rest; hence, unless some other ovision is made for accomplishing this end, it will not operate smoothly as the double-acting engine. On the other hand, it s certain mechanical advantages; for example, the cross-head d stuffing-box may be omitted and a single rod used to replace piston and connecting rods. The vast majority of steam gines, however, are double-acting, although a few of the single- ting engines, notably the Westinghouse and the Willans, have en very successful. These will be described in Chapter XX.

Reciprocating and Rotary Engines.

All that has thus far been said in regard to steam engines xcepting the definition) applies only to reciprocating engines—at is, those in which the force of the steam is used to produce a ciprocating motion of the piston, which, by means of other parts the engine, is converted into a rotary motion.

In the rotary engine there is no reciprocating motion whatever, e force of the steam being used to produce at once a motion of tation. Rotary engines are not economical in the use of steam, nd, while a great many different types have been designed, they re but little used.

motion in th [illegible]
of a pair of [illegible]
valve for e [illegible]
link. (For [illegible]
tives are n [illegible]
speed being [illegible]
neer. It m [illegible]
but prefera [illegible]
of steam.

In estim [illegible]
is not gen [illegible]
engine and [illegible]
its load, o [illegible]
effect du [illegible]
drawn, an [illegible]
of the en [illegible]
of the di [illegible]

The p [illegible]
at the [illegible]
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mean [illegible]
bar of [illegible]
pow [illegible]
wh [illegible]

Economy of Steam Engines.

The principal reason which has impeded [illegible] the designers of steam engines was to attain additional ec [illegible] the use of fuel, and yet with all that has been don [illegible] since the time of James Watt, the steam engine [illegible] wasteful machine, and only a small percentage of the [illegible] in the fuel is actually converted by the steam [illegible] work. There are certain losses of energy which [illegible] impossible to avoid, and so long as these [illegible] will the process of transforming the latent [illegible] mechanical work by means of the steam engi [illegible]

[illegible] evaporating [illegible] F. into steam at [illegible] heat units	1 [illegible]	
[illegible] per horse- [illegible] high speed steam	30 [illegible]	
[illegible] evaporating [illegible] steam at [illegible] the work of	3 [illegible]	
[illegible] for 100	900	
[illegible] inches	22000	
[illegible] al con-	1,000,000	
[illegible]	778	
[illegible]		2500
[illegible]	1,080,000	
[illegible]	198,000,000	
[illegible]	79,800,000	
[illegible]		172
[illegible]		1,62
[illegible]		6

n **example** of the losses which occur in the steam engine, case of a modern water or fire tube boiler and a high-on-condensing engine, a combination which can be found st every isolated plant for electric lighting. Engines of ss usually operate under a steam pressure of 80 pounds, quire about 30 pounds of water per indicated horse-power- Suppose the plant under consideration has a capacity of incandescent lights, and that an engine of 100 indicated power is used. The preceding tabular statement shows how of the energy contained in the coal is actually transformed seful work at the shaft of the engine under favorable condi-

at is, of the total energy contained in the fuel less than 7 per is available at the shaft of the engine. The principal reason his is that so much heat or energy is absorbed in changing water into steam, and in the non-condensing engine this is ely lost. Of course the steam, after leaving the engines, is uently used for other purposes, such as heating, etc., in which much of the heat it contains is utilized. Besides, this type ngine is one of the least economical in use at the present day. figures given in the table on page 357 show the comparative nomy of different types of steam engine, and by a calculation ilar to the above the percentage of energy utilized by each y be easily ascertained.

A large part of this loss of energy occurs in the steam generator boiler. It is due partly to the high temperature at which the ses escape from the chimney, which is necessary for the production of the draught, as explained above, and partly to the excess air over and above that necessary for complete combustion of e fuel. There is rarely more than 10 to 12 per cent. of carbonic id in the flue gases, and this means that there is more air supplied than is necessary for the combustion of the fuel, and in ating this excess to the temperature of the products of com-n a loss of energy equal to about 16 per cent. of the *el consumed is incurred.* Additionally there are losse due to radiation, to leakage, and to the heat carried away in the ashes.

The losses in the engine proper are due mainly to the presence of moisture in the steam cylinder. Nearly all of this moisture, which is either carried into the cylinder with the steam from the boiler, or is produced by condensation on the cylinder walls or in the steam passages, is re-evaporated during the expansion and exhaust periods, and in re-evaporating, abstracts heat from the steam. Very little of the heat which is used in this way is returned to the engine as useful work, and consequently the presence of moisture may be said to rob the engine of an amount of useful energy proportional to the heat required for its evaporation. It is therefore of the utmost importance to the economy of steam engines to prevent the entrance of water into the cylinder, or its formation by condensation on the walls of the cylinder and in the passages.

The moisture which enters the cylinder with the steam is not properly chargeable to the engine. Dry steam may be had at the throttle of the engine by the use of properly designed boilers, steam separators, and non-conducting pipe covering. The production of moisture in the cylinder, however, is due to the design of the engine and to the conditions under which it operates. As an example, consider a plain slide valve engine, and suppose the steam is admitted under a pressure of 100 pounds per square inch, is cut off early in the stroke, expands, and is exhausted against the pressure of the atmosphere. The entering steam has a temperature of about 338° F., and as the steam expands this is gradually reduced, until at the end of the stroke, when the exhaust begins, the temperature is only 212° F., and this is maintained during the entire return stroke. Furthermore heat is continually radiated to the surrounding atmosphere, and consequently by the time steam is again admitted the walls of the cylinder and the steam passages have been so much reduced in temperature that a very considerable amount of heat must be abstracted from the steam to again raise the temperature of the walls. This will in-

cause condensation of a portion of the steam, which will
ed at every stroke, and result in a material reduction in
ency of the engine.

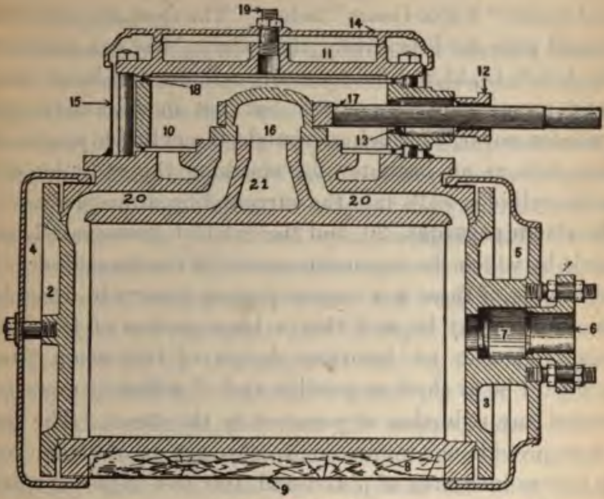
ondensation of steam in the cylinder, called initial con-
, is greater, the greater the surface exposed for a given
steam passing through the engine, and consequently it
great proportionally in large engines as in small ones.
y, also, it is proportional to the range of temperature to
cylinder is exposed, and it is for this reason that multi-
nsion engines are more economical. This has already
lained in discussing the latter type of engine above. As
condensation in the steam passages is concerned, it has
id that this could be almost entirely eliminated by clos-
xhaust before the end of the stroke, so as to compress the
d thus raise the temperature of the walls and passages,
effectually, by providing separate passages for admission
ust. This is the reason why the so-called Four Valve
Corliss types of engine are more economical than those in

M CONSUMPTION OF DIFFERENT TYPES OF ENGINES.

tion of Engine.	Horse-power.	Steam Pressure.	Water per 1 H. P. per hour.	
			Non-Condensing.	Condensing.
e Valve with long Cut-off about $\frac{5}{8}$...	25–100	75–80	40–50 lbs.	30-40
, High Speed alve. Cut-off $\frac{1}{4}$...	50–150	75–80	25–35	20 25
, Four Valve and High Piston Cut-off about $\frac{1}{5}$...	50–500	75–100	24–32	18–24
l Automatic High Single valve......	200–500	110–120	22–30	16–24
l Automatic, Four nd Corliss High Speed................	400 or over	110–120	20–27	13–20
pansion............	*500* or over	120–160	20-27	12¾-18

sessing the qualities of hardness and toughness, be moulded and cast with great care, and bored with great accuracy. Cylinders, from the moment they are put into use, have a tendency to wear oblong, also to wear larger in some places than others. This involves the necessity of reboring them, which is one of the largest items of expense incurred in the repairs of a steam-engine.

There are certain peculiarities connected with the wear of steam-cylinders upon which engineers have hitherto been unable to agree, among which is, why the cylinders of different engines of the same size, design, and manufacture, and under the same conditions, wear in opposite directions. The cylinders of some horizontal engines wear more on the lower than on the upper side, while others of the same size and build wear more on the sides opposite the ports, and others on the sides next the ports. Nor is it always the largest cylinders and heaviest pistons that wear most on the lower side of the cylinder. The same peculiarities hold good in relation to vertical engines. On some lines of ocean steamers, where four or five of the engines were built by the same manufacturing firm, and whose design, quality of material, character of workmanship were intended to be as much alike in every respect as it was possible to make them, it was found on examination that the cylinders of all were worn oblong—some in the middle, others at both ends, and others still at only one end. It is a general impression among engineers that the cylinders of very large horizontal engines are more liable to wear oblong than those of vertical engines of the same bore; but experience and observation have proved this to be a mistaken idea. The trouble is frequently due to imperfect alignment, and it is difficult to imagine why an engine piston should exert any pressure against the cylinder walls, other than that due to gravity, when all of the reciprocating parts are perfectly true with the centre line of the engine and with each other. Care should be taken to see that this is the case, and also that the packing is placed with uniform thickness *around the piston* rod, as any material inequality may throw the *engine out of* alignment. The wear which would occur on the bottom of the cylinders of large horizontal engines on account of the weight of the piston is frequently avoided by extending the rod through a stuffing-box in the outer cylinder head.



Steam Cylinder.

The above cut, which represents a steam engine cylinder as used on a modern locomotive,* shows all of the essential parts of a steam cylinder. 1 represents the cylinder proper, 2 and 3 the heads, which are held in position by means of bolts. The back cylinder head, 3, has a stuffing-box, into which fits the gland 6. It will be observed that the hole in the stuffing-box is slightly larger at the outside. This is for the packing around the piston rod, which makes it tight, the gland 6 being forced inward until the packing entirely fills the space provided for it. A similar stuffing-box and gland, 12, is provided for the valve rod, 17. The steam chest 10 is held in position by the cover, 11, which is bolted to

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* From an "Illustrated Catalogue of Narrow Gauge Locomotives," Baldwin *Locomotive Works, Philadelphia.*

the cylinder casting, although a more usual construction is to cast the cylinder and steam chest in one piece and bolt the cover to the latter. The slide valve 16 is actuated by means of the valve rod 17, and admits steam behind the piston, as will be explained under "Valve Gears" below. The stem, 19, is for attaching an oil pipe for lubricating the valve. The cut also shows a casing, 4, 5, 9, 14, 15, around the entire cylinder and heads, which is common practice in locomotives but not in stationary engines. The wooden cover, 8, which surrounds the cylinder proper, called lagging, acts as an insulator for checking the radiation of heat from the cylinder walls into the surrounding atmosphere.

The steam passages, 20, and the exhaust passages, 21, are the channels by which the steam enters and leaves the cylinder. The proportioning of these is a very important feature in designing an engine, and it may be said that a large portion of the losses in engines is due to an incorrect design of the steam passages. They should be as short as possible and of sufficient cross section to prevent any reduction of pressure in the steam. The general rule is to provide one square inch cross section of steam port for every square inch area of piston and 100 feet of piston speed per second. Hence, to determine whether the steam passages are properly proportioned,

Rule.—Multiply the area of the piston in square inches by the piston speed in feet per minute and divide the product by 6000. The result will be the proper cross section of the steam passage in square inches.

The term clearance is understood by engineers to mean the unoccupied space between the piston- and cylinder-heads when the crank is at the dead-centre; but it also applies to the space between the cylinder and the face of the valve or valves, either slide or poppet. The amount of clearance of any engine affects its economy; and if the clearance is small, the engine will be more economical than if large; a certain amount is an absolute *necessity. It is,* therefore, an object of importance, in point of *economy, to* have the valve-face as near the base of the cylinder possible. In this lies one of the most important features of that ss of engines known as four-valve engines as well as those of e Corliss type. The clearance varies with different builders, d in different engines from 1½ to 10 per cent. of the cubic con-ts of the cylinder.

The clearance is often as high as fifteen per cent., in some old-hioned long stroke, slide-valve engines. This arose from a mis-nception, at the time they were designed, of the waste the large earance would occasion, and is, perhaps, in many instances, due the caprice of the inventor of some patent piston, who made his ston-rings of less depth than the original designs, thus increasing e space between the piston- and cylinder-heads, when the crank at the dead-centre. There are even cases to be met with, where e old fashioned, hemp-packed piston has been replaced by me-llic packing of not more than half its depth, without any means ing taken to fill up the spaces at each end of the cylinder. ow, providing that the clearance is fifteen per cent. of the cubic ntents of the cylinder, and that the engine makes from one ndred and fifty to two hundred strokes per minute for ten urs, it may easily be seen how enormous the waste must be. ne quantity of fuel that might be saved by replacing such an gine by one in which the clearance would be reduced to a mini-um, would more than pay for the latter in five years. Persons nploying steam-power, or intending to purchase steam-engines, ould pay attention to the foregoing fact.

As the clearance space is generally irregular in form, particu-rly in slide-valve engines, it is somewhat difficult to calculate e exact cubic space. The most accurate method of ascertaining e exact amount of the clearance is to place the crank at the ad-centre, and fill the space with water up to the face of the lve (the quantity of water being previously weighed or meas-red). Then deduct the amount remaining in the vessel from the hole, and the remainder will be the quantity contained in the earance in cubic inches or gallons, as the case may be.

***Jacketing** is a term applied* to a method which is adopted in many of the larger engines, working at high pressures to reduce the initial condensation in steam cylinders. A steam jacket consists of an annular space around the cylinder, which is filled with live steam from the boilers.

The Piston and Piston Rod.

The piston is that part of the steam engine which first receives and transmits the pressure of the steam to the other mechanism, which, in a sense, is subsidiary to it. It consists of an iron disc fitting into the cylinder, and the nature of the work which it has to perform requires that it should be strong, durable, light in weight, accessible, and, above all, that it should maintain a steam-tight contact with the cylinder walls. It is impossible to give any rule for calculating the thickness of pistons, as different conditions require different designs. If it is not steam-tight, there will be a continual leakage of steam, causing a serious loss in the economy of the engine. This is one of the most common losses in a steam engine and one which must be carefully watched, not only by builders of engines, but also by those who have charge of running them. The usual method of keeping steam pistons tight is to provide them with one or more cast-iron rings which fit into grooves cut into the circumference of the piston. The piston is first turned to a diameter slightly smaller than that of the interior of the cylinder. The piston rings are of cast-iron and slightly larger than the diameter of the cylinder. After they have been turned to a smooth finish on the outside a piece of sufficient width is cut off the circumference of the ring, and it is then placed in the groove of the piston and sprung into the cylinder. When in place the tendency of the rings is to spring outward, and in this way a steam-tight joint is effected.

A great many different styles of pistons have been devised; in fact, different kinds of engines require different kinds of pistons. Those illustrated in the accompanying cuts represent four different methods of packing employed by the Baldwin Locomotive s. In Fig. 1 the method referred to above is used—that is, ng consists merely of cast-iron spring rings, 8, which inst the cylinder by virtue of their elasticity. In n the end of the piston-rod is slightly tapered. It is t the extreme end, where it projects through the piston, d in place by a collar and nut. In Fig. 2 the packing brass and composition rings, 10, held in place by means plate 2, called the follower, and pressed outward by three gs, 11. The follower is used so that the rings may be and adjusted without disturbing the piston. The piston to the rod by means of the key 6, and the follower is the body of the piston by means of tap bolts, 3, and 4. In Fig. 3 the packing consists of a cast-iron tee ring, ing rings, 8. It is virtually a combination of the first d methods, embodying the use of cast-iron spring rings, ith the advantages derived from the use of the follower, ccessibility for removing the packing without disturbing proper. The same design is used in Fig. 4, except that 8, instead of being spring rings, have independent steel gs 13, placed between the tee ring and the piston rings *force the latter out*ward against the cylinder.

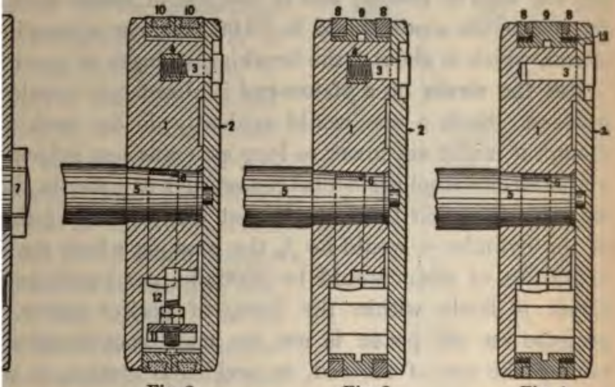


Fig. 2. Fig. 3. Fig. 4.

Pistons.

Piston-Rods.

The diameter of piston-rods varies with different builders, the range being between $\frac{1}{6}$ and $\frac{1}{10}$ the diameter of the cylinder, according to their length and probable maximum pressure. The high-pressure piston-rods of the American line of steamships are about $\frac{1}{7}$ the diameter of the cylinders, and the low-pressure about $\frac{1}{10}$. The piston-rod of the Centennial Corliss Engine was about $\frac{1}{6}$ the diameter of the cylinder. A rod $\frac{1}{10}$ the diameter would be $\frac{1}{100}$ the area of piston; and if 100 lbs. of steam were acting on the piston, the strain would be 10,000 lbs. per square-inch section of rod, which is about $\frac{1}{5}$ the breaking strength of good iron.

But the strain on a piston-rod is alternately tensile and compressive. Such a size would evidently do for such a pressure, though it might not break so long as it was not subjected to any undue strains from accidental causes, such as water in the cylinder, etc. On the other hand, the largest size in use — $\frac{1}{6}$ the diameter of the cylinder — would be $\frac{1}{36}$ the area, on which the strain due to 100 lbs. of steam would be 3600 lbs. per square-inch section, which is fairly within the limits of perfect safety. But the pressure on the piston is not the main consideration in determining the size of the rod, as accidental strains, to which it is liable to be subjected, must be adequately provided for. Some of these strains bear no relation to the steam pressure, so that the diameter of the piston should be made the main factor in determining the size of the rod. Bourne's rule is to *multiply* the diameter of the cylinder in inches by the square root of the pressure on the piston in pounds per square inch, and *divide* the product by 50. The quotient is the size of the piston-rod.

Piston-rods may be smaller in diameter than the foregoing, if made of steel, and if they possess sufficient rigidity and strength to resist all strains to which they may be exposed, and at the same time induce less friction, do more service, with less liability to flute or require returning, while the difference in first cost would be very tri hat of fitting about the same.

Piston, Connecting-Rod, and Crank Connections.

idea very generally prevails among engineers that th
k of a steam-engine travels
r at one part of the stroke
at the other. This is evident-
mistake. The crank travels
uniform speed throughout its
ution, but the piston travels
er to make one-half its stroke
the other. If the connecting-
were indefinitely long, or a
d yoke were substituted for it,
novement of the piston would
termined by the crank alone;
oints of mid-travel would cor-
nd exactly with the corre-
ling points in the travel of the
k, and the piston would occupy
ame position at the first and
half of each stroke. But in
quence of the distorting action
ie connecting-rod, the piston
ls farther during the half of
stroke farthest from the crank,
consequently, when the crank
its point of mid-travel, that is,
it is perpendicular to the
line of the cylinder, the piston
rer the crank than its point
id-travel by an amount which
s inversely with the length of
connecting-rod, and which is
to the difference between the
and the *hypothenuse of* the
ngled triangle formed by the

connecting rod, the crank and the distance between the cross-head pin and the shaft when the crank is perpendicular to the centre line of the engine cylinder.

Rule for finding the distance the piston is ahead of its central position in the cylinder on the forward stroke, and also the distance which it lags behind on the backward stroke when the crank is in the central position.

Subtract the square of the length of the crank from the square of the length of the connecting-rod; find the square root of the difference or remainder, and subtract it from the length of the connecting-rod. The remainder will be the variation of the piston from a central position when the crank is at right angles to the centre line of the engine.

Example.—Length of crank, 12 in.

Length of connecting-rod, 72 "

$$\begin{aligned} \text{Then } 72^2 &= 5184 \text{ in.} \\ 12^2 &= \underline{\ \ 144} \text{ "} \\ \text{Difference} &= 5040 \text{ "} \end{aligned}$$

$\sqrt{5040} = 70{\cdot}992$ in.; and

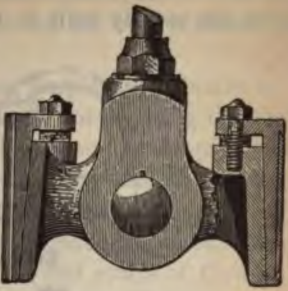
$$\begin{array}{r} 72 \\ \underline{70{\cdot}992} \\ 1{\cdot}008 \end{array}$$

1·008, which is the variation in inches.

The connecting rod is usually made from four to eight times as long as the crank—that is, two to four times the length of the stroke. Long connecting rods have many advantages, but the longer they are the greater must be their thickness, consequently it may be said that short connecting rods are more economical in the use of material. The usual length for high-speed engines is about five times the length of the crank.

The Cross-head.

The cross [illegible] part of the engine which, moving be*tween gu* [illegible] motion of the piston-ro the same time supplies a bearing, called the wrist-pin or ad pin, for the rocking motion ıd of the connecting-rod. The and proportions of the cross- 'e largely a matter of experi- d taste, although the areas of es, if not carefully calculated ›ressure to which they are sub- are liable to heat. The ac- ying cut shows a simple form -head, being that used in the engines built by the New afety Steam Power Company. be seen from the cut, it has ›le gibs on either side, by f which and the screw bolts any wear in the slides may be aken up. Cross-heads may of cast iron, wrought iron, or ıt the latter material is the mmon at the present day on account of its lightness for a trength. The area of the wearing surface or slides de- n the pressure to which they are subjected. In a horizon- ne, if it "throws over," all of the wear comes on the lower hile, if the engine "throws under," the reverse is the case. ould be taken into account in proportioning the slides, hould be on a basis of from fifty to eighty pounds per nch of surface.



difference between throwing over and under may be ex- as follows: An engine throws over when the crank-pin s the upper portion of its travel while the piston is moving the main shaft and throws under when the crank-pin s the lower portion of its travel while the piston is moving the main shaft. This is illustrated in the following cuts, *h the arrows indicate* the direction of motion. A little

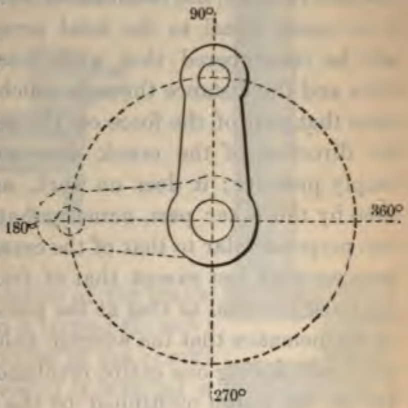
will be remembered that work was defined as the pr
force and the distance through which it acts, hence in thi
case that part of the force on the crank-pin, which is ex
the direction of the crank does not produce any mo
simply pressure; it does no work, and hence all of the
done by the other part, namely, that which is exerted i
tion perpendicular to that of the crank. Therefore, sinc
been no work lost except that of friction, the work at t
pin must be equal to that at the piston. Again, it may
by mathematics that the average value of the turning fo
crank-pin during one entire revolution is equal to the to
ure on the piston multiplied by the number .6367, henc
the figures given in the example above, the average tur
during each revolution would be 10,000 × .6367 = 636
Now since the length of the crank is one-half the leng
stroke, or in this case one foot, the crank-pin will tra
tance equal to 2 × 3.1416 = 6.2832 feet per revolution.
also that the average turning force is 6367 pounds.
work done in turning the crank is

$$6367 \times 6.2832 = 40000 \text{ foot-pounds,}$$

which is the same as the work done on the piston, as fo

termittent; but, so far, no rotary arrangement has ever
ble to compete, in point of economy, with the reciprocating

tly speaking, there is no loss of power in the use of the
as, while there is a great variation in the power a given
pressure will exert at
t points of the stroke,
al power at the crank
one revolution of the
is the same as that
piston during two
, except for the losses
tion, which in a well-
ngine are not great.
uality in the work at
ton and at the crank-
l be easily understood
n example. Suppose
ton has an area of
uare inches and the steam pressure is 100 pounds per
inch, while the stroke is 24 inches. The total pressure on
ton is 100 × 100 = 10,000 pounds, and since the stroke is 2
work done during each stroke is 2 × 10,000 = 20,000 foot
, and during each revolution 2 × 20,000 = 40,000 foot
. Now, at the crank-pin the force is not always in the
irection. Its direction is in the line of the connecting-rod,
nsequently the effort to turn the crank is not always the
At the beginning of the stroke, for example, there is no
cy whatever to turn the crank, the total pressure being
l against the main bearings, and if it were not for the fly-
the engine would come to rest at the beginning and end of
roke. As the stroke advances, however, the turning effort
es, and when the connecting rod is perpendicular to the
which is near the middle of the stroke, the total force of
m is utilized in turning the crank, after which the turning



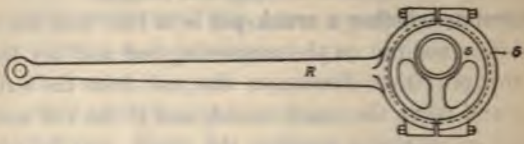
e, but that so many do not. An increase in the dimensions pin would, it is true, proportionately diminish the pressure uare inch; but the loss of power, by the increased friction iduced, would be equally as objectionable as the evil which intended to remove.

length of a crank-pin should be equal to the horse-power engine divided by the stroke; the quotient multiplied by ficient which has been found by experiment to range from 1·5. For instance: if a crank-pin is required for an engine 48″, capable of developing 250 Hp., then 250 ÷ 48 × 1·5 l, or 7$\frac{13}{16}$ in., which is the required length.

determine whether a crank-pin is in line with the centre of linder or not, put on the connecting-rod and key the box up on the pin; then disconnect the rod from the wrist of the iead and move the crank round, and if the rod maintains a l line in whatever position the crank may be placed, the -pin is in line with the centre of the cylinder. This test will erve to prove the correctness of the boring of the pin-boxes. y are not bored exactly at right angles to the centre line of od, troubles similar to those caused by an untrue pin will . Another oversight not generally thought of, and which s much trouble with crank-pins, is that, in planing off the nds of the connecting-rod, the machinist, through ignorance ttention, planes more off one side than the other. As a re- very time the rod changes its position, the box will pinch on ank-pin, and cause undue heating.

The Eccentric.

e Eccentric.—An eccentric is substantially a crank, with ı enlarged in diameter so as to inclose the shaft on which it ced within its periphery. It gives exactly the same motion vould be obtained from an ordinary crank of equal throw. ccentric is sometimes called a cam, which is erroneous, as tter is always used *to obtain* a motion different from what *e obtained from a crank.* The term "cam," when used without qualification, is indefinite and conveys no impressio its precise form or functions. It is a mechanical element of s a form that a solid body held against, but not revolving with, periphery of contact may have an intermittent, alternating mot An eccentric consists of the *sheave S*, which is a circular usually of cast-iron, keyed to the shaft, and a *strap, S'*, or gro ring surrounding the sheave and sliding loosely around it. strap is usually made of brass or of cast-iron lined with some friction metal. It is made in two halves bolted together as sh The *eccentric rod R*, which is in one piece with or bolted t



strap, transmits the motion to the valve or other part which be moved. The groove in the strap fits around a correspo collar in the sheave and holds the strap in position. Ecce are generally used for converting rotary into reciprocating m while cranks are used for the opposite purpose, although e would accomplish either result. The principal reason why e trics are used instead of cranks to actuate the valve gear i cause the motion must generally be taken off at some point the middle of the shaft, and hence a centre-crank would b quired which would, as already explained, weaken the shaft. distance between the centre of the eccentric sheave and the c shaft is called the *throw* of the eccentric or *eccentr* orresponds to the length of the crank, the sheave c *to the* crank-pin, the strap to the connecting rod end, *tric* rod to the connecting rod.

Crank Shafts, Journals, and Main Bearings.

Crank shafts are made of wrought iron or steel. They must be ficiently strong to withstand both the twisting action produced the load and the bending action produced directly by the am pressure. The twisting stress depends solely upon the rse-power to be transmitted and the speed, while the bending ess depends upon a variety of conditions, such as the point at ich the crank is attached to the shaft, the distance from the nk to the nearest bearing, the distance between bearings, the ler pressure, etc. Hence, no definite rule can be given to de- mine the diameter of a shaft suitable for resisting the bending esses. To determine the proper diameter of a shaft to transmit iven horse-power at a given speed, independent of the bending esses,

Rule.—*a.* If steel, multiply the horse-power to be transmitted 75 and divide the product by the number of revolutions per nute. Extract the cube root of the result, which will be the uired diameter of the shaft in inches.

. If wrought iron, multiply the horse-power to be transmitted 100, then proceed as above.

xample.—Required the diameter of a wrought-iron shaft for 00 horse-power engine running at 100 revolutions per minute, afely withstand the twisting strains,

$$\sqrt[3]{\frac{100\times500}{100}}=7.937 \text{ ins.}$$

he usual method to determine the proper diameter for the k shaft is to calculate it according to the above rule and then to ider it as a beam carrying a load equal to the total maximum sure of the steam on the piston and determine what diameter ld be necessary to safely carry that load. The greater of the results will be the proper diameter for the shaft.

he journals, or those portions of the shaft which are sup- ed in the bearings, are usually made of about the same diame- s the rest of the shaft, while their length varies from one to ınd the main casting. The adjustments for taking up etc., require no further explanation. In stationary bearings usually form part of the frame, and frequently parating the main box and the cap, instead of being is at an angle of about 30° from the perpendicular. ıe so that the resultant strain passes through the solid ead of through the joint between the box in the cap, es when this is horizontal.

Fly-Wheels.

ect of the fly-wheel is to equalize the motion whenever power communicated or the resistance to be overcome . In the one case, the fly-wheel may be said to be a of power. The complicated impulses, acting on the ıotion, preserve the momenta, without disturbing the of movement. The effect of one impulse is so absorbed ted in the momentum of the wheel, that it may be said ardly been diminished before the next impulse is re-

ther case, or where the fly-wheel is used to overcome a esistance, it may be considered a conservator of power. having been exerted in getting up the speed, is retained ing mass, and the whole of the power expended, with the of that which has been lost through friction and resist- e air, can be brought to bear at any instant upon the to be overcome. When the crank and connecting-rod straight line, as they must be twice in each revolution, is said to be on its dead-centre, because there the e piston is dead or ineffective. It is evident that, when is at right angles to the connecting-rod, the latter is he maximum of power; but when the forward or back- l-centre is reached, the crank would remain there, but ion of the fly-wheel, which, by its accumulated momen- es it over the dead-centre.

hrough the momentum of the fly-wheel, no perceptible variation occurs in the velocity of the engine; the unequal leverage of the connecting-rod is corrected and a steady and uniform motion produced The fly-wheel, as before stated, is a regulator and reservoir, and not a creator of motion. As regularity of motion is of much greater importance in some cases than in others, the weight and diameter of the fly-wheel must depend on the work and the character of the machinery it is intended to drive; so that, in proportioning a fly-wheel to a given engine, attention must be paid to many particular circumstances rather than to any given rule. There are circumstances under which the use of a fly-wheel may be dispensed with, as where a pair of engines work side by side, whose cranks are at different angles, so that one assists the other to pass the centres, or where smoothness of motion is not an absolute necessity.

Great care should be taken in erecting fly-wheels to see that they are balanced—that is, that the centre of gravity of the wheel coincides with the centre of the shaft, as if it does not both the shaft and the wheel will be subjected to unnecessary strains, which may produce disastrous results. The balancing may be accomplished by loading or cutting away portions of the rim, as the case may require, and it may be said in general that the perfectly circular form of the wheel is of no importance so long as the centre of gravity coincides with the centre of the shaft. The effectiveness of the fly-wheel in steadying the motion of the engine depends upon the distance of the metal from the centre, the weight being the more effective the greater its distance from the centre. For this reason the material of which the fly-wheel is composed should be concentrated as much as possible in the rim. The steadying action also varies as the square of the speed of the rim. Hence, increasing the diameter saves weight. There is a certain limit, however, beyond which the speed may not be in-
c without danger of bursting. The speed of the rim is
ve 80 feet per second, and if carried beyond 200 feet
the strains produced by the centrifugal force would
sufficient to rupture the wheel.

ly-wheels are nearly always made of cast iron, and when not large are cast in a single piece. Very large wheels, how- , are often cast in sections, because of the difficulty of hand- as well as the expense of making very large castings. In cases one section of rim is often cast with one arm and one ion of the hub; more frequently, however, the arms are cast rately, the rim in as many sections as there are arms, and hub in two sections. The sections of the rim are held to- er by means of links and cotters, while the arms are dove- d into the rim and the hub and secured by wedges. The es of the hub are bolted together. The arms of fly-wheels ld be made of sufficient size to support the weight of the rim. y merely act as distance pieces between the hub and the rim, their weight adds little to the effectiveness of the fly-wheel. arms are usually given a slight taper, increasing in thickness the rim to the hub, to provide resistance against the bending s due to their own centrifugal force.

CHAPTER XVIII.

VALVES AND VALVE GEARS.

he term valve gear embraces all intermediate connections be- en the eccentric on the driving-shaft and the valves, and is licable to all mechanical arrangements employed for working valves of steam engines.

he valves most generally employed for the admission of steam he cylinders of steam engines are the slide, poppet, Corliss or irotary, and rotary; plug- or piston-valves are also used, but erally for steam-pumps. All valves, whether used for the ission or escape of steam to or from the cylinders of steam nes, receive their motion from cams, eccentrics, or cranks. atever the device employed to give motion to the valves may ermed, whether cams, eccentrics, cranks, gearing, rockers, wrist plates, toes, lifters, trips, links, rods, levers, etc., they be placed under the head of valve-gear.

There are engines without valves, such as the Wardwell, v was on exhibition at the Centennial Exposition at Philadel and some kinds of oscillating engines, in which faces on th inder fit against faces on stationary steam-chests, through v the steam enters and escapes from the cylinder. Such arr ments are now but rarely used, because they possess inheren fects which render them useless for the most important pur for which the steam engine is employed.

A "releasing" valve-gear is an arrangement in which the is liberated from the control of its moving agent, and allow close in obedience to the action of a spring, weight, or other independent of that which opened it. The agent which mines the time of release may be the governor, or it may be often is, some device adjustable by hand.

An automatic cut-off valve-gear is one in which the move of the cut-off valve is so controlled by the governor, as to c the steam as early or as late in the stroke as may be requir maintain the desired uniformity of speed, under variations of and pressure.

A positive cut-off is an arrangement of valve-gear by v the expansion of the steam is effected by what is known as *l* the valve, the steam being cut off at the same point in each st independent of load or pressure.

An "adjustable" cut-off is an arrangement of valve-ge which the point of cut-off can be adjusted by the hand of th gineer, outside of the steam-chest, by means of a screw, hand-w or other mechanical arrangement, to meet the requiremen work and pressure. The link, in its application to the stea ngs to this class of cut-offs, as it effects the adjust ff by means of coincident variations in the travel ince using a single valve.

-off.—A term applied to cut-off valves which of the main steam-valve.

pendent cut-off is one in which the expansion is effected
pendent or auxiliary valve riding on the back of the
e, and receiving its motion from an independent eccen-

pansion " valve-gear is one that cuts off the supply of
ny required point of the stroke. It embraces all the
rrangements.

le " stroke valve-gear is one that admits steam through
length of the stroke.

rsing " valve-gear is an arrangement employed for re-
motion of engines. It is effected in different ways: in
with a single eccentric, while in others with two ec-
in the case of the link; and in others, still, by means
eccentric which revolves on the shaft, but is prevented
ing a complete revolution by two stops so placed that
it in the proper position for the forward, and the other
kward motion. This arrangement is peculiarly adapted
s and ferries, owing to the ease and quickness with which
can be reversed.

beat valves are poppet-valves so arranged, that the
f steam is nearly equal on both sides, thus rendering the
the valve much easier than in the case of an ordinary
valve.

-valves are valves located in the steam pipe, through
m is admitted to the steam chest. Every engine is
a throttle valve, which is turned off when the engine is
down.

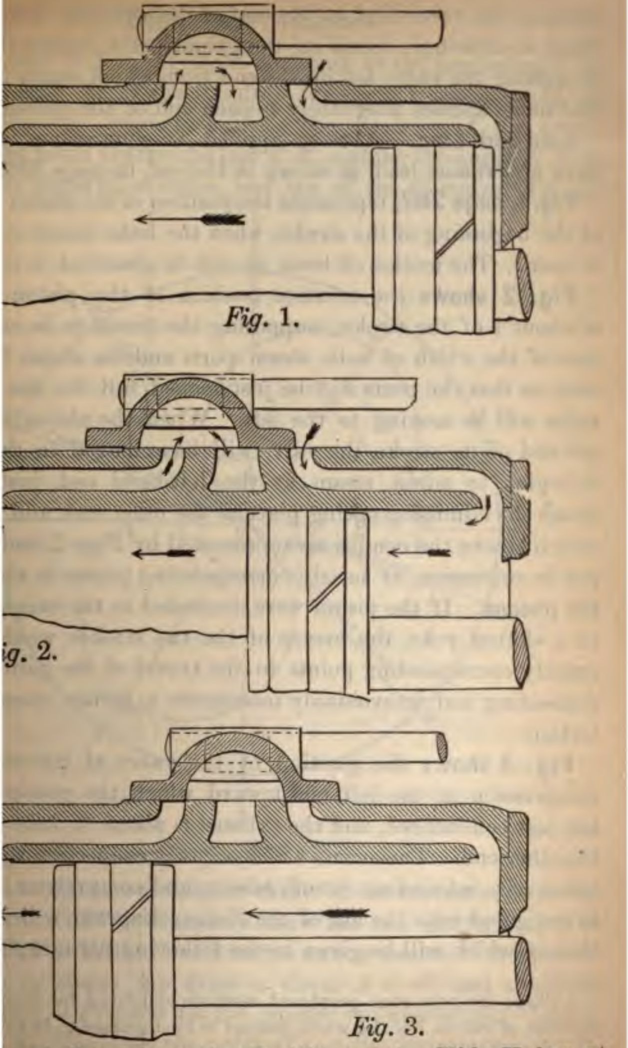
alves are used on the cylinders of large engines, par-
narine, to prevent fracture of the cylinder-head and
n consequence of an accumulation of water in the latter.
reater pressure is exerted in the cylinder than would
n the ordinary pressure of the steam, the relief-valve
and admit of the discharge of the water, thus averting
t. They are used on fire-engines for the purpose of

of the eccentric. (See page 378.)

Overtravel is the distance travelled by the valve over a
that necessary to fully open the steam port.

Lap on the Valve.—The term lap on the valve de
amount the edges of the valve extend over the ports w
valve is in the centre of its travel. The object of lap is
the benefit to be derived from working steam expansivel
on the steam side is termed outside lap, while lap on
haust side is termed inside lap. Poppet or conica
cannot have any lap, but the same effect is produced
as of the slide valve by arranging the cams and liftin
that the valve may close at the proper time to give the
degree of expansion. The lift of poppet valves, to give
equal to the area of the port, is ½ the radius or ¼ the

Lead is the amount the port is open at the beginni
The object of lead is to enable the steam to
cushion against the piston before it arrives at the end of th
enable it to reverse its motion easily, and also to supp
[illegible] the piston the instant it has passed dea
different engines from $\frac{1}{32}$ to $\frac{3}{16}$, without r
Some valves have no lead at all, others l



xed *Cuts show* the Position of the Slide-Valve at different *Points* in its Travel. (*See explanation on page* 390.)

now able to take from the diagram all of the data necessary for a complete understanding of the distribution of steam in the cylinder:

$O X_1$ is the position of the crank when admission of the steam begins.

$O X_2$ is the position of the crank when cut-off takes place, hence

$X_1 O X_2$ is the angle traversed by the crank during the period of admission.

$O X_3$ is the position of the crank when the exhaust opens.

$O X_4$ is the position of the crank when the exhaust closes, hence

$X_3 O X_4$ is the angle traversed by the crank during the period of exhaust, and

$X_4 O X_1$ is the angle traversed by the crank during the period of compression.

The distances from the intersection of the circles R and R' with the lines $O X$, $O X_1$, etc., representing the crank in its different positions to the centre, represent the travel of the valve corresponding to those positions of the crank. The circle R represents the forward and the circle R' the return stroke, hence

$O K$ is the distance the valve has travelled from its central position at the beginning of the stroke.

$O K'$, the same for the return stroke.

$O A$ is the outside or steam lap, hence

$A K$ is the distance the steam port is open at the beginning of the stroke or the steam lead.

$O R$ is the full travel of the valve.

$O B$ is the inside or exhaust lap, hence

$B K$ is the distance the exhaust port is open at the beginning of the stroke or the exhaust lead.

At the points C and D the travel of the valve is just equal to the outside lap; hence in these positions of the crank the steam port opens and closes respectively; similarly at the points E and F the travel is just equal to the exhaust lap; hence, in these *positions of* the crank the exhaust port opens and closes respect[illegible] we lay down from the point A a distance $A H$, equal

of the port, and with *O* as a centre and a radius
arc, cutting the line *O R* at *J*.
tance the valve travels more than enough to fully
port, or the over-travel.
if we lay off from *B* the distance *B L*, equal to the
port, and from the centre *O* and a radius equal to
n arc, cutting the line *O R* at *M*.
distance the valve travels more than enough to fully
he port to the exhaust.
us be seen that by a careful study of the diagram all
n necessary for the proper design and setting of the
may readily be had. For example, in the above dia-
cut-off takes place a little later than ¾ stroke. It is
hat if it is desired to have the cut-off take place earlier,
stroke, it will be necessary for the outside lap circle,
to intersect the valve circle *R* in the line *Y Y′*. This
accomplished by increasing the outside lap, by reducing
ntricity, or by changing the angle of advance. However,
e of these changes would also affect the entire distribution,
would probably be necessary to lay down several diagrams
the most advantageous dimensions could be obtained.

How to Set the Valves of Steam-Engines.

o definite instructions that would apply to all cases can be
n for setting the valves of steam-engines. As the circum-
ces under which the engines and valves are employed must,
certain extent, influence and control this operation, fast-run-
g engines require more lead than those that run slowly. En-
es doing heavy and irregular work also require more lead than
se working with a uniform load. Some engines require no lead
all, while others require a great deal.
The valves of a steam-engine may be adjusted with great ac-
acy by an intelligent and practical engineer, providing that
the valve-gear is of correct proportions; but there are diffi-

culties to be contended with which frustrate the efforts of the mo practical mechanics, and must ever do so, unless we discover new material for valves and valve-gear. Valves may be set wi the nicest mechanical accuracy, opening and closing the ports wi precision when the valves and valve-gear are cold; but when exposed to high temperatures they may be far from accurate i their travel. All metals expand with heat and contract with col and a valve that will give uniform lead at each end of the strok when cold, will not, in all probability, do so when exposed to th action of the steam, as the valve and valve-rod will expand, pr duce a loss of lead, increase the amount of lap, and alter the co ditions under which the engine was intended to work.

This change is not confined to slide-valve engines, as the sten of poppet-valves are lengthened by expansion, decreasing the lif and also the lead, and inducing a very different condition of thing from what would exist if the valves could be used at the temper ture at which they were adjusted. Thousands of indicator dia grams show conclusively that the behavior of valves, when expose to high temperature, is very different from what they are whe cold. One of the best aids in correct valve-setting is a good indi cator, as nothing shows the action of the steam in the cylinder s correctly as this instrument. It tells exactly when the steam goe in and out of a cylinder, because it maps down the motions of th steam as determined by the motions of the valve and piston, re cording faithfully the times and pressures as they actually are.

To set a slide-valve, place the *crank* on the *dead-centre* an the valve centrally on its seat over the ports; then adjust th valve-gear to the right length, and move the *eccentric* round i the direction in which the engine is intended to run, until th w [illegible] ead is attained, as shown in Fig. 1, page 204; then turn th [illegible] he *opposite centre*, and, if the lead is exactly the same, [illegible] ight to travel equally on its seat, and the exhaus [illegible] Fig. 2, page 204. Any difference in the lead a [illegible] ust be equalized by lengthening or shortening th [illegible] the case may be.

n intelligent engineer can generally tell by observation whether
ines exhaust regularly or not; as, if the steam is discharged
h long or short puffs, alternately, or shows what is technically
med a long and short leg, it is evident that the valve has an
lier and a freer exhaust at one end than at the other; never-
less, one exhaust may be heavier than the other, and yet the
ervals between them may be equal. In such cases the exhaust
equal as to time, but not as to amount. The difference in
ount may be caused by unequal degrees of expansion, and this
turn may be caused by unequal cut-off, or unequal clearance,
both. Such inequality cannot be cured by mere adjustment,
ce the lap requires to be changed; but in most cases an im-
vement may be effected by a compromise between equalized
-off and exhaust, so that the effects of the inequality of both
uld not be noticeable.

n the case of fast-running engines, or where the exhaust has
pass through long pipes, this inequality is not easily determined
m the appearance of the exhaust; but it may be done more
urately by holding the ear close to the exhaust pipe. This
ter method may also be resorted to in the case of low-pressure
gines exhausting into a condenser.

w to Determine the Amount of Lap and Lead on a Valve without Opening the Steam-Chest, and whether it is Equal at both Ends or not.

Open the cylinder drain-cocks and disconnect them from the
ip-pipes, so that the steam may be seen and heard to issue from
em. A better plan is, to open the holes made for the indicator,
there are any; at all events, open as large holes as possible; then
in a very little steam, turn the engine around by hand, and
te, by the commencement and cessation of the flow of steam,
st where the steam is admitted and cut-off. The point of cut-
can be most accurately ascertained by turning the engine
ckwards; the steam will in this case commence blowing at the
ne point in the stroke at which it would cease blowing when

turning it forward; and, owing to the elasticity of steam, th commencement of the issue is always more clearly defined tha the cessation, particularly when the issuing orifice is small. Fo the same reason, the point of admission can be most accuratel located by turning the engine forward.

To determine the lead, having found the point of admission make a mark on the valve-stem at a known distance from som fixed point, and another after the pin has reached the centre; thi will give the lead. If the admission forward takes place when th crank-pin is exactly on the dead-centre, there is no lead. Havin obtained the lead and cut-off for both ends, the travel and lengt of the connection being known, a diagram may be constructed similar to that on page 391, which will give the lap and port-opening.

The point of exhaust and compression cannot be determined s readily. With a small engine, in which the piston and valve ar steam-tight, the points may be ascertained by blowing into the cylinder through pipes attached to the cylinder-cocks or the holes fo indicator, if any. The exhaust would be indicated by the poin where the air would begin to pass through into the exhaust, and the closure, by noting the point where it ceased to pass through.

But in engines of any size, especially leaky ones, the plan of blowing in with the mouth would be inapplicable. With non-condensing engines, however, much may be learned by listening to the exhaust; if the puffs occur at equal intervals, and are of equal force, good equalization may be inferred; and, if they ar short, quick, and free, and are followed by a free and nearly noiseless escape of the residuary steam, the exhaust is early and ampl enough. On the other hand, too late an exhaust will produc more prolonged and labored puffs. It is needless, however, t remind the reader that nothing can take the place of the indicato for determining all the conditions and adjustments of the valve, particularly its exhaust and compression, as, even when the nicest rements and calculations are resorted to, doubts may still s to the truthful movements of the valve, which nothing pplication of the indicator can satisfactorily remove.

TABLE

SHOWING THE AMOUNT OF "LAP" REQUIRED FOR SLIDE-VALVES WHEN THE STEAM IS TO BE WORKED EXPANSIVELY.

When the travel of the valve is known, and the point of cut-off decided, the following table will show the amount of lap required.*

Travel of the Valve in Inches.	The Travel of the Piston when the Steam is cut off.							
	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{5}{12}$	$\frac{1}{2}$	$\frac{7}{12}$	$\frac{2}{3}$	$\frac{3}{4}$	$\frac{10}{12}$
	The required "Lap."							
2	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{11}{16}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{8}$
$2\frac{1}{2}$	$1\frac{1}{16}$	1	$\frac{7}{8}$	$\frac{13}{16}$	$\frac{11}{16}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{7}{16}$
3	$1\frac{1}{4}$	$1\frac{3}{16}$	$1\frac{1}{8}$	1	$\frac{15}{16}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{9}{16}$
$3\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{1}{8}$	$1\frac{1}{16}$	1	$\frac{7}{8}$	$\frac{3}{4}$
4	$1\frac{3}{4}$	$1\frac{9}{16}$	$1\frac{7}{16}$	$1\frac{5}{16}$	$1\frac{1}{4}$	$1\frac{1}{16}$	1	$\frac{13}{16}$
$4\frac{1}{2}$	2	$1\frac{13}{16}$	$1\frac{9}{16}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$\frac{7}{8}$
5	$2\frac{1}{8}$	2	$1\frac{13}{16}$	$1\frac{9}{16}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{4}$	1
$5\frac{1}{2}$	$2\frac{5}{16}$	$2\frac{3}{16}$	2	$1\frac{13}{16}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{8}$
6	$2\frac{1}{2}$	$2\frac{7}{16}$	$2\frac{3}{16}$	2	$1\frac{13}{16}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{3}{16}$
$6\frac{1}{2}$	$2\frac{3}{4}$	$2\frac{9}{16}$	$2\frac{7}{16}$	$2\frac{3}{32}$	2	$1\frac{13}{16}$	$1\frac{5}{8}$	$1\frac{1}{4}$
7	3	$2\frac{11}{16}$	$2\frac{9}{16}$	$2\frac{3}{8}$	$2\frac{3}{32}$	2	$1\frac{3}{4}$	$1\frac{7}{8}$
$7\frac{1}{2}$	$3\frac{3}{16}$	3	$2\frac{11}{16}$	$2\frac{1}{2}$	$2\frac{3}{8}$	$2\frac{3}{32}$	$1\frac{7}{8}$	$1\frac{1}{2}$
8	$3\frac{5}{16}$	$3\frac{3}{16}$	3	$2\frac{5}{8}$	$2\frac{1}{2}$	$2\frac{3}{8}$	2	$1\frac{5}{8}$
$8\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{5}{16}$	$3\frac{3}{16}$	$2\frac{13}{16}$	$2\frac{11}{16}$	$2\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{3}{4}$
9	$3\frac{13}{16}$	$3\frac{5}{8}$	$3\frac{5}{16}$	3	$2\frac{13}{16}$	$2\frac{11}{16}$	$2\frac{1}{4}$	$1\frac{7}{8}$
$9\frac{1}{2}$	4	$3\frac{13}{16}$	$3\frac{5}{8}$	$3\frac{3}{16}$	3	$2\frac{13}{16}$	$2\frac{3}{8}$	2
10	$4\frac{1}{4}$	4	$3\frac{13}{16}$	$3\frac{5}{16}$	$3\frac{3}{16}$	3	$2\frac{1}{2}$	$2\frac{1}{16}$
$10\frac{1}{2}$	$4\frac{7}{16}$	$4\frac{1}{4}$	4	$3\frac{1}{2}$	$3\frac{5}{16}$	$3\frac{1}{8}$	$2\frac{5}{8}$	$2\frac{3}{16}$
11	$4\frac{9}{16}$	$4\frac{7}{16}$	$4\frac{1}{4}$	$3\frac{5}{8}$	$3\frac{1}{2}$	$3\frac{3}{16}$	$2\frac{3}{4}$	$2\frac{1}{4}$
$11\frac{1}{2}$	$4\frac{13}{16}$	$4\frac{9}{16}$	$4\frac{7}{16}$	$3\frac{7}{8}$	$3\frac{5}{8}$	$3\frac{3}{8}$	$2\frac{7}{8}$	$2\frac{3}{8}$
12	5	$4\frac{13}{16}$	$4\frac{9}{16}$	$4\frac{1}{8}$	4	$3\frac{5}{8}$	3	$2\frac{1}{2}$

Rule for finding the point of cut-off required to produce a given terminal from a given initial pressure.

---

* *If a valve has ¾ lap, it will* overlap each steam-port ¾ of an inch when *placed centrally over them.*

Example.— [illegible] = 1
[illegible] the stroke.

[illegible] when the initi
[illegible]

[illegible] the atmosphere to the initi
pressure, [illegible] the mean pressure by the initial
[illegible] number, page 32, the number nea
[illegible] number opposite to it in the expan
[illegible] the quotient will be the point
[illegible] of the stroke.

Example.—Stroke of piston, 10 in. **Initial pressur**
[illegible] Mean pressure [illegible] lbs. **Mean effective pre**
[illegible] added, 22·50. Initial **pressure, atmosphere**
quotient of first divided by last, ·918. **Expansion nu**
opposite ·918, which is nearest **number to above quotie**
[illegible] = ·625 or [illegible] of the stroke. **Either of the foregoi**
make the cut-off take place **a trifle earlier than it woul**

Different Forms of Slide Valves.

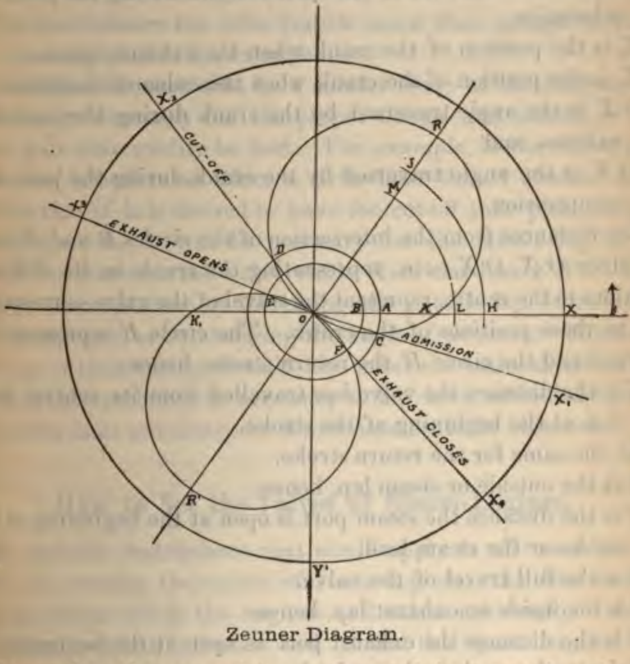
A certain amount of power is always consumed i

equal to the total pressure of steam on the back
the upward pressure on an area equal to that
ports. This method of calculating the pressure on
is not, however, entirely correct, because the num-
inches in a slide-valve, and the pounds pressure per
represent only the weight on its back if we consider
solid block of iron, with a smooth surface resting on
id bearing, perfectly steam-tight, in which case the
press on every square inch of surface with the same
nd weight. There is good reason to believe that such
re never found in a slide-valve, except in one position,
he valve overlaps both ports and the engine is at rest.
wever, as the valve moves, the steam enters the open port,
ssure is partially taken off that end of it. There is no
ver, that in many cases the power required to operate
very great, and the better the slide valve fits the seat
wer it will take to work it. A valve that fits its seat
—that is, in such a way that there can be no leakage of
een its face and the seat—requires much more power
than one which is leaky, because the pressure of the
on the seat and there is nothing to lessen the friction
lubrication.

on valve has been designed to meet this difficulty. This
le valve is illustrated in the accompanying cut, which
the cylinder and valve of the Armington & Sims en-
vill be observed that in this piston valve the steam,
producing pressure on the seat, is evenly balanced,
uently the only pressure against the seat is that due to
of the valve; for this reason these valves are known
nced valves. As usually constructed, the valve chest is
bushing being accurately turned to form the valve
he valve is made tight by the use of piston rings, the
am pistons. In the Armington & Sims type it will be
he steam enters the cylinder around the inside edge of
nd also through additional passages cut in the valve

The Zeuner Diagram.

Draw a line $O\ X$ to represent the crank at the beginning of the stroke, and with this as a radius draw the crank circle XX_1, X_2, X_3, X_4. Suppose the crank to turn in the direction of the arrow. Through the point O draw the line $R\ R'$, making the angle $R'\ O\ Y'$ equal to the angle of advance, and lay off the distances $O\ R$ and



Zeuner Diagram.

$O\ R'$ equal to the eccentricity or throw of the eccentric. On the lines $O\ R$ and $O\ R'$ as diameters draw the two circles $O\ C\ R\ D$ and $O\ E\ R'\ F$. With O as a centre and a radius $O\ A$ equal to the outside or steam lap draw a circle $A\ C\ D$, and similarly with a radius $O\ B$ equal to the inside or exhaust lap, draw a circle $B\ E\ F$. Through the point O and the intersections C, D, E, and F *draw the lines* $O\ X_1$, $O\ X_2$, $O\ X_3$, and $O\ X_4$. We are

[illegible]

The above cut represents [illegible]

[illegible] in connection with the [illegible] Cut-Off,

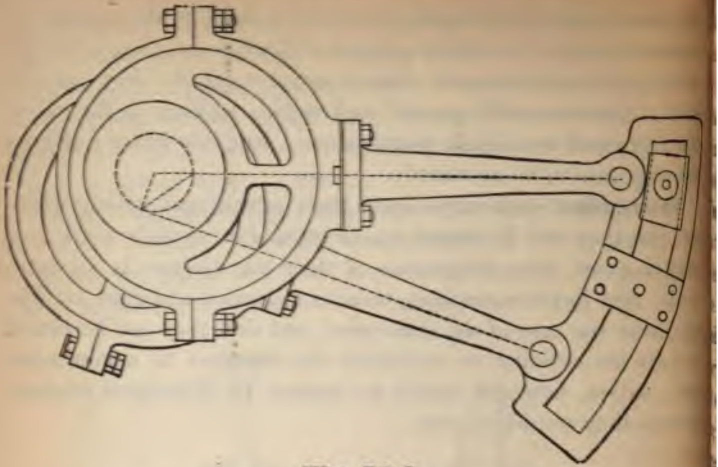
[illegible] Front. It will be observed that

[illegible] are open for the admission of steam, he present case, $\frac{1}{8}$ lift would give an area equal to the opening of he steam-port. One of the greatest difficulties experienced in the orking of such valves is, that, however carefully they may be tted, their stems will expand and induce leakage in the valves hen exposed to a high temperature. For this latter difficulty ere appears to be no remedy.

Nevertheless such valves have their advantages, among which e, that they can be turned up, or ground on to their seats at a oderate cost, since the process of their manufacture is all lathe ork; that in their working, there is no power absorbed by fric- on, as in the case of the slide-valve, and that they can be placed near the cylinder as to reduce the clearance to a minimum. uch valves, however, would not answer for high-speed engines, ecause they would not seat.

Variable Cut-off and Reversing Gears.

In order to reverse the direction of motion of an engine ope- ted by a slide valve and single eccentric it is evident that the ccentric would have to be slipped around on the shaft until it ccupied the same position relative to the valve on the opposite de of the shaft, while in order to vary the rate of expansion or ut-off it will be evident from an examination of the Zeuner dia- ram on page 391, that some means must be found for effecting a uitable variation, either in the steam lap or in the travel of the alve. Both of these methods are used; the former, a variation the steam lap, is employed in Myer's gear, which will be de- cribed below, while the latter, a variation in the travel of the alve, is the principle employed in nearly all automatic cut-offs ith fly-wheel governors. These will be described under "Gov- rnors" in the next chapter. Finally, there is a device, invented y Stephenson, by means of which the engine may be not only versed, but the cut-off varied to any desired extent in a very mple manner. This is called *the link motion.*



The Link.

The link-motion is an arrangement of valve-gear for reversing engines and varying the rate of expansion. It consists of two eccentrics, with straps and rods. The eccentrics are so placed that when one is in the right position for the engine to move forward, the other is in the position for moving backward; and by raising or lowering the link, motion will be communicated to the valve and the engine will move backward or forward. The result of this combination is that the link receives a reciprocating motion in its centre; since, when one eccentric is moving the end of the link in one direction, the other is moving the other end in the other direction; so that the link will have nearly the same motion communicated to it as if it were suspended from a pivot at its centre.

The horizontal motion communicated to the link by the joint action of the eccentrics, is a minimum at the centre of its length, where it is equal to twice the linear advance, and it increases ward the extremities, being nearly equal at either extremit *otion which* would be imparted to it by the eccentric at *ty alone*, without regard to the other. The valve r *to* a block which slides in the link, and the posi lock is varied by means of a combination of rods and levers, ıed in some cases to the block and in others to the link

In either case the link is suspended by a rod at some point, he length of this rod as well as the location of the point on nk to which it is attached, have an important influence on otion of the link.

e travel of the valve depends upon the distance of the block the centre of the link. By moving the link up or down on lock or the block up or down in the link, the travel of the may be increased or decreased. The central position corre- s to no motion whatever, while the nearer the block is to eccentric the more its motion will be under the control of ccentric. Now since the travel of the valve, other things equal, determines the point of cut off, it follows that the e of expansion varies with the position of the block relative link. In the above sketch, for example, suppose that the eccentric is set for forward motion and the back eccentric for se motion. The link is suspended at the centre by a rod hown), and in the position represented in the cut the block he top, and it is therefore entirely under the control of the rd eccentric. Consequently the engine is going forward and eam is cut off at the latest possible moment, the exact point of roke where the cut-off takes place depending on the lap and dimensions of the valve gear. Now as the link is raised avel of the valve decreases and the cut-off takes place earlier the block is in the centre, when there is not enough travel cover the ports; hence steam may be said to be cut off the stroke begins and the engine is at rest. If the link is still more, the other eccentric will control the block and ngine is reversed, the cut-off depending, as before, on the ce of the block from the centre of the link. The *term* "full- orward" means that the link is dropped to its full extent; "full-gear backward" means that the link is lifted to its tent. When the link-block stands directly under the sad- *te both ports are closed*, and neither admission nor exhaust

can take place. The distance between the block and the
the link when in full gear is termed the clearance.

The radius of the link is the distance from the centr
driving-axle, or shaft on which the eccentric is located
centre of the link; while the link itself is a segment of th
of that diameter. The length may be greater or less, b
variation from these proportions will give more lead at
than at the other while working steam expansively; but
dius may be several inches shorter or longer without ma
affecting the motion. The vital point in designing a va
motion is the point of suspension of the link. If it is su
from the centre, it will invariably cut off steam sooner
front stroke than in the back stroke, while working expa

It is customary to susp
link at the point which
used in running the
In the accompanying
method of attaching
to a vertical engine is

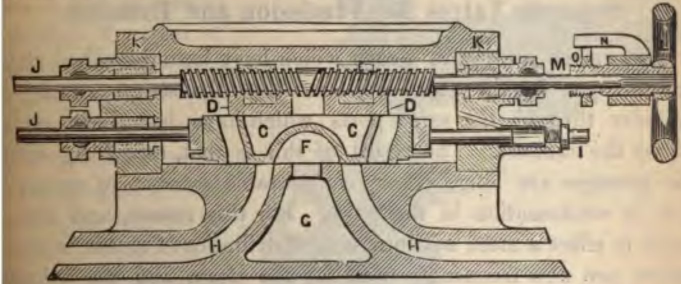
A A shows the be
B, the pillow-block b
D, the shaft; *E E*, th
tric rods; *C*, the con
rod; *F*, the link; *G*, th
head guide; *J*, the bo
steam-chest; *I H*, th
cylinder; *K*, the c
head; *L*, the steam-pi
the front column whi
ports the cylinder;
reach-rod; *O*, the reve
of the bell-crank by wh
link is moved back and
P, the lifting arm;
means of which the link is reversed; *S S*, the

rough which the spindle of the screw R moves; Q, the hand-heel by which the lifting arm P is moved up or down for the irpose of changing the position of the link. In the type of link ed for locomotives the screw and hand-wheel is replaced by a ng lever moving in a notched segment, the notches correspond-g to the various cut-offs on the forward and reverse motion.

The ease and facility with which the link may be handled are ery important features in its favor. In fact, what could we do ithout it when handling engines, especially large locomotives or arine engines, which have of necessity to run backward with e same ease, speed, and facility as they run ahead? The link a splendid mechanical conception, and one of the greatest im-rovements that has ever been made in the locomotive, marine igine, or any other class of engine requiring a reversing gear.

Meyer's Valve Gear.

A very simple and effective method of varying the rate of xpansion without interfering in any way with the admission,



release, and compression, is by means of what is known as a *riding cut-off*, which consists of an additional valve to control the cut-off, riding on the back of the main or distribution valve. There are numerous varieties of this type of valve, but perhaps the most widely used is the Meyer valve. This is illustrated in the accompanying cut, in which C C is the main or distribution valve. *This is similar to an* ordinary D valve, except that the steam, instead of being admitted around the ends of the valve, enters the cylinder through ports as shown. The main or distribution valve admits steam and opens and closes the exhaust in exactly the same way as a plain slide valve. The cut-off, however, is effected by means of a separate valve, *D D*, called the riding cut-off or expansion valve. As will be seen, it consists of two blocks containing nuts, which are carried on a right- and left-hand screwed spindle *M*. By turning the wheel *L* on the outside of the steam chest the distance between the blocks may be adjusted, and in this way the cut-off or degree of expansion varied to suit the conditions. The main and expansion valves are operated by separate eccentrics, and if the engine is to be reversible the main valve may be actuated by a link motion. The wheel *L* may be operated either by hand, or it may be connected with a centrifugal governor in such a way that the cut-off will be regulated automatically. The principal objection to this type of valve is the excessive loss in friction of the valves against their seats.

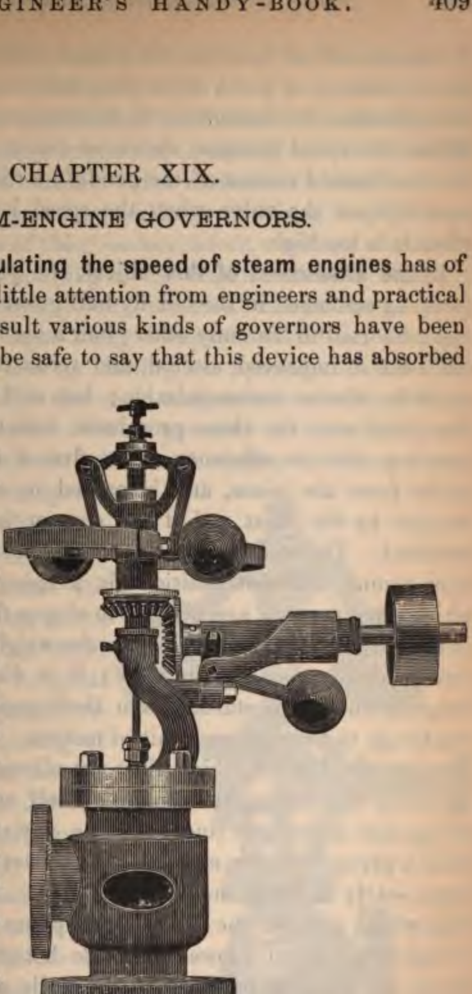
Separate Valves for Admission and Exhaust.

The valves and valve gears which have been described above are all open to the great objection that the steam enters the cylinder through the same ports which have just been cooled off by the exhaust. The result of this is that, especially where the passages are long, a very considerable amount of energy is lost by condensation in the ports. For this reason, and also in order to effect a more advantageous distribution of steam, separate valves are now frequently used for the steam and the exhaust. Engines of this kind are known as *Four Valve Engines*, and their increased economy in the use of steam amply justifies the additional complication introduced by the separate valves. *Corliss Engines*, with their semi-rotary valves, belong to this class. The valve gears of this class of engines will be described in Chapter XX.

CHAPTER XIX.

STEAM-ENGINE GOVERNORS.

The subject of regulating the speed of steam engines has of te years received no little attention from engineers and practical ventors, and as a result various kinds of governors have been troduced. It would be safe to say that this device has absorbed ore thought, and reived more attention the part of mechan, than any other adnct of the steam-enne. In the first govnors the principal rt of the apparatus nsisted of a pair of lls revolving round ertical axis or spine driven by a train mechanism, genery mitre-gears, which uses their angular veity of revolution to ar a fixed ratio to the locity of the prime ver. The rods of e pendulums place emselves at an an with the vertical is, so that the common height of the pendulums is that corre*nding to the number of* turns in a second. The regulator must



The Waters Governor.

steam, instead of being admitted around the ends of the valve, enters the cylinder through ports as shown. The main or distribution valve admits steam and opens and closes the exhaust in exactly the same way as a plain slide valve. The cut-off, however, is effected by means of a separate valve, *D D*, called the riding cut-off or expansion valve. As will be seen, it consists of two blocks containing nuts, which are carried on a right- and left-hand screwed spindle *M*. By turning the wheel *L* on the outside of the steam chest the distance between the blocks may be adjusted, and in this way the cut-off or degree of expansion varied to suit the conditions. The main and expansion valves are operated by separate eccentrics, and if the engine is to be reversible the main valve may be actuated by a link motion. The wheel *L* may be operated either by hand, or it may be connected with a centrifugal governor in such a way that the cut-off will be regulated automatically. The principal objection to this type of valve is the excessive loss in friction of the valves against their seats.

Separate Valves for Admission and Exhaust.

The valves and valve gears which have been described above are all open to the great objection that the steam enters the cylinder through the same ports which have just been cooled off by the exhaust. The result of this is that, especially where the passages are long, a very considerable amount of energy is lost by condensation in the ports. For this reason, and also in order to effect a more advantageous distribution of steam, separate valves are now frequently used for the steam and the exhaust. Engines of this kind are known as *Four Valve Engines*, and their increased economy in the use of steam amply justifies the additional complication introduced by the separate valves. *Corliss Engines*, with their semi-rotary valves, belong to this class. The

s of this class of engines will be described in Chapter XX.

tances that necessitate the use of openings for the passage of steam that are too small in area, so much so that the useful ts of the steam are considerably diminished. On this depends ll repute of throttling engines as compared with those which late by governor controlled valve motions or variable cut-off. ie valve of a governor has too large openings, it will, owing ie unsteady action of the governor, admit too large a quantity team, and cause a jumping of the engine; then, in trying to off this extra amount, it shuts it all off; in fact, the governor not fix it exactly right, being incapable of delicate changes. s difficulty is best met by making the openings in the valve peculiar shape, so that they open and close in a ratio different n that of the governor. With a governor that would run per- ly up to theory, and be steady and capable of taking a posi- n in keeping with the speed, l not leaving it without a inge in speed, a very large a might be used, and the ful effects of the steam would t be impaired, neither would ere exist a necessity for great anges in speed to get the re- ired opening and closing of e valve. The extra amount steam required to drive a avy addition of load on an gine is surprisingly small, ovided that the engine can get e steam at the very instant the id is applied, and before the omentum of the machinery comes much reduced; but the engine once get below *ed the cir* [redacted] will th-

The Shive Governor.

out any load, the engine would take some time to come to speed.

The third defect in governors on throttling engines is that the spindle or valve-stem has of necessity to pass through steam-tight, packing- or stuffing-boxes, which have to be screwed up to prevent leakage, without any guide save the judgment of the engineer, which increases the friction and interferes with the free action of the governor. There is also the friction on the governor-valve necessary to overcome the power required to move the valve-stem through all its bearings, stuffing-boxes, guides, etc., under the pressure of steam. Were it possible to construct a governor for throttling engines which would approach in practice what theory would demonstrate, the fly-ball or centrifugal governor would be a perfect regulator; but this appears, according to mechanical laws, to be impossible. By the use of isochronous governors, which would not admit of any variation of speed, but would be in equilibrium at any speed, whether the balls were up or down, or in any other position, the defects of the common governor were supposed to be obviated; but it was found by experience that power and stability were necessary, and isochronism in its strict sense unattainable.

In the fly-wheel governor these defects have been partially eliminated. True, there is still a certain amount of friction in the joints, but this can be made insignificant by proper lubrication. On the other hand, there are no packing or stuffing boxes to stick, as in the case of the throttling governor, and, above all, the full pressure of the steam acts upon the piston at the beginning of each stroke, independent of the load on the engine, and consequently there is no energy lost in expanding the steam before it enters the cylinder. The action of the throttle valve in reducing the pressure of the steam is simply an expansion without any useful return, and consequently a waste of energy equivalent to the heat which was necessary to raise the steam from the pressure at which it is used to the boiler pressure. For example, the en- r contained in one pound of dry steam at 100 pounds pressure with the aid of a well-designed governor of this type, it is possible to regulate the engine to within one per cent. of its rated speed when the full load is thrown on or off.

The economy of a good governor has rarely been appreciated by owners of steam-engines and steam-users. Experience has shown the speed best adapted for each and every process in the manufacturing and mechanical arts, and the governor that fails to meet all the varied requirements of each process is of no value in an economical point of view. Every stroke which an engine makes below its regular speed increases the cost of production, and every stroke above it is a waste of steam, and consequently of fuel. If an engine is geared to run at 80 revolutions per minute, when a heavy piece of machinery is thrown off, the governor admits of an increase of speed of from 10 to 15 revolutions per minute. This incurs a waste of power, and consequently a waste of from 12 to 20 per cent. of fuel. On the other hand, when a heavy piece of machinery is thrown on, the governor allows the engine to lag behind its regular speed by from 10 to 15 strokes per minute; this increases the cost of production. If a governor is unreliable, it is worthless; if reliable, its first cost is merely a nominal consideration. There are many processes, such as milling, weaving delicate fabrics, printing from small type, or the very accurate turning of fine material, where a good governor is of immense value.

Governors are sometimes attached to marine engines for the purpose of equalizing the revolutions in heavy sea-ways, and preventing the engines from racing, which is caused by an insufficient immersion of the paddle-wheels or propellers, and which may be ascribed either to the lightness of the load or the heavy swell of the sea. But from whatever cause racing may occur, it is always attended with danger, as the undue strain to which the machinery is subjected is liable to result in a breakdown.

Governors should be kept perfectly clean and free from accumulations induced by the use of inferior oil, as such gummy substances have a tendency to interfere with the easy movement the different parts. Many first-class regulators have been condemned as not being capable of controlling the engine at a uniform speed, when all that was required was a good cleaning.

Governor-spindles working through stuffing-boxes should be frequently and carefully packed, as, when the packing becomes old and dry, if screwed up to prevent leakage, it interferes with the free action of the governor.

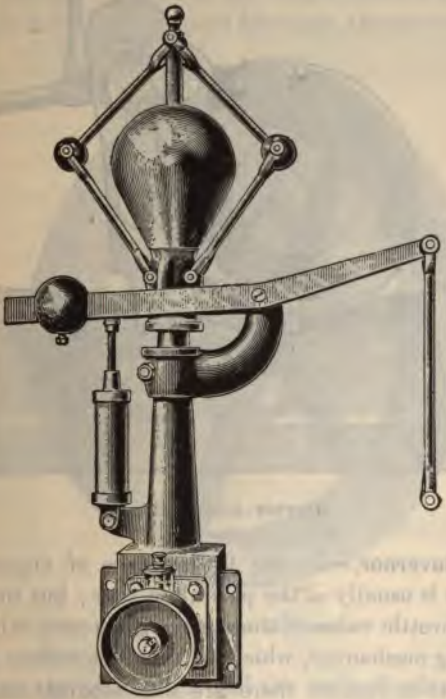
Rules for calculating the size of pulleys for governors.—*To find the diameter of the governor shaft-pulley.* Multiply the number of the revolutions of the engine by the diameter of the engine shaft-pulley, and divide the product by the number of revolutions of the governor.

To find the diameter of the engine shaft-pulley.—Multiply the number of revolutions of the governor by the diameter of the governor shaft-pulley, and divide the product by the number of revolutions of the engine.

Description of Different Governors.

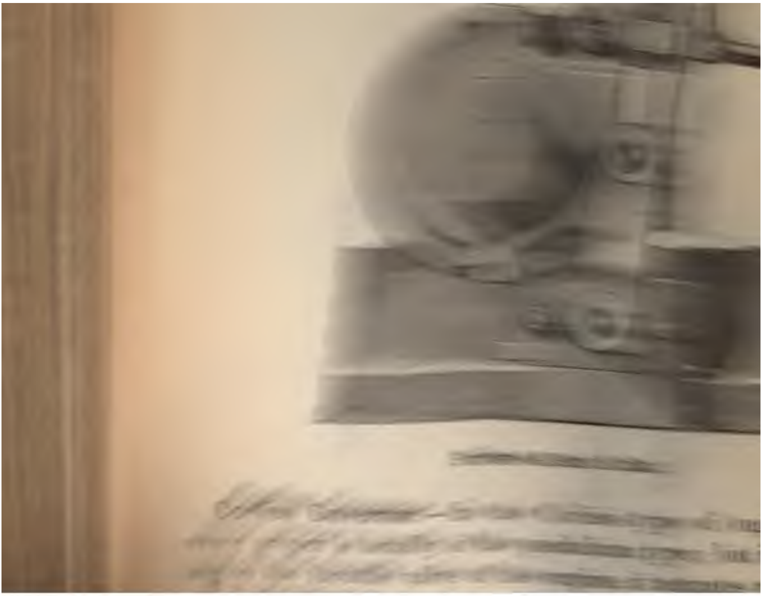
Throttling governors are those in which the centrifugal force of a pair of weights acts upon the throttle valve of the engine. There are hundreds of types in use, but they differ only in the details of construction, the principle in all being the same as that employed by James Watt in the early days of the steam engine. Waters' Governor, illustrated on page 409, is a fair representative of this type. In this the springs shown are used to aid the force of gravity in resisting the centrifugal force of the balls—in other respects this type requires no further explanation.

Porter-Allen Governor.—In this type of governor the regulation of the speed is effected by altering the position of the block in a slotted link attached to the eccentric. Both the governor proper and the eccentric with its link are illustrated in the accompanying cuts. The former, as will be observed, is a loaded pendulum governor, and, though it was first designed in connection with the Porter-Allen engine, it is now frequently used in connection with Corliss gears, and also as a throttling governor on de-valve engines. One of its chief advantages is that the ness is more nearly constant with varying speeds than inary forms of pendulum or even fly-wheel governors. tical link shown on the right of the first cut moves up and



Porter-Allen Governor.

the speed varies, and as this is attached to the link shown in the second cut, the travel of the valve and e cut-off are varied with the load on the engine. The link l in one piece with the eccentric strap, and is pivoted as *The operation of this* governor is very simple, and the



e **Straight-line engine governor,** illustrated in the accom-
ng cut, consists of a single weight carried on one end of an arm
is pivoted in the middle to one of the arms of the fly-wheel.
tal strap connects one side of the arm to the end of a flat steel
g, while the other side of the arm is linked to the eccentric
ch a manner that when the weight travels away from the
which it does as the speed increases, the eccentric is shifted,

Straight-line Governor.

ing both the eccentricity and the angle of advance, and thus
lates the cut-off to suit the load on the engine. The gov-
r is adjusted by altering the weight of the ball, which is cast
w and weighted with lead shot. This is one of the simplest of
lder types of fly-wheel governors and it has proved a very
ssful one.

he **Ball-engine governor** is similar to the straight-line governor
is respect, that both the angle of advance and the eccentricity

[illegible]

Ball Governor.

gs, and in addition a dash pot attached to one
. The eccentric sheave, 1, is bolted to the hub
ile the strap is made in two parts, 2 and 3, the

being a disc which carries a crank-pin, 4, to which the valve-rod is attached. The weights are connected by links to the eccentric straps, so that when the weights overcome the tension of the springs and move away from the shaft, the strap and disc are rotated around the sheave, giving the pin, 4, a motion in the arc of a circle whose centre is the centre of the eccentric sheave, and in this way the desired variations of the eccentricity and angle of advance are obtained. The supplemental spring and dash pot are used to provide a "double elastic cushion" for checking any undue movement on the part of the regulating mechanism and insuring absolute control of the speed under the greatest variation of load. The spring is capable of either tension or compression, so that a motion of the weights in either direction immediately puts it under strain, which is at once relieved by the dash pot. Hence the device exerts only a steadying influence on the speed of the engine.

The Buckeye Engine Governor, illustrated in the next cut, is one of the oldest forms of shaft governors. In the Buckeye Engine two valves are used, a main or distribution valve actuated by a fixed eccentric and a cut-off, or an expansion valve actuated by the governor mechanism. By referring to the cut, it will be observed that the governor differs from those hitherto described in this essential feature: that the angle of advance only is varied by the centrifugal action of the weights, this being all that is necessary. In the case of a single valve operated by a shaft governor, if the angle of advance only is altered, the cut-off may be varied to suit the conditions of load, but in that case the lead will also vary in such a way that it would increase as the cut-off decreased. If, on the other hand, the regulation is performed by varying the eccentricity alone, the reverse would take place, and hence for shaft regulation in connection with a single valve it becomes necessary to vary the eccentricity and angle of advance simultaneously. This is not the case where a separate distribution and expansion valve are used as in the Buckeye *Engine, because the admission* and exhaust closure are effected

CHAPTER XX.

DESCRIPTIONS OF STEAM

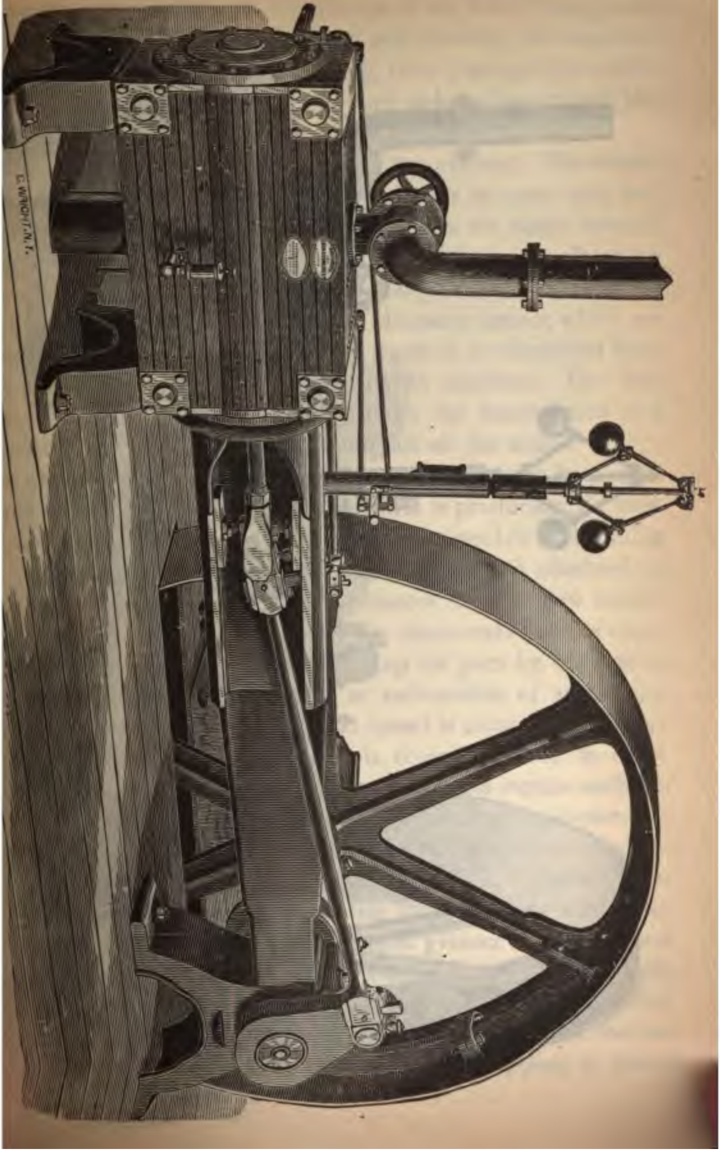
Corliss Engines.

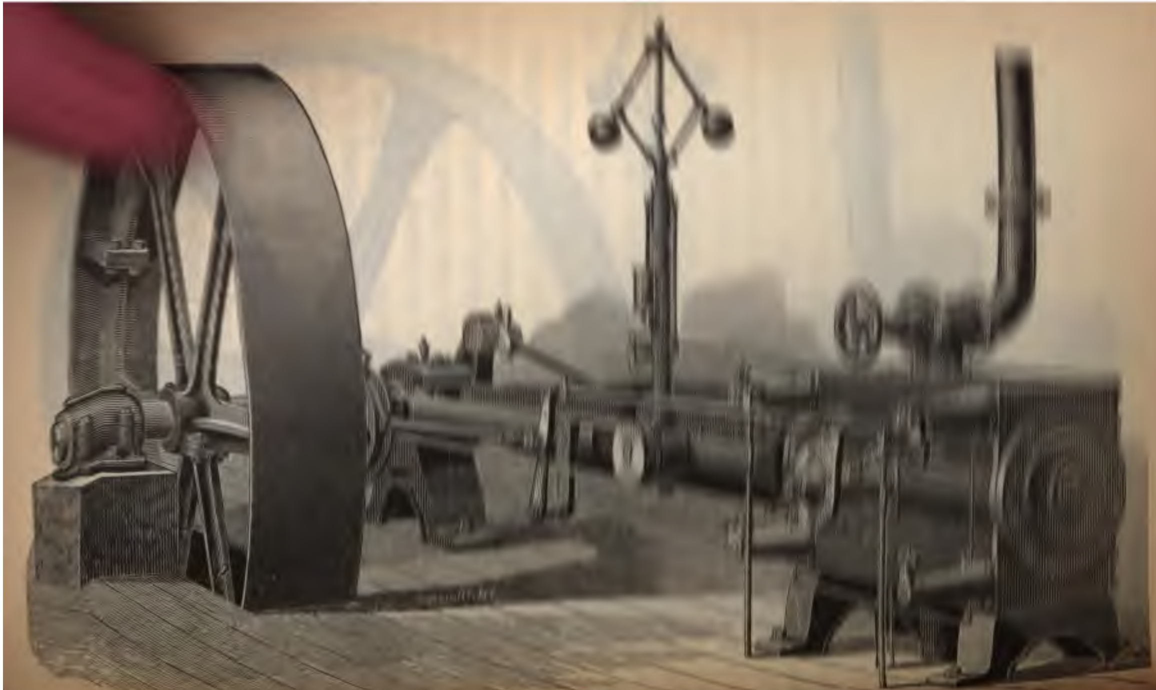
To this class belong all engines, whether
condensing or non-condensing, horizontal
the distribution of steam is effected by the
known Corliss gear. Briefly, this type of
four separate valves of the semi-rotary typ
and cutting off the steam and two for the
being controlled by a special mechanism in
ports are opened to steam by a fixed eccent
point in the stroke, determined by a pendu
valves are released by the eccentric and quic
of springs or dash pots. The exhaust valve
by the same eccentric, have a fixed point of
The engine is therefore an automatic cut-off en
of the method by which the cut-off is controlle
in the distribution of steam are effected whic
in many respects to most other engines of th
type. There being separate ports for admissi
fresh steam entering the cylinder does not c
surfaces which have been previously cooled
furthermore, the valves being very close to t
are extremely short, and hence the condens
passages is reduced to a minimum. The val
formed of portions of cylinders oscillating on
responding form, and they are so arranged that
steam forces them against their seats only when
—when open they have practically no fric
Hence the power re [illegible] *to the valves.*

ase of slide valves, is practically *nil* in the Corliss type, the same time a tight joint between the valve and its seat ed. The effect of the springs or dash pots is to secure a ick closure of the ports, and hence the indicator diagram perfectly clean, sharp cut-off, instead of a rounded one, as ase of plain slide valves. Finally, the admission, opening, ing of the exhaust being independent of the governor, the ype of valve-gear has the advantage over automatic cut- shaft regulation, that the lead and compression remain under all conditions of load, the entire regulation being varying the point of cut-off.

e are innumerable different styles of Corliss Engines, which are excellent, and the economy in the use of steam close regulation which has been attained certainly make ss of engines very desirable for a great many purposes. to the method of effecting the cut-off, they are, however, as to speed of rotation, and it is consequently customary e the advantages which are to be derived from high-pis- eds by making the stroke very long. Of course, this them unfit for direct coupling to electrical and other ry which needs to be run at a comparatively great num- evolutions per minute, but there are many other uses to e Corliss engine can be put with advantage. It would lead far if we were to attempt to describe all of the different Corliss Engines which have proved successful, and besides involve a great deal of repetition. Among the best types the following are worthy of especial mention: ls-Corliss, built by the Edward P. Allis Co. of Milwaukee, e Hamilton-Corliss, built by The Hooven, Owens & Rent- o. of Hamilton, O., the Wetherill-Corliss, built by Robt. ill & Co. of Chester, Pa., the Atlas-Corliss, built by the ngine Works of Indianapolis, Ind., and the Harris-Corliss, the Wm. A. Harris Steam Engine Co. of Providence, The last will be more fully described as a representative *lass of engines.*

[illegible] well proportioned, rigidity and
[illegible] where the greatest longitudi
[illegible] the cylinder-flange and the
To th [illegible] these points the frame, w
conden [illegible] deep and strongly ribbed,
the dis [illegible] stiffness than could be obtaine
known [illegible] same amount of material. T
four se [illegible] the frame. The main pillow-
and cu [illegible] the feet well spread out; an
being [illegible] rest upon supports the entire
ports [illegible] are only slightly elevated ab
point [illegible] attendant to reach every part wi
valves [illegible] and chests are neatly lagged in
of sprin
by the [illegible] packing is of the most improved kind,
The eng [illegible] steam-tight under all circum
of the [illegible] of German silver spiral springs,
in the [illegible] arising from the cylinder becoming
in many [illegible] liability to become cut or fluted, i
type. [illegible] too tight. Besides, the piston-
fresh [illegible] centre of the cylinder. The spring


C. WRIGHT, N.Y.



ing-ring is carried by the steam over to the side of the groove
e junk-ring, making a joint there, and allowing the steam to
down and under the packing-ring, thus placing it in equili-
m; then all that is required is a very light spring to hold the
ing in contact with the cylinder.

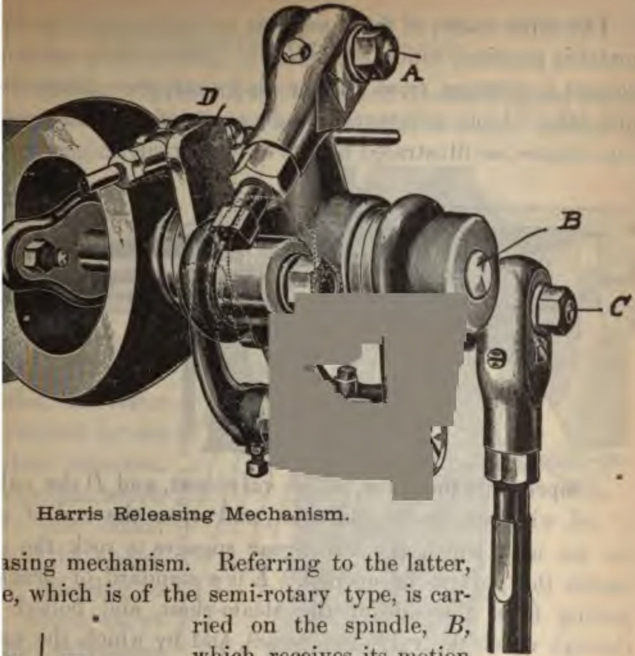
here are four valves — two steam and two exhaust. The steam-
es are located on the top of the cylinder at each end, and
directly into the clearance, which obviates the waste induced
e use of long passages. The exhaust-valves are placed in
xhaust-chest on the lower side of the cylinder, and, as in the
f the steam-valves, open into the clearance spaces, which ar-
ment facilitates the escape of the water of condensation from
ylinder, and obviates the liability to accident. The four
s are moved by one eccentric through the intervention of a
plate; the same valves admit and cut off the steam.

e steam-valve in these engines commences to open its port at
d of the cylinder when the eccentric is producing its most
movement, and, as the motion of the eccentric is declining
ds the end of the throw, an increasing speed is obtained by
s of the wrist-plate, which compensates for the slow motion
e eccentric. At the same time the steam-valve at the oppo-
nd of the cylinder commences to lap its port by the motion
e eccentric, but by a reverse or subtraction of speed pro-
l by the same wrist-plate, which speed is constantly decreas-
ill the throw of the eccentric is completed. Or in other
s, the lapping and opening of the steam-ports require each the
amount of throw of the eccentric, producing, for instance, a
f ½ an inch at one end of the cylinder, while the opposite
has an opening of one inch and one-eighth. The exhaust-
s are moved by the same eccentric and the same wrist-plate
e spoken of, but they have a much greater travel for the
se of ridding the engine of the exhaust steam easily through
xhaust-ports, which are as long and twice as wide as the
-ports, and therefore back pressure on the piston of the en-
is *avoided. The rapid opening* and slow lapping of the ex-

[illegible] as in the case of the [illegible] is greater on the opening [illegible] steam-port, in order [illegible]

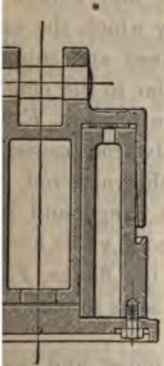
The variations of load upon these engines are communicated to the [illegible] by the governor, the valves being moved by a lever [illegible] from it, yet subjected to its regulation. The governor in no case performs any work, and only indicates the changes required in the levers which move the valves, and needs only sufficient force to move a small stop. Its movement is [illegible] with the least possible friction; the stop presents hardly any resistance to the governor, except at the very instant when it is in actual contact with the lever constituting its fulcrum. This momentary resistance by the bearing of the lever on the stop as a fulcrum occupies so small a space of time that, compared with the period during which the governor is left free to move the stop, it is practically nothing. As a precautionary measure, a safety stop is connected with the valve-gear, so that in case the governor should become inoperative, and should fail to act, the steam-valves become unhooked, and cannot open, and, as a universal result, the engine is stopped, although the valve in the steam-pipe may be wide open. The valves are circular, and oscillate on fixed bearings in the front and back bonnets. The valve-stems have flat blades, which extend the whole length of the valves in the steam-chest, and to which levers are keyed for the purpose of giving them motion. The valves are fitted in such a manner as to be capable of adjusting themselves to their seats, as their faces and seats become warm. Any one of them can be adjusted independent of the other, and can be removed from the valve-chests by unscrewing four bolts, and withdrawing a key at the point at which it is attached to the lever. The valve-gear of these engines may be worked by hand, even under extreme steam

[illegible]tomatic cut-off feature will be understood from an exam- [illegible] the accompanying cut, which shows an enlarged view of



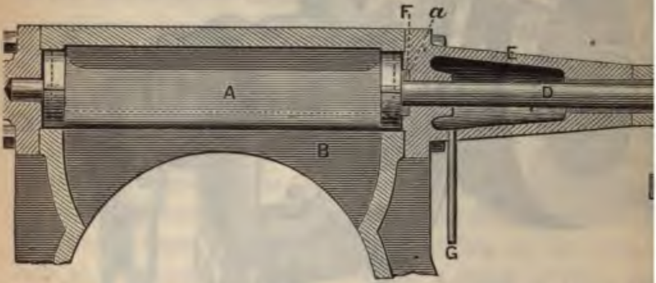
Harris Releasing Mechanism.

sing mechanism. Referring to the latter, e, which is of the semi-rotary type, is carried on the spindle, *B*, which receives its motion from the wrist-plate by means of a rod which is attached at the point *A*. The motion of the governor is transmitted to the releasing mechanism by means of the rods shown at *D*, and this motion is used to effect the release of the valve from the wrist-plate. As soon as it is released the dash pot, which is attached to the bottom of the rod *C*, quickly pulls down and thus closes the valve. It will be observed that there are no springs used in anism, the closing being effected entirely by means of the , which is very simple and will be understood from the *ying sectional cut.*



ash pot.

The valve-stems of these engines are packed with an im metallic packing, which is claimed to possess many advant respect to freedom from friction and wear, over hemp, cot any other fibrous substance, for the stems of oscillating or ing engines, as illustrated by the following cut:



A **represents the valve,** *B* the valve-seat, and *D* the valv or rod, which is outside the chest, and upon the end of wh the toe with which the valve-gear engages to rock the va enable the port to be opened. *E* is a standard or bracke jecting from the side of the steam-chest, and bolted th through which the valve-rod passes, and by which the valv and the valve connected with it, are sustained and suppor their proper relation, all of which is familiar to the constr of steam-engines. At the inner end of the bracket, *E*, an centric with the hole through which the valve-rod passes, a is cut. A collar, *F*, is then shrunk upon the valve-rod, or wise tightly fitted thereto, so as to make a flange, and is off to face and fit the recess when the valve-rod, valve, and b are in their proper relation. The face of the flange, *F*, an seat of the recess, *a*, should also be round, so as to make a tight joint.

The Harris-Corliss Engine is one of the oldest and best types of Corliss Engines, and besides the distinctive features original Corliss engine, it contains many improvements ls of construction. It is built by the William A. Engine Co. of Providence, R. I.

The Improved Greene Engine.

illustration represents the Improved Greene Engine, which ıe automatic cut-off type, and is similar in many respects to ırliss engine, but ys flat slide instead of the otary type. The motion consists ır separate flat valves, two for eam and two for haust, the latter operated by an endent eccentric. ıechanism which es the steam will be under- by referring to ıt, which shows team valve-gear to a larger scale. is *J* represents a g bar which re- a reciprocating n from a separate tric by means of ker arm, as shown front view of the e. Through this g bar extend two ts, *G G*, attached e bottom to a plate *L*, which is *n position by means of* the rod *F* attached to the governor.

Front View of the Improved Greene Automatic Cut-off Engine.

[illegible] pendulum ty
[illegible] as the speed increases, it

[illegible]

is lowered, and vi [illegible] diagram. E [illegible] the steam and E. If the valv to which are attac arms C C of th levers A A. B sockets which ena toes K K to rise operation of the val may now be expla follows: As the slid D moves, say, in th tion of the arrow, the knob of the tappet G engage the and opens the valve attached to the stem D to steam. Ev this will take place at exactly the same point in each str dependent of the position of the governor balls; hence the constant. As the motion continues the toe will be rele some point in the stroke, depending on the height of the G, or, in other words, on the position of the governor When it is released the toe drops into its original positi closes the valve quickly. In the meantime the other toe been forced into the socket H as shown in the cut, from position it drops by virtue of its own weight when the tap has moved far enough to the right. On the reverse stro course, the other toe is brought into action, and the valve opposite side of the cylinder is opened and closed in a s

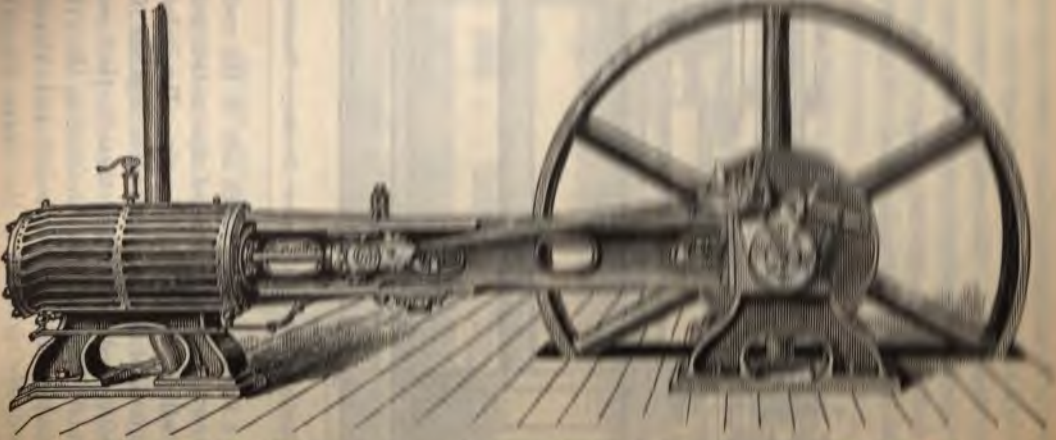
The amount of opening of the steam valves an h they are closed are determined by the height h, as has already been stated, are under cont

The governor has a safety-stop motion, so arr he governor belt run off or the governor stop ssion of steam to the cylinder would be pre other respects the engine offers no special features. It has en in use for many years, and has proved very successful under nditions similar to those which render the Corliss type of en- nes desirable. It is built by the Providence Steam Engine ompany, of Providence, R. I.

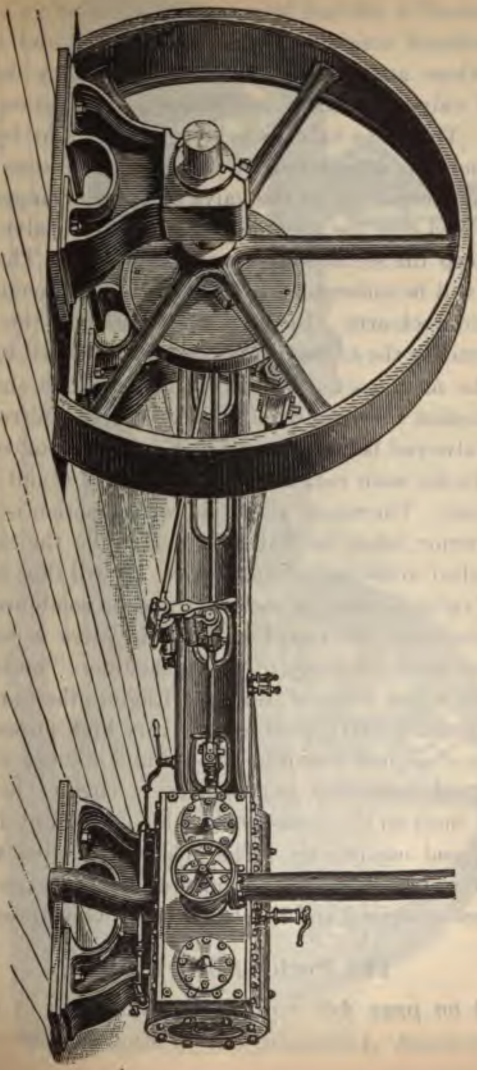
The High-speed Automatic Cut-off Engine.

The class of engines known as the high-speed automatic cut- f type, which now comprises a large variety of designs, owes its evelopment largely to the unusual growth of electric lighting om isolated plants, and electric railway service. Engines of this ass, while applicable under various conditions, are designed imarily to meet the requirements which the nature of this ser- ice imposes. An engine used for driving a lighting or power enerator is constantly subjected to sudden, and often very con- iderable, variations of load, and under these circumstances must aintain a constant or nearly constant speed. It must also be conomical in the use of steam, run at a comparatively high otary speed, and be simple in design. These, briefly, are the onditions which have evolved the high-speed automatic cut-off ngine, a few of the leading types of which will now be described. n general, it may be said that these engines, while not so eco- omical in the use of steam as the Corliss type, are vastly better han the old throttling engines. They consume from thirty to hirty-five pounds of steam per horse-power hour when operating nder a boiler pressure of eighty pounds, and cutting off at one- uarter stroke, while, when compounded, which is frequently ne, their steam consumption is about twenty-five pounds. The gulation of the speed, which can be effected to a great nicety, the riation being often less than two per cent. from the normal en the full load is suddenly thrown on or off, is usually by ans of a single valve and shaft governor, although this arrange- nt is modified in some instances, as in the "Four Valve," uckeye," and "Porter-Allen" engines.

While there are a great many different designs of engines of



Front View of the Buckeye Automatic High-Pressure Cut-Off Engine.



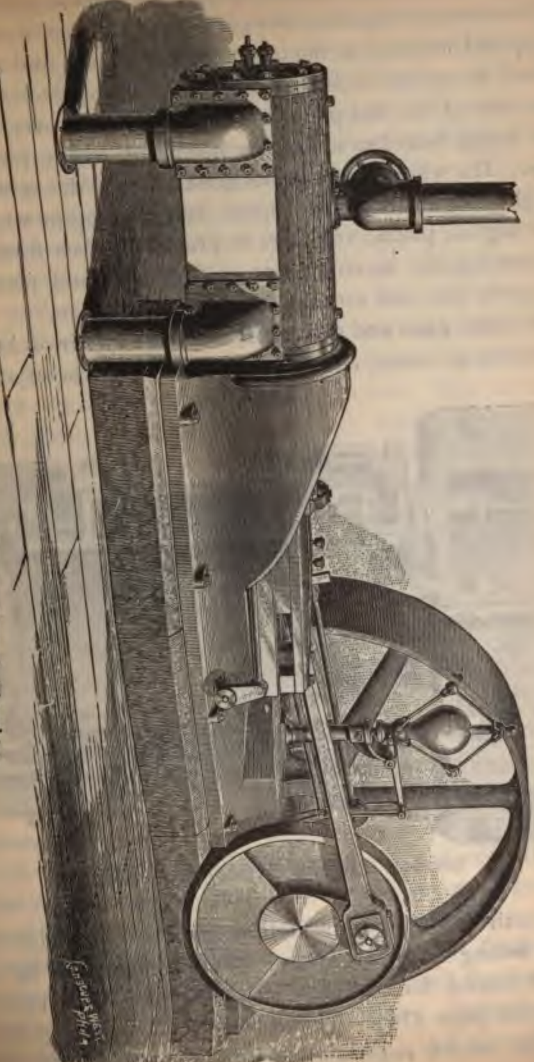
Back View of the Buckeye Automatic High-Pressure Cut-Off Engine.

through the space *G*, outside of the valve, and leaving by the pipe *K*. The cut-off is effected by means of a cut-off valve operated by the combined action of the main eccentric and the cut-off eccentric, whose angular advance is determined by the governor. The cut-off valve consists of two plates, *c c*, placed on a common valve-rod. The main valve is held against its seat by the steam pressure, and this is relieved by the balance pistons and relief chambers or recesses cut in the valve seat, the arrangement being so proportioned that the average pressure on the valve is just sufficient to keep the surfaces in a good condition. The motion of the valves will be understood by referring to the section through the bed and rock-arm. In this cut, *a* represents the rock-shaft, which vibrates in the adjustable bearing *b b*, attached to the engine frame. The main rock-arm *A* is attached to this shaft and receives its motion from the fixed main eccentric referred to above, the main valve-rod being attached at *F*. The cut-off rock-shaft *B* is carried in the main rock-arm, and has arms *C* and *D* attached at either end. The cut-off eccentric, whose motion is determined by the governor, takes hold at the pin *E*, while the cut-off valve-rod is attached to the end of the arm *D*. It will thus be seen that the cut-off valve derives its motion from the combined action of the two eccentrics. Its travel on the main valve is constant, and hence there is no tendency to "wear shoulders" on its seat. In many of the newer forms of Buckeye Engines the flat valves are replaced by piston valves for use with very high pressures.

The type of engines shown on pp. 438 and 439 are simple, slow-[illegible] speed horizontal, non-condensing engines, but they can be, and are built on the same general lines to run at high speeds, compound and condensing. The Buckeye Engine was one of the first in which shaft regulation was used; its governor has already been described and illustrated (see "Governors," p. 422).

The Porter-Allen Engine.

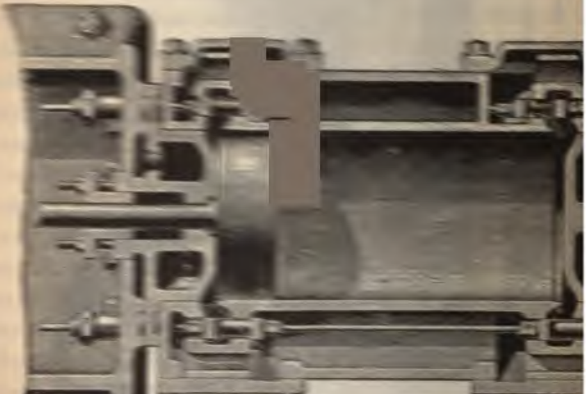
The cut on page 441 represents a front view of the Porter-Allen High-speed [illegible] Cut-off Engine, showing the



The Porter-Allen High-Speed Engine.

plate, governor, crank, guides, steam and exhaust piping, will be observed that the bed-plate is of the box form, the top and widened at the base, strongly ribbed, and with internal flange at the base. The main journal-boxes are at one end of the bed-plate, while the cylinder overhang other, being bolted to a circular head cast in one piece frame. The whole frame is designed to resist the strains by high pressure and high speed, and the engine when at the highest piston velocities is practically free from thus keeping the moving parts in alignment and permi bearings to run cool without excessive lubrication.

The valve gear and governor, invented by Mr. John are worthy of notice, as they constitute a system of ste



Section through Cylinder and Valves.

bution entirely different from that employed in other engines belonging to this class. The governor with its and link motion have already been fully described und rs" (see page 416). The valves are illustrated in th ng cut, which represents a longitudinal section th cylinder. There are four valves, two each for steam and exhaust. Each of the steam-valves is operated by a separate rod, while the two exhaust-valves are coupled to a common rod. The motions of the valves will be more fully described below. All of the valves, as will be observed from the arrows in the cut, open, simultaneously, four passages to the admission or release of the steam. They consist of flat plates sliding between their seats, and "pressure-plates" which relieve the steam pressure, producing a balanced valve. This feature, together with the fact that the rods take hold in the centre line of the valve, insures minimum and uniform wear both on the valve and seats. The exhaust, as already stated, is effected by means of independent valves and passages, and therefore the passages through which the steam enters are never chilled by the exhaust. The economy in the use of steam which results from this arrangement and the attainment of a variable cut-off without any change in the release and compression, constitute the principal advantages of the "four valve" over the "single valve" type of engines. In the sectional cut the piston is shown at the beginning of its stroke, and the steam-valve at the lower crank end has just opened the ports to admission, while the one at the head end is at the extremity of its lap. The exhaust-port at the head end is full open. The pressure-plates at the back of each valve are, as will be observed, recessed opposite the ports, and these plates are so arranged that they will not only relieve the pressure acting upon the backs of the valves, but will also act as relief valves in case there should be any water in the cylinder. The steam pressure always acts on these plates, but whenever the pressure in the cylinder exceeds that in the steam-chest, the plates are moved back until they come in contact with the cover, thus allowing the excess of pressure to be relieved before it can do any harm in the cylinder.

The motion of the valves, will be understood from the cuts showing the eccentric and link on page 417, and the accompanying elevation showing the valve connections. Referring to the latter, *the rod shown partially* at the left is the one which at its other end is attached to the link-block, the position of which in the link is, as will be remembered, under the control of the governor. This rod imparts its motion to an arm, as shown, which motion is communicated by a rock-shaft to two other arms, to which the steam-valve rods are attached. These arms are set at different angles on the rock-shaft, so that one is in a nearly vertical position and moving its valve with the greatest possible velocity, when the other is almost horizontal and hence imparting practically no motion at all to its valve. The object of this arrangement is clear. The vertical positions of the rock-arms correspond to the opening positions of the valves, which is hence accomplished quickly, while the horizontal positions, correspond-

Elevation Showing Valve Connections.

ing to those in which the valves are closed, reduce the motion of the valve practically to an interval of rest. By this arrangement, called a differential valve-movement, the valves are quickly and fully opened, while the period during which they are closed is obtained by a very slow motion, instead of by moving them a greater distance at a uniform speed. The exhaust-valve rod is attached to a fixed point at the top of the slotted link, so that the opening and closing of the exhaust-valves remain invariable. The admission as well as the cut-off being under control of the g [illegible] there is a slight difference in lead for different loads [illegible] at all times a difference in lead at either end of the [illegible] tter being proportional to the difference in the piston [illegible] ised by the angularity of the connecting-rod.

[illegible] **er-Allen** was one of the first successful high-gines. It is built by the Southwark Foundry and Machine Co. Philadelphia, in sizes ranging from 45 to 2500 horse-power, d it has met with great success, not only on account of the rits of its design, but also, largely, on account of the high class workmanship embodied in its construction. Its speed regula- n is very close, and it is therefore well adapted for electric hting service.

The Straight Line Engine.

The Straight Line Engine was one of the first of the high-speed gines in which a single slide valve was used, in connection with haft-governor, to regulate the speed under varying conditions load by altering the point of cut-off, but it is now built both a single- and double-valve engine. The cut on page 447 repre- ts the single-valve type, and examination of this at once sug- ts the derivation of its name. Professor Sweet, the designer of s engine, claims that all strains go in straight lines, and he has de the plan of the engine to conform to this idea. All bound- lines are made straight, ending in curves to avoid corners, and cross-sections are rectangular with the corners rounded. The ving arms are wide and thin, with the greatest dimension in direction of the greatest strain. The frame, cylinder, and am-chest are all cast in one piece, the whole being supported the foundation at three points, which has the great advantage at the engine remains in perfect alignment, although it is some- at more expensive to build than it would be if the cylinders re cast separately and bolted to the frame. For re-boring the linders a portable arrangement for mounting on the engine has en devised which makes the process of re-boring a very simple e.

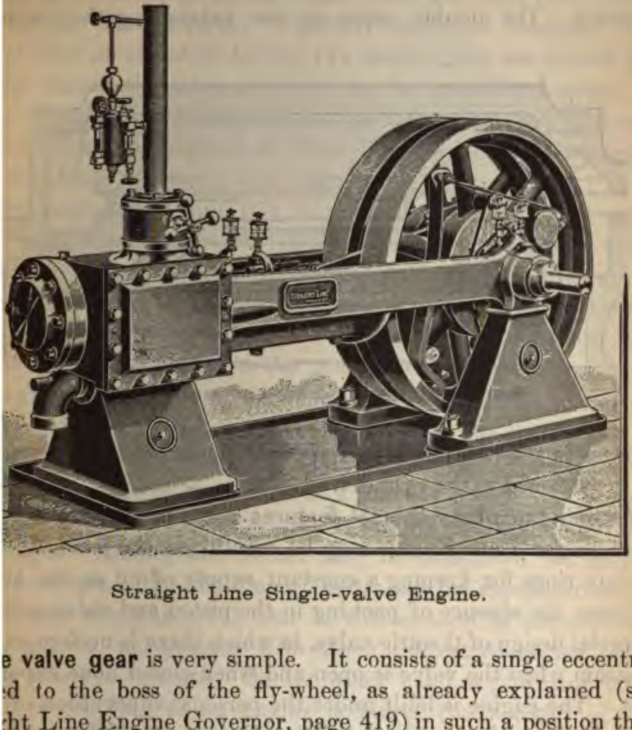
The piston used in this type of engine contains several novel atures. In the smaller engines, the packing consists of ordinary ring rings, but in those of larger diameter than 10″ a different rangement is used. This style of piston, which is illustrated in e cuts, has so-called "limited expansion" packing-rings, which

[illegible] the cylinder, and sprung
[illegible] They are then pinned in that position
[illegible] in the cylinder. The pin-
[illegible] the rings are free to compress
[illegible] they can easily and neither

Pop Piston.

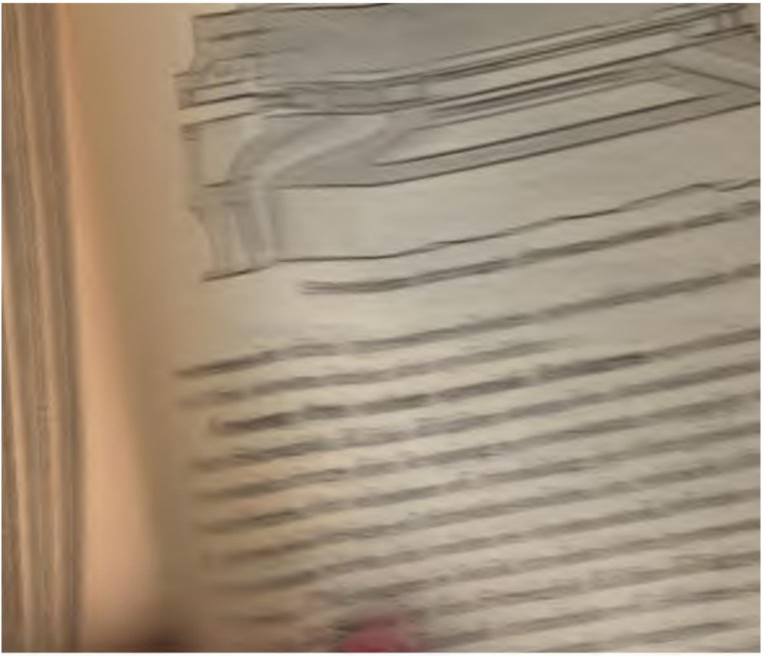
ylinder. The above cut shows also the pop featu
of forcing taper plugs into the piston from wi
such a way that it will require a pressure of 2
re inch to force them into the piston. If the
filled with water, these plugs will be driven
ereasing [illegible] ance and allowing the engine
[illegible] al course of e
ould b [illegible]

lugs are again forced out, restoring the piston to its normal ition. In the mean time it has been running with an increased ance volume and the slight loss incident thereto.



Straight Line Single-valve Engine.

e valve gear is very simple. It consists of a single eccentric d to the boss of the fly-wheel, as already explained (see ht Line Engine Governor, page 419) in such a position that able lead is had. The eccentric connects directly by means od to the valve. The slides for the valve-rod have long ng surfaces and are provided with an adjustment for taking e wear. The valve, which is illustrated in the accompany- ctional cut, is a thin rectangular plate with five openings. ressure on the back is relieved by a pressure-plate between and its seat *the valve slides.* The pressure-plate has open- *n it opposite the ports* and rests against distance-pieces in



ugle valve. It differs from the latter mainly in the design alve, which is of the piston type, which the builders of ine were among the first to adopt. The Armington & ston Valve has already been fully described (see Valves, 9). The governor originally employed consisted of a orm of eccentric having two sheaves, the one placed like around the other, operated by the centrifugal action of f weights. This governor has been discarded, however, of the Armington & Sims Engines are now equipped Rites Governor (see page 422).

engines are built in a large variety of sizes and designs, g horizontal, vertical, simple, tandem-compound and cross-id. They have been used very extensively in the various tations of the Edison Companies throughout the United being belted direct to the generators, and they are now ly coupled direct to the generator-shaft either by means ible coupling or by extending the engine-shaft and mount-rmature spider on the prolongation of the shaft.

t connection of engines of the high-speed type to electric and railway generators is a practice which has become eral during recent years. It has its advantages and dis-ges. Among the former may be mentioned the saving oor space, the abolition of belts, and the many sources of and annoyance inherent in this method of transmitting nd the noiselessness with which a direct connected plant made to operate. On the other hand, a generator built t coupling to an engine is larger (on account of the speed) and consequently considerably more expensive belt-driven machine of the same output. The plant is ible, because any slight mishap in either the engine or r renders both useless until the trouble is remedied, and when the armature is mounted directly on the engine e whole frame of the generator is necessarily in electrical on with the steam *piping,* and hence also with the earth.

***ut on page** 450 represents* a 120 horse-power cross-com-

such a way that an exceedingly
the pressure-plate and the va
at the same time preventing t
occurs, the distance-pieces
restored. The double po

type, directly

Se

ound Engine Directly Connected to
watt Dynamo.

recesses in th
of the steam i

Among th
the Straigh
contain rin
surfaces, th
a special d
to steam w
rust. Th
John E.
York.
include
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ship.

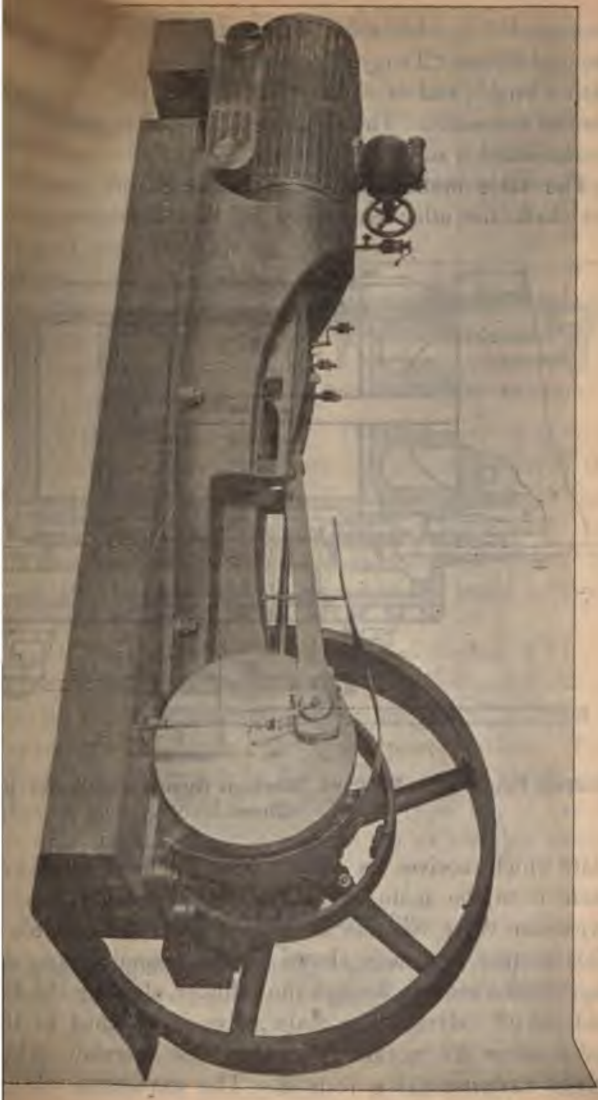
dynamo. These engines are built by
of Providence, R. I.

Four-valve Engine.

is a type which has been designed to
ncipal advantages of the Corliss and
It resembles the high-speed type in that
the changes in load by means of a
sembles the Corliss engine in having
admission and exhaust, thus avoiding the
le-valve engines and at the same time re-
be derived from high rotative speed,
account of the absence of the releasing

The
regulat

valve **engine**, as will be seen from the



pound horizontal engine of the Armington & Sims type, directly

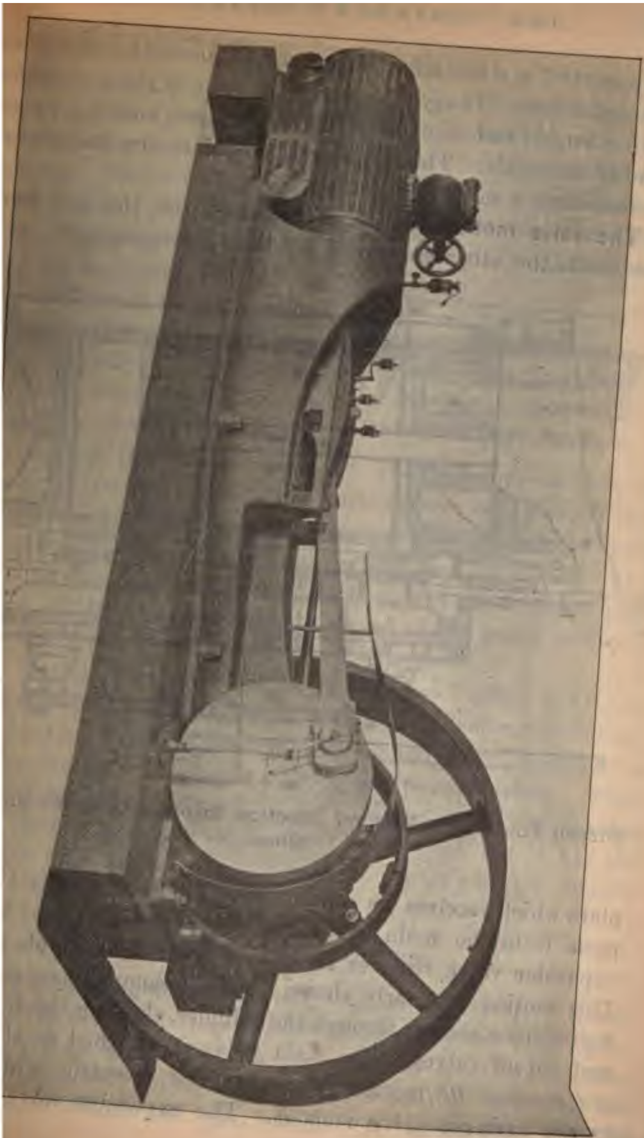
120 Horse-power Cross Compound Engine Directly Connected to 75 Kilowatt Dynamo.

connected to a 75 kilowatt dynamo. These engines are built by the Armington & Sims Co. of Providence, R. I.

The Russell Four-valve Engine.

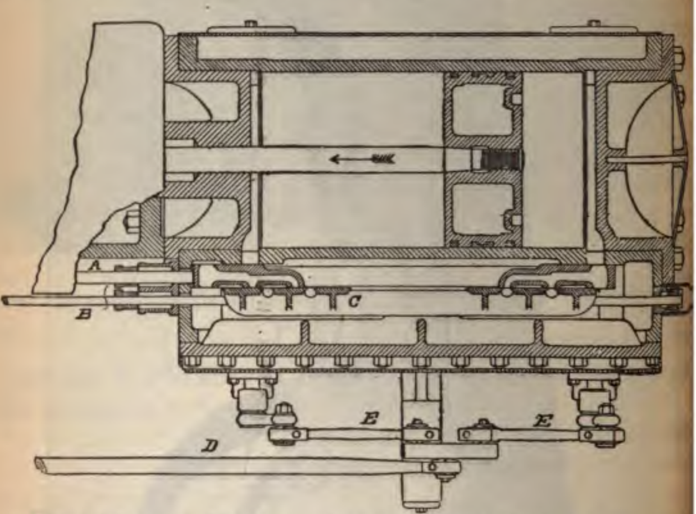
The four-valve engine is a type which has been designed to combine some of the principal advantages of the Corliss and the high-speed engine. It resembles the high-speed type in that the cut-off is varied to meet the changes in load by means of a shaft governor, and it resembles the Corliss engine in having separate passages for the admission and exhaust, thus avoiding the losses inherent in single-valve engines and at the same time retaining the advantages to be derived from high rotative speed, which may be had on account of the absence of the releasing mechanism.

The Russell four-valve engine, as will be seen from the cu



on page 451, is a horizontal side-crank engine with a bed-plate of the well-known "Tangye" pattern. It rests on the foundation its entire length, and is so constructed that the working parts are readily accessible. The cylinder is bolted to the bed-plate and its outer end is supported but not bolted.

The valve motion consists of two eccentrics, the one fixed on the shaft, the other controlled by the shaft governor; a wrist-



Russell Four-valve Engine. Section through Cylinder and Steam Chest.

plate which receives its motion from the fixed eccentric and imparts it to the main valve and the exhaust valves, while the expansion valve receives its motion from the variable eccentric. This motion is clearly shown in the accompanying cut, which represents a section through the cylinder, showing the distribution and cut-off valves. The main valve is attached to the rod *A*, ceives its motion from the fixed eccentric, which moves exhaust-valve rods E. The expansion valve *C* receives motion from the rod *B*, which is connected to the governor. will be observed that the main valve is of the gridiron type, ntaining three ports. It is balanced by admitting steam be- een the valve and its seats, leaving narrow bridges for the valve ride on. The cut-off or expansion valve rides on the back of main valve. The exhaust valves, which are shown in a sepa- e cut, are cylindrical and of the semi-rotary type, their motion ng identical with that of the aust valves in the Corliss type engines. The method of con- ting the rods to the wrist-plate uch that the valves move rap- at the time of release and wly during the exhaust period. The governor consists of weights counterbalanced by spiral springs so arranged that en the speed changes the eccentric is rotated around the shaft, ying the angular advance, and in this way the cut-off. It is y much like the Buckeye Engine Governor illustrated on page , and all that has been said in regard to the latter applies to Russell Governor as well.


Section through Exhaust.

The Russell four-valve engine is built by Russell & Co., of ssillon, Ohio, both as a single and as a tandem-compound en- e. It is an engine of moderate speed and is well adapted for in connection with electric lighting and power stations. From standpoint of economy it is far superior to the single-valve gine, though not so good as the Corliss type, but it has the vantage over the latter that it may be run at a higher rotative ed.

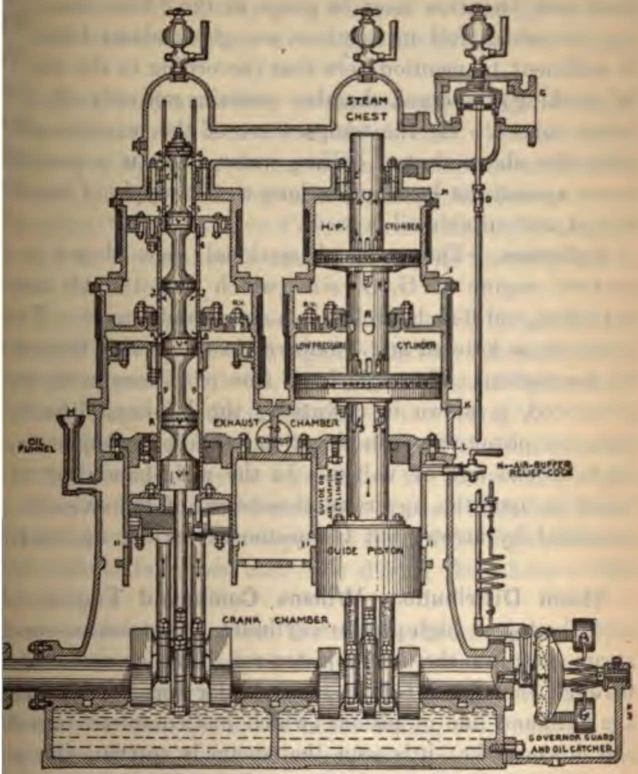
Single-acting Engines.

The Willans Engine is essentially one of high rotative speed, rying from 470 revolutions per minute in a 50-horse-power unit wn to 270 in an 800-horse-power unit. It is a single-acting gine of extremely simple design with throttling governor and lves *placed within the piston*-rods. It is usually built as a

All Parts in Compression—Brasses.—It will be noticed that the upper crank-pin brasses of the connecting-rods are wider than the lower ones. This is because the upper brasses alone are intended to be in actual contact with the crank-pins; the lower ones are only a stand-by in case of accident. All the moving parts of the engine are designed to be strictly in "constant thrust;" the connecting-rods are always in compression, never in tension. From the fact that the upper or working brasses never leave the crank-pins, and so are never exposed to hammering action, however slight, they exhibit great durability when properly lubricated; at the same time it is evident that no wear which can take place in them, however great, can lead to knocking, as the connecting-rods will follow up the wear automatically. But as the lower brasses, to be useful as a stand-by, should not be too far from the crank-pin, the wear should be taken up when it becomes excessive, say as soon as it reaches $\frac{1}{32}$ inch, care being used that the lower brasses are not brought actually into contact with the crank-pin, and that sufficient slack is left to insure an audible knock if the engine is allowed to race, so as to attract attention.

The eccentric-rod is intended to work always in compression, in the same way as the connecting-rods, the holding-down power being furnished by the pressure of the steam in the steam-chest, acting constantly upon the uppermost piston-valve. It may sometimes happen, if the engine is run with a light load but at high speed, that the pressure in the steam-chest (being throttled down by the governor) is insufficent to keep the eccentric-rod in contact with the eccentric upon the up-stroke. If so, a slight knocking may be heard, as the lower eccentric-strap is purposely left an easy fit upon the eccentric (for reasons already explained in the case of the connecting-rod brasses). Such knocking is unimportant, if not allowed to continue too long; it will cease as soon as the engine is given work to do.

A further reason for the moderate wear of the brasses (and *eccentric-straps*) is that they dip bodily into the lubricant in th mber at every revolution. In doing so they splash it main bearings and to the upper ends of the connecting-



PISTONS ON DOWN STROKE, ABOUT ONE-FOURTH OF STROKE COMPLETED: STEAM ENTERING AS SHOWN BY ARROWS: PISTON-ROD IN SECTION, SHOWING VALVES IN ELEVATION.

PISTONS ON UP STROKE, ONE-FOURTH OF STROKE COMPLETED: STEAM EXHAUSTING AS SHOWN BY ARROWS: PISTONS AND PISTON-ROD IN ELEVATION.

ertical Section of a Central-valve Compound Engine

d eccentric-rods, and into the guide-cylinders as well as *t part of the hollow* piston-rod where the guide V¹ works.

constantly in compression—a condition rendered p
the fact that the pistons are single-acting, giving
crank upon the up-stroke, but only a push upon th
In any engine running at high speed, however, the
can only be kept in compression upon the up-s
powerful cushioning, which is rarely obtained in o
engines without excessive compression in the cylin
wasteful use of the steam. Sometimes, when a hig
exhausts into a vacuum, sufficient cushion cannot
means, be obtained at all. In the Willans Eng
compression is given in the steam-cylinders, for li
required; the requisite cushioning is obtained ind
special means, the subject of a separate patent. I
vided, without the addition of a single moving part
by the guide-pistons. These, on the up-stroke, co
contained in the guide-cylinders, and thus any d
of cushion can be obtained, according to the clear
The work expended in compressing the air is give
its expansion on the succeeding down-stroke, and
the engine is running at good speed is proved by
grams to be too minute to be worth considerati
holes 11, 11, in the guide-cylinders, which are un
guides at the bottom of the stroke. As the casi
which surrounds the guide-cylinders (and form
framing of the engine) is open to the atmospher
that the air compression always commences at atm
ure, and is constant and invariable in its results,
ation may be made in the destination or the p
exhaust steam.

Internal Relief Valves.—In the low-pressure

---

* The amount of cushion is fixed in each case to suit th
and may be insufficient to prevent knocking if that speed i
If [illegible] ny reason it is desired to run an engine material
[illegible] intended, and the engine is found to knock at th
[illegible] must be reduced until the knocking disappear

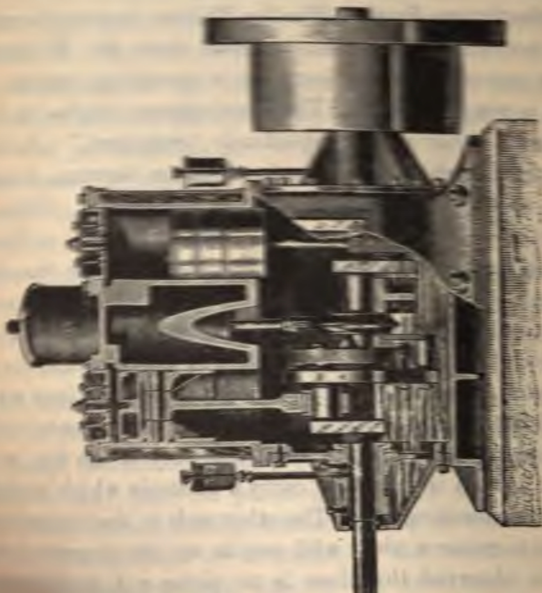
gines, and in the high-pressure cylinders if large enough to be treated, internal relief-valves are fitted, consisting of a guntal plug screwed into the top of the low-pressure cylinder. e plug is pierced by holes, covered by a single thin gun-metal c. When the disc is raised there is free communication beeen the cylinder and the receiver (or steam-chest) above it. is kept down under ordinary circumstances by the excess of receiver pressure over that in the cylinder; therefore no ring is required, and there is no part liable to get out of order. from water in the cylinder, or any other cause, the pressure es above that in the receiver, the valve lifts, and though the ter is only passed back into the receiver, the relief is found to sufficient, and in fact far more effective than that given by linary external relief-valves. Engines so fitted have been ted by discharging a cubic foot of water suddenly into the am-pipe; also by connecting the steam-pipe with the waterace of the boiler (by a half-inch pipe, with a difference of eighty unds between the pressure in the boiler and that in the steampe)—without any injury to the engine in either case. In cases ere internal relief-valves cannot be used, ordinary external lves are fitted. When an engine is run without load the comession in the low-pressure cylinder may rise beyond the presse in the receiver; the disc of the valve may then be heard to at each revolution, but the noise will go off as soon as the eiver pressure is increased by giving the engine work to do.

Air Cocks.—Relief cocks are fitted upon the guide-cylinders in ler to avoid compressing the air in them when the engine is ng turned by hand, and to facilitate starting. If the cocks opened at starting, they must be closed again immediately. ey must never be open when the engine is running at speed, or necessary cushion will be wanting. The cocks will be seen at vel slightly lower than the exhaust-pipe, but they are usually the front of the engine and not at the end, where, for conveni-e, they are shown in the lithograph.

rain Cocks.—*The drain cocks* on the receivers should be fully

nks and shaft are forged in one piece, while in the larger uni
e cranks are forced on the shaft and keyed. The main bearing

SECTION THROUGH VALVE.



LONGITUDINAL SECTION OF ENGINE.

Westinghouse Standard Engine.

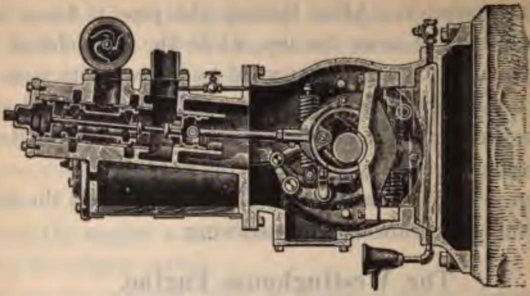
ith Babbitt metal, and are supplied with a wiper,
the outer head, which takes up the oil which

orked its way past the bearings and returns it to the crank-case. n additional bearing is provided near the centre of the shaft for e purpose of relieving the shaft of the strain produced by the rust of the pistons.

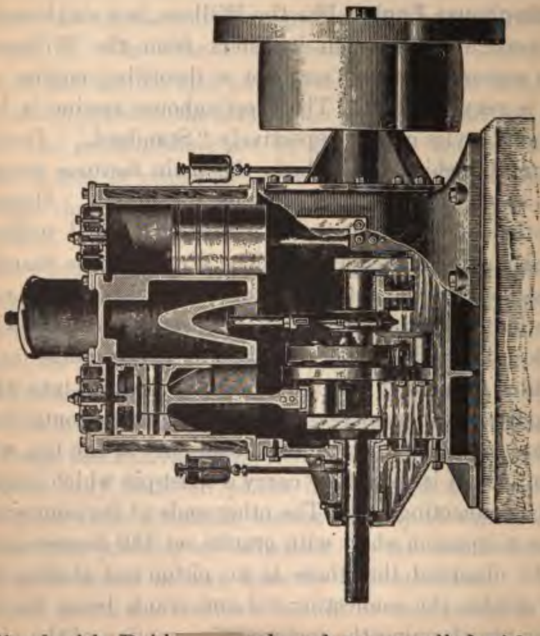
The valve, which is of the piston type, is placed, in the Standrd Engine, in an oblique position between the pistons, the ports eing so arranged that steam is admitted alternately into the two ylinders, just as in a double-acting, single-cylinder engine it is dmitted alternately at either end of the cylinder. The valve reeives its motion from an inertia shaft governor placed between e cranks, which depends for its action upon the inertia of two eights counterbalanced by spiral springs, so arranged that when e speed increases, the throw of a loose eccentric, and hence also e travel of the valve is reduced. The governor has no novel featres, and it works under the disadvantage, shared by all governors this class, that the compression and release are altered with the t-off.

The "Junior" Engine differs slightly from the Standard in degn. The governor is placed in the wheel outside of the casing, d the valve-chest is placed horizontally over the cylinders, inead of between them. In the Compound Engine the high- and the w-pressure cylinders (each single-acting) are placed side by side. he general design, however, and the method of lubricating are the me in all. These engines are well adapted for a variety of uses. hey are especially valuable in locations where the engine is exosed to dust, since the working parts are almost completely nclosed in the casing. Its high speed and close regulation make useful also for electric lighting and railway service, although it not nearly so economical in the use of steam as many of the pes of engines which are used for this purpose.

cranks and shaft are forged in one piece, while in the larger units the cranks are forced on the shaft and keyed. The main bearings



SECTION THROUGH VALVE.



LONGITUDINAL SECTION OF ENGINE.

Westinghouse Standard Engine.

are lined with Bab[illegible]tal, and are supplied with a wiper, *shown near the* [illegible]hich takes up the oil which ft, if there be any, to the floor, at three or four different places its length; but if there be no shafting, measure from the side the building to the centre, at five or six points in its length; n strike a line across all these points. This line will show with ficient accuracy the line of the building by which the templet y be set up; the latter, as shown in the cut on page 468, should a fac-simile, or exact counterpart of the bottom of the bed-plate. may be made of inch pine boards, and set on four props over excavation, after which it must be squared and levelled with lines previously taken. The anchor-bolts may now be hung the templet, and the bricklayers proceed with their work. It ustomary to lay from two to three courses of bricks on the bot- of the foundation before the anchors are reached. These con- of plates of cast-iron or old boiler-plate, generally about a foot are, with a hole sufficiently large for the foundation bolts to through; though in some instances the anchors extend entirely oss the foundation and take in two bolts each.

Engine Foundations.

oundations.—A foundation plan, as well as a wooden template holding the bolts in their proper places while building the ndation, is usually furnished by the builders. If no template urnished, it may easily be constructed from the drawings in manner indicated in the accompanying cut,* which shows the ndation in the course of construction, with the template hold- the bolts in position. The dimensions for foundations given the builders are usually safe. It is not well, as a rule, to make m any less, and the condition of the ground often makes it essary to increase the depth of the foundation, which should ays be carried to solid bottom.

efore beginning the foundation itself, a suitable bed should repared to receive it. The nature of this is dependent upon nature of the soil at the bottom of the excavation. If this

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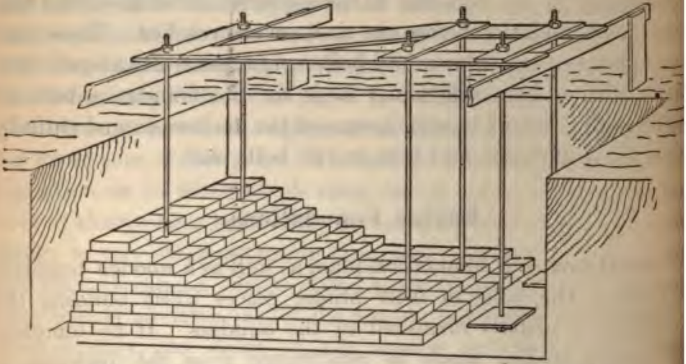
* From the *catalogue of the* Atlas Engine Co. of Indianapolis, Ind.

be solid rock or a compact stony soil, it need only be levelled
and the brick-work begun at once. If there is water prese
this should be removed by suitable drains, and if there is a
indication of a soft soil beneath, which is liable to yield laterall
this should be confined by means of piling. If after excavati
to a reasonable depth the soil continues to be of a soft earthy
sandy nature, a layer of rubble should be laid and well ramme
and on this a layer of from six to twenty-four inches of strong co
crete, also well rammed and finished level, to serve as a bed for th
foundation. If no indication of solid ground is met at a reason



Engine Foundation in the Course of Construction.

able distance, and the soil continues to be of a yielding or com
pressible nature, a suitable bed may be prepared also by drivin
a sufficient number of piles spaced two or three feet apart, sawin
them off to a common level, excavating the earth between th
piles to a depth of two or three feet, and filling the spaces wi
concrete, finishing the whole to a level for receiving the found
tion.

The materials used in the foundation should be concrete
d-burned brick or stone laid in cement. The best foundati
rial is a single solid rock, but this is usually not attainab

nd a built-up brick or concrete foundation answers all practical urposes. Bricks or stones *should always be laid in clear cement- ortar* and no lime used under any circumstances. This mortar hould be made of one part of Portland cement to two parts of lean, sharp sand, or nearly in that proportion, with as little water possible. If concrete is used, it may be made in the propor- on of five parts of hard broken stone, two parts of clean, sharp nd, and one part of Portland cement. It is desirable, also, ough not necessary, to finish off the top of the foundation with capstone.

Foundation bolts should never be built solidly into the founda- n, as the spacing of the holes in the bed-plate of the engine is ble to vary, and furthermore if a bolt should break it could not removed if built solidly into the foundation. For these reasons is customary to allow a certain amount of space around the lt, increasing toward the top. Foundation-bolts should be readed at both ends, and provided with nuts and washers and chor-plates of ample size to resist the pull. The anchor-plates ould be provided with pockets for holding the lower nuts and event their turning if it should become necessary to screw them or out.

The foundation should be widest at the bottom, and slope up- rds about 2 inches to the foot, till the level of the floor is ached, after which it may be carried up straight. When fin- ed, it may be an inch wider on each side and end than the d-plate; after which it should be made perfectly level by means a coat of good, strong mortar or cement. A parallel piece of ne wood, 1 inch in diameter and from 3 to 4 inches wide, made rfectly straight on both edges, on which a spirit-level may be aced, will answer for levelling the foundation.

After the foundation is level, the bed-plate may be placed on it, ther by means of a crane, block and tackle, or skids and block- g, after which it may be tied down and accurately levelled. It customary, in the case of large engines, to place wedges between e bed-plate *and foundation,* for the purpose of leaving an inter-

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he outlets provided on the engine. The pipes should be
straight as possible, and if they are excessively long, say
ifty feet, a size larger should be used. Horizontal pipes
be inclined slightly, so as to *allow the condensation to flow*
same direction as the steam. If the steam is moist, it is well
ride a separator somewhere in the line, so as to insure dry
at the engine. If the exhaust is condensed and again used
boiler, an oil separator should be placed in the exhaust
(see Separators, p. 261). The steam-pipe should run
lly down to the engine, and provision be made for carrying
condensation and entrained water. Drips from the steam-
separator, cylinder, and valve-chest must be provided with
and may be carried into a common drain-pipe. The drips
etimes connected to the exhaust, but this is not good prac-
Steam- and exhaust-pipes when long must be run in such
as to provide for expansion. This may be done either by
g long U-bends, or by laying out the line so that the play
joints at the fittings will allow a certain amount of play in
ection of the length. The pipes should be suitably sup-
by pipe-hangers, and all live steam-pipes covered with
non-conducting pipe-covering—preferably magnesia. Ex-
ipes may be painted if the engine exhausts directly into
nosphere, but should be covered with pipe-covering when
at contained in the exhaust is to be utilized. For large
f pipes long-turn elbows, tees, and crosses are preferable to
rd cast-iron fittings.

principal pipes connected with marine engines and boilers
e main steam-pipe, donkey-pipe, cylinder jacket-pipe, whistle-
the steam winch-pipe, ballast engine-pipe, feed-pipes, donkey
ipes, donkey suction-pipes, and a hot-well connection-pipe,
ling water-pipes, feed suction-pipes, air-pump discharge,
discharge, bilge-suction, bilge-injection, cylinder drain-pipes,
jacket drain-pipes, and steam-jacket drain-pipes, blow-off and
pipe, main-steam *pipe*, *cooling-pipe*, water-service pipes.
pipes, cocks, and **valves** used in connection with the loc

adjusting the valve, so that it may move uniformly on its s thereby giving the same amount of lead at each end of the stro then, if the valve is well proportioned, and the connections th oughly fitted and skilfully adjusted there is no reason why engine should knock from this cause. But the knocks aris from bad proportion in the valve or steam passages are the m difficult of all to remedy, as they are inherent in the machine.

How to Reverse an Engine.

Place the crank on the dead-centre and remove the bonnet the steam-chest; observe the amount of lead or opening that valve has on the steam end; then loosen the eccentric and turn round on the main shaft in the direction in which it is inten the engine should run, until the valve has the same amount lead on the other end. To determine whether the lead is exac the same at both ends, a small piece of pine wood may be tape in the shape of a wedge, and inserted in the port; the marks on it by the edge of the port and the lip of the valve will sh how far it has entered. The engine should then be turned on other centre for the purpose of equalizing the lead; the cra should also be placed at half-stroke, top and bottom, for the p pose of determining whether the port opening is the same in b positions. When the crank is at half-stroke, the centre of crank-pin is plumb with the centre of the crank-shaft.

How to Repair Steam-Engines.

It would be reasonable to suppose that any machinist w be capable of repairing steam-engines; and yet, on an examina of numerous cases where repairs have been done by persons cal themselves mechanics, it appears that very few machinists ar to be trusted to do so. A man to be competent to do repairs first understand the original character of the engine or mac *and its defects*, whether arising from design, inferior materia *workmanship*, how [illegible] vement can be made in its w

in the steam-chest caused by looseness in the valve connec-
ns may be remedied by readjusting the jam-nuts or the yoke.
ocking arising from this cause manifests itself more frequently
en steam is shut off from the cylinder, preparatory to stopping
engine, than when the engine is running; the lost motion is
ken up in the valve connections by the pressure of the steam
the back of the valve.

Knocking in the piston is generally caused by the rod becoming
ose in the head, and, if it continues for any length of time, it
stroys the fit of the rod in the hole. The only practical remedy
der such circumstances is to remove the rod, rebore the hole,
d bush it or thicken the rod at that point by welding, and fit it
the head after the hole is rebored perfectly true. Knocking in
e follower-plate is generally caused by the bolts being too long,
from dirt being allowed to accumulate in the holes, which prevents
them from entering sufficiently far to take up the lost mo-
on in the plate, and may be remedied by shortening the follower-
lts, or removing the deposits from the bottoms of the holes, as
e case may be.

The knocking caused by shoulders becoming worn in the cyl-
der at each end can be remedied by reboring the cylinder, and
aking the counter-bore sufficiently deep that a part of one of
e rings will overlap it at each end of the stroke. Knocking
used by shoulders becoming worn on the guides can be remedied
planing the guides and making the gibs or shoes sufficiently
ng that they will overrun the guides when the crank is at either
ntre. The knocking induced by any of the foregoing causes is
nerally a source of great annoyance to the engineer, as any at-
mpt to adjust the boxes on the cross-head or crank-pin, or the
ston-packing in the cylinder, generally aggravates the cause of
e knocking, as any adjustment of the connecting-rod boxes alters
e position of the piston in the cylinder and the cross-head on
e guides, and causes them to strike harder against the shoulders.

Knocking caused by the valve or valves being improperly set
y be *remedied by removing* the bonnet of the steam-chest and

[illegible] levelled, so that it m [illegible] the axis of the cylinder at [illegible] The connecting-rod boxes should be [illegible] "brass bound," and if [illegible] The main pillow-block bearing sho [illegible] determine if it is worn oval or lo In fact, every part should receive attention, because defects t have not been thought of may be revealed as the work progres It has been generally heretofore supposed that any one bear the name of a machinist is competent to repair a steam-engi which, of course, is a grave error, as thousands of mechanics fu competent to build a machine are totally unfit to repair it.

This arises from the fact, that the repairing of steam-engi and other machinery requires a different class of talent from th necessary to build them. A machinist may be a good hand either a vise, lathe, or planer; he may be a thorough fitter and neat finisher; and yet he may lack that keen observation, that co patient, and searching perseverance which are so essential in t party that will become an adept in the repairing of steam-engi and other machinery. It not unfrequently happens, that wh everything has been done that was considered absolutely nec sary, an engine works badly when started up, which is very d couraging to any one, except those who take a peculiar interest ferreting out the causes of minor defects which have been ov looked when the more prominent ones were remedied. Alm any one can tell if an engine is badly out of line, the cylin fluted, or the crank-pins loose or worn oval; but it requires a d ferent kind of talent to determine the different causes for t defective working of steam-engines, and prescribe a remedy them, as many of them apparently did not exist at the commen of the work, but cropped out as it progressed. One of t mistakes in the repairs of steam-engines and other is that those who have them in charge are expected to work in too limited a time. This being impossible, urce left is to slight it.

How to Increase the Power of the Steam-Engine.

It frequently happens that engines which were originally of fficient power to do the work of a manufacturing establishment, come unable to do the work, owing to an increase in the busi- ss; and while the cost of replacing an engine with one of suffi- ent power would be a matter of nominal consideration, the time pended in removing and replacing it with a larger one might volve a serious loss to the owner. Under such circumstances, the ost practicable ways to remedy the difficulty for the time being ould be—*first*, to raise the pressure, providing the boiler is con- lered safe; *second*, to increase the speed of the engine; *third*, to place the old cylinder with a new one of larger diameter, which ould, of course, involve the necessity of a new piston, steam-chest, d valve; *fourth*, to compound the engine by adding a low-press- e cylinder with suitable changes in the valve-gear; *fifth*, to add condenser, if the engine originally ran non-condensing.

For a moderate increase in power, the last plan would be the ost safe and practicable, as the active condition of steam-boilers not always understood, and without a thorough knowledge on e subject it would be unwise to increase the pressure; nor should y engine be run at a higher speed than it is capable of stand- g without springing or shaking to pieces. The increase in power at would result from replacing the old cylinder with a new one o inches larger in diameter may be illustrated as follows: Take, r instance, a 10-inch cylinder, which contains 78·54 square inches area, while a cylinder 12 inches in diameter contains 113·09 uare inches, which makes a difference of 34·55 square inches in e piston. Now, if the engine having a 10-inch cylinder was able to do the work with 60 lbs. pressure per square inch, it ould do the work easily with the 12-inch cylinder at the same essure, as the new cylinder would make a difference of from 5 6 horse-power. Measures might be taken, and the new cylin- r, piston, and steam-chest prepared and placed in position at a *ven time, without causing any* interruption to the business.

Of course the margin for increasing the size of cylinder for any engine, and using all the other original parts of the engine, is limited, and should never exceed 2 inches; as, to exceed that limit, the other parts would be too light, and become liable to spring. To increase the speed of an engine, it would be necessary to have a new counter-pulley, so that, while the piston velocity is increased, the speed of the shafting may remain the same. An engine will develop more power by increasing its speed, but will use more steam, and as a consequence more fuel will be consumed. The overtaxing of steam-engines and boilers, or any other class of machines, is sure to induce waste either in fuel or wear and tear; but there are circumstances under which manufacturers and steam users find themselves placed, in which it would be impossible to avoid waste. Steam-engines or boilers, or any other class of machines that is too large or too small for the work to be performed, are not economical.

The Dead-Centre.

All reciprocating steam-engines have one dead-centre in each stroke and two in each revolution, and that point is the point at which the steam is exhausted, and the centre of the crank-pin is parallel with the centre of the axis of the cylinder. The centre of the cross-head, in some cases, may be above or below the centre of the cylinder; but by placing a spirit-level on the top or bottom of the stub-end strap, the dead-centre may be easily found. The experienced engineer or machinist can generally tell by the eye when the crank is at the dead-centre; but to insure accuracy it is always better, in the case of horizontal engines, to try it with a level, and in vertical engines with a plumb-bob and line. The cranks of all engines have to be placed accurately on the centre when the valves are set.

A single reciprocating engine is completely helpless when the crank is at the dead-centre and would stop there if it was not for *the momentum of the* [illegible]el. Double reciprocating e es, such as locomotives and marine engines, which have their nks set at right angles, require no balance-wheel, as they pull h other off the dead-centre, in consequence of one crank being its full-power point while the other is at the weakest. There some engines, such as the rotary, which have no dead-centre their revolution.

Fitting the Cranks of Steam-Engines to their Shafts.

Boring the hole for the shaft in the crank is not so easy a task the average engineer would suppose. Theoretically, when the le is bored in the crank, if the boss is faced true, and then bolted a true face-plate on a lathe, it must be true. But inaccuracy quently arises from the fact that there are few face-plates which e true, and continue to remain so for any length of time. And en when the boring is as well done as can be expected under e circumstances, the crank is frequently thrown out of line in ying it on the shaft. For this reason, no crank should leave e works where it was made without being tested after having en keyed on.

When the crank is in the form of a disc, or wheel, the best an is to turn it true, first on a mandril, and then so fit it to the aft, and the key to its seat, that after the keying it will run ue; but with the ordinary crank, this cannot be so easily done, all the surface available for testing its truth is near the centre; such cases, the main reliance must be placed in fitting the key as ell as the crank itself to the shaft. The key should never be finally iven till it has first been frequently partially driven, its points contact filed or scraped, and it fits perfectly its whole length.

The essential conditions necessary for the production of a well-ting and durable crank-shaft journal are, good material, a stiff, rong lathe, a skilful machinist, and a sharp, well-tempered, and rrectly set tool. The finishing cuts should be light, and, if it nnot be made sufficiently smooth with the tool, it must not be led, but may be ground and polished smooth by blocks of wood, ad, copper, or some other suitable material fitted to the journal in such a manner that the imperfections left by the turning-tool will be corrected instead of aggravated by the use of a file or end of a stick, as is commonly the case. The polishing powder used should be very fine; emery is considered, by many, objectionable for polishing wearing surfaces, but on good homogeneous material, free from flaws, fine emery may be used without any injurious effects.

Duplicating the Parts of Steam-Engines.

Duplicating the parts of any class of machines is an advantage, as it insures more uniform proportions in their original construction than could otherwise be obtained, as the term duplication of parts conveys the impression that they are made to standard gauges, and for any number of machines must retain the proportions of the original. While duplication of parts is convenient, and sometimes of great value in cases of emergency, it is rarely so in case of repairs; since, as soon as any journal or bearing is put into use, its dimensions begin to change, the cylinder commences to enlarge and the piston to diminish. This change of shape extends to the piston-rod, and glands of the stuffing-boxes, wrist-pins, crank-pins, rocker-shafts, etc. The eccentric wears flat on two sides, in consequence of the thrust at these points, and the straps wear flat, owing to the push and pull at two points.

Now how can it be expected that a new eccentric will fit the old straps, or the new straps conform to the old eccentric, or that the new piston will prove a good fit for the old cylinder, or the new piston-rod for the worn-out gland? If the crank-shaft becomes worn oval, it will not adjust itself to a new main-bearing made from the original standard; or if the crank-pin becomes worn tapering, owing to the engine being out of line, a box made of the
oportions will not drop into its place and work har-
but, as before stated, in case of emergency, such as
or where interruption to business would entail great
parts are a tolerably good make-shift, and that is
e said in their favor. For this reason, the duplica-
which in case of breakage would be most likely to

sable a machine, ought to be encouraged, especially in case of arine engines, locomotives running in sections of the country here there are no repair shops, and stationary engines located isolated places.

QUESTIONS.

What constitutes a steam engine? What is the simplest form steam engine?

Name and describe the principal parts. What is the function each?

Who was the inventor of the steam engine and in what par- ulars does a modern engine differ from the first forms?

How is the power of engines expressed? What is the differ- ce between indicated and net horse-power?

What four factors determine the power of an engine? Explain e rule for calculating horse-power.

What is the horse-power of the following engine?

Cylinder, 18 × 20.
Steam pressure, 100 pounds.
Cut-off, ¼.
Speed, 200 R. P. M.

At what speed would the above engine develop 300 horse-power?

Required the diameter of cylinder of an engine to develop 300 rse-power at a piston speed of 600 feet per minute and mean ective pressure of 55 pounds per square inch?

Write out a formula for calculating the stroke of an engine ien the horse-power, mean effective pressure, piston speed, and ameter of cylinder are given.

Write out a formula for mean effective pressure in terms of ameter of cylinder, stroke, speed, and horse-power.

How are steam engines classified?

Explain what would be meant by a vertical, triple-expansion, *h-speed, single-acting,* non-condensing automatic cut-off, stationary engine. Which of the engines described in Chapter XX. would answer to this description?

What are the advantages of high piston speed? What kind of service requires high rotative speed?

Explain, briefly, the advantages to be derived by properly proportioning the reciprocating parts of an engine. Illustrate by a diagram.

Why must high-speed engines run under high pressure?

What is the difference between condensing and non-condensing engines?

If the vacuum in a 14 × 20 condensing engine running at 250 revolutions per minute is 26 inches, what is the gain in power due to the condenser?

What advantages are to be derived from compounding? What is the difference between a tandem and a cross compound engine?

Explain the difference between throttling and automatic cut-off engines. Where are throttling engines used?

In what respects do stationary, marine, and locomotive engines differ?

How is the power of locomotives measured?

What are rotary engines? Why are they not used more extensively?

What are the principal sources of loss in steam engines?

Calculate what percentage of the energy contained in the fuel is utilized in steam plant consisting of a boiler which evaporates eight pounds of water per pound of fuel, and an engine which consumes twenty-five pounds of steam per indicated horse-power hour if the coal contains 10,000 heat units per pound.

What is the principal source of waste in the engine proper? How may it be reduced?

Which is the most economical type of engine and why?

What is the function of bed-plates and housings? How should be built?

ake a sketch showing the usual design of steam cylinders and ain the principal features.

What is the cause of cylinders wearing unevenly? How can it be avoided?

How calculate the area of the steam passages?

What is meant by clearance? Why is it a necessity and how can it be determined in a given engine?

What is the object of jacketing steam cylinders?

Explain the use of the piston and the usual methods of construction.

Make a sketch showing piston, connecting-rod, and crank connections.

Give the rule for finding the distance the piston is ahead of its central position when the crank is in a position perpendicular to the centre line of the engine.

What considerations determine the length of connecting rods? How long are they usually made?

What is the function of the cross-head?

Explain the difference between "throwing over" and "throwng under."

Make a sketch showing a connecting-rod end and explain how the adjustments are had.

What are the three different forms of cranks? Where would they be used?

What are the disadvantages of centre cranks? Of what material are they usually constructed, and why?

How may we determine whether or not the crank-pin is in ine with the centre line of the cylinder?

What is an eccentric? In what respect does it differ from a crank? When is it used in preference to a crank, and why?

Explain what is meant by "throw" of an eccentric.

Calculate the diameter of a steel shaft which will safely transmit 600 horse-power at 100 revolutions per minute.

What is the function of the fly-wheel? Where should the bulk f its weight be concentrated? Make a sketch showing how a fly-wheel may be constructed when the rim, hub, and arms are *cast separately.*

Does it make any difference whether a fly-wheel is evenly balanced?

Explain the terms: "Valve gear," "releasing valve gear," "automatic cut-off," "positive cut-off," "riding cut-off," and "reversing gear."

What are "relief valves," "balance valves," "rotary valves," "semi-rotary valves," and "gridiron valves?"

Explain by diagrams the action of the plain slide valve.

Define the terms: "Admission," "exhaust," "cut-off," "expansion," "compression," "angle of advance," "travel," "over-travel," "inside lap," "outside lap," "steam lead," "exhaust lead," and "negative lead."

Given the throw of the eccentric, angle of advance and inside and outside lap, show how by the Zeuner diagram the distribution of steam may be studied.

Explain how to set the valves of steam engines.

Explain how the lap and lead may be determined without opening the steam chest.

Why are plain slide valves not used with large engines and high pressures?

Describe the piston valve and state its advantages and disadvantages as compared to a plain slide valve.

Make a sketch of valve and steam chest showing how the pressure against the valve may be relieved.

What is meant by a poppet valve? How is the lift determined?

What is meant by a variable cut-off gear?

Explain the Stephenson link motion and illustrate it by a sketch.

Explain the Meyer valve gear and make a sketch showing how it might be used as an automatic cut-off gear. Why is it not used more extensively?

What is the function of the governor? Explain the action of a simple throttling governor.

at are the principal defects of throttling governors?

is shaft regulation used so extensively with high-speed

Explain the action of a simple form of fly-wheel governor.

Make sketches and explain the action of the following forms of governors: Porter-Allen, Ball, Buckeye, and Ritos.

What is the effect on the steam distribution if the cut-off is varied by altering the angular advance only or the eccentricity only?

In what form of valve gear is it not necessary to vary both the angular advance and the throw of the eccentric?

How calculate the diameter of governor pulleys?

What is the maximum variation in speed which a good shaft governor should allow?

How does the governor act in the Corliss type of engines?

Describe the Corliss engine and state why its economy is greater than the slide-valve engine.

Explain by a sketch the releasing mechanism employed in the Harris-Corliss engine.

What is the function of the dash pot? Why is it better than a spring in connection with Corliss gears?

In what respect does the improved Greene engine differ from the Corliss type?

Why can Corliss engines not operate at high rotative speed?

What are the characteristics of high-speed automatic cut-off engines? For what class of service are they especially adapted?

What is the steam consumption per horse-power hour in this class of engines?

Explain the method of regulating the speed in the Buckeye and Porter-Allen engines. Which of the two should, other things being equal, be the more economical in the use of steam?

Explain the use of pressure plates for relieving slide valves of the steam pressure on their backs.

What advantage is derived from the differential valve motion as used in the Porter-Allen engine?

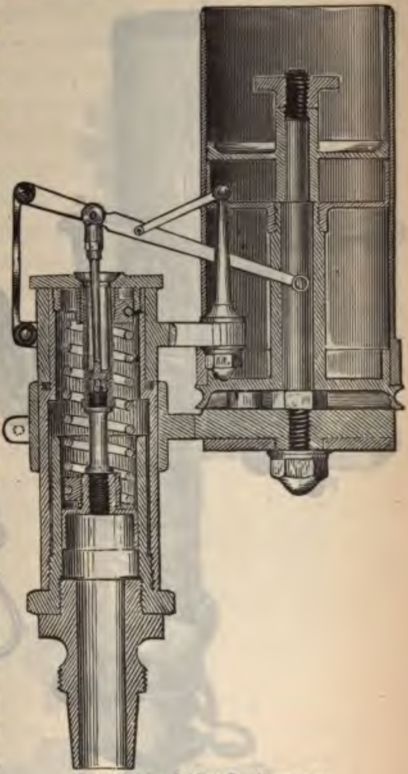
In what essential respects does the Straight Line engine differ from the *Buckeye?*

changes in construction that it can hardly be recognized as the same device. Be this as it may, Watt's indicator though imperfect, answered for engines travelling at a piston speed of about 200 feet per minute, and for pressures averaging 7 lbs. above atmosphere, which he thought was the fastest speed and the highest pressure that would ever be needed. But experience soon demonstrated that the highest economy was attained with high piston speeds and correspondingly high pressures, and, as a result, Watt's indicator proved to be unsuitable for these conditions. The requirements of such an instrument were more fully appreciated by McNaught, of Glasgow. The world is more indebted to him for improvements in the steam-engine indicator than to any one previous to his time.

The indicator was further improved by Hopkinson, Stillman, and others; but these improvements were not in the mechanical design or arrangement of its working parts, but rather in the accuracy and refinement of the workmanship employed in its construction, as the mechanical principles embodied in the Watt indicator were continued in them all. They consisted of an upright cylinder, into which a piston was accurately fitted. To the piston-rod a spiral spring was attached, to resist the steam and the vacuum when acting against it. The pencil was also attached to the piston-rod; the result of which was that the piston, piston-rod, and spring had the same movements as the pencil. With such instruments the vibration of the piston was so great as to render them totally unreliable with fast running engines, or when steam was worked expansively.

Gooch was the first inventor that gave the pencil a greater range of movement than the piston. In his instrument the cylas placed horizontally, and when its piston was subjected it compressed two elliptic springs. The top of his as connected to the short arm of a lever, to the long h the pencil was attached, thus giving considerably e than could be obtained by any former instrument. moved in the arc of a circle instead of a straight line.

agram was traced on a web of paper while it was unwound ne drum and wound upon another. This arrangement ad- of a succession of diagrams being taken without any in- iate manipulation of the instrument. The communication n the indicator and m-cylinder was closed ide-valve instead of a But as the principle rking steam expan- became almost uni- an instrument more e than any of these sly mentioned be- a necessity of the and such was found Richards' Indicator. instrument the fol- construction and pro- s have been adopted, dhered to from the The area of the piston square inch, the di- of which is very $\frac{8}{10}$ of an inch, or, xactly, ·79 inch. The of the long arm of er, to which the rod piston is attached, is es, and the distance he pivot of the lever point of attachment of the piston is $\frac{3}{4}$ of an inch, thus giv- free end of the lever, and with it the pencil, four times vement of the piston. The secondary lever is equal in to the first, and the link which connects the two, and which the *pencil at its centre,* is $1\cdot\frac{7}{8}$ inches long. These propor-


Section of the Indicator.

tions give a practically straight pencil movement for a distanc
of 2½ inches.

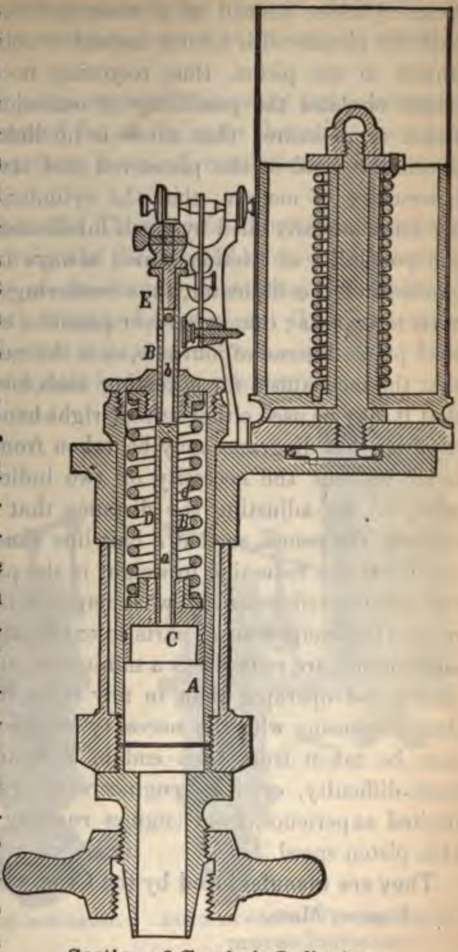
The indicator was further improved by Harris Tabor, (cut
of whose instrument may be seen on pages 503 and 504;) bu

Crosby's Improved Indicator.

more recent improvements made in the indicator have been effected by George H. Crosby, a mechanical engineer of Boston, Mass. It has apparently been the aim of Mr. Crosby to avoid unnecessary weight in the reciprocating parts, to insure correctness of action, and to so simplify the method of manipulating the instrument as to bring it within the understanding of engineers of limited education and persons of ordinary intelligence. In these objects he seems to have been partially successful, as the Crosby Indicator is an improvement, in some respects on other devices of the kind in use. It is reliable in its
dings, whether employed for taking diagrams from auto-
cut-off, throttling, simple, compound, fast- or slow-run

ngines and it is free from some objectionable features er instruments, render the dia- taken by them ous. In the con- of this instru- he inventor seems e predetermined of the circum- es, emergencies, equirements that possibly arise in of the indicator, ovided for them.

advantages of rosby Indicator at the parallel is not a geomet- pproximate imi- of, but a true ; that the motion pencil is a uni- multiplication of ston of the indi- and is solely con- by the motion piston-rod; that are no guiding- ither straight or , to induce fric- that there is no ensating arm to any fixed as in other indicators; that the pencil is located close to ston-*rod, instead of* projecting several inches to one side,



Section of Crosby's Indicator.

as in other cases; that an air-chamber or jacket surround steam-cylinder instead of a steam-jacket, as in other insta that the piston-rod is hollow instead of solid, and that it is so united to the piston, thus requiring no joints below the which obviates the possibility of corrosion by the action of steam or moisture; that there is no link or connecting-bar tween the head of the piston-rod and lever to cause frictio inaccuracy of motion; that the cylinder, piston, and piston are automatically oiled by a self-lubricating device, thus remo the possibility of friction, which always induces error in th cordings of the indicator, thus rendering the diagram decep even to experts; that, wherever possible, every joint is made steel pivots instead of journals, as is the case in other instrume that the mechanism for adjusting each instrument is so arra that it may be used either left- or right-handed, as the case ma in order that diagrams may be taken from either end of the inder without the necessity of two indicators; that means provided for adjusting the distance that the paper shall towards the pencil, so that a hair-line can be drawn without tion; that the reduction in weight in the piston and hollow pis rod and the refinement of workmanship in the levers and jo render the reciprocating parts so extremely light that momen and friction are reduced to a minimum; that it is more easily justed and operated than in any other instrument of the k thus dispensing with the necessity of experts, and that diagr may be taken from each end of a steam-cylinder without least difficulty, even by engineers of ordinary intelligence limited experience, from engines running at the highest pra able piston speed.

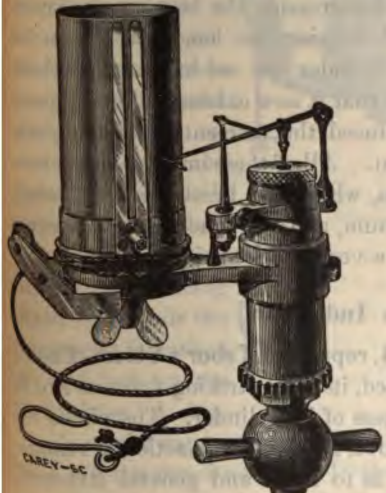
They are manufactured by the Crosby Steam Gauge and V Co., Boston, Mass.

The Thompson Improved Indicator.

***The Thompson* Indicator**, see page 501, improved and pate *J. W. Thompson*, of Salem, O., is another instrument can be used on high-speed engines with success; and it works equally well on slow- and quick-running engines. It will give correct results under any attainable speed of an engine or locomotive.

The adoption of high-piston speed of stationary and locomotive engines has created a demand for an indicator that will take cards at a very high speed, say three hundred revolutions per minute, or even more.

It will be observed that Mr. Thompson's improvement mainly consists in reducing the weight of the parallel motion, by lessening the number of vibrating pieces, thereby decreasing the tendency to make wavy lines in both steam and expansion. By this arrangement, the instrument is lighter and more compact,—qualities which will be fully appreciated by all intelligent engineers.



The Thompson Improved Indicator.

Section of the Thompson Improved Indicator.

By an ingenious device, invented by Mr. Thompson, cards can be taken with this instrument at a pressure as high as five hundred *pounds to the square inch.*

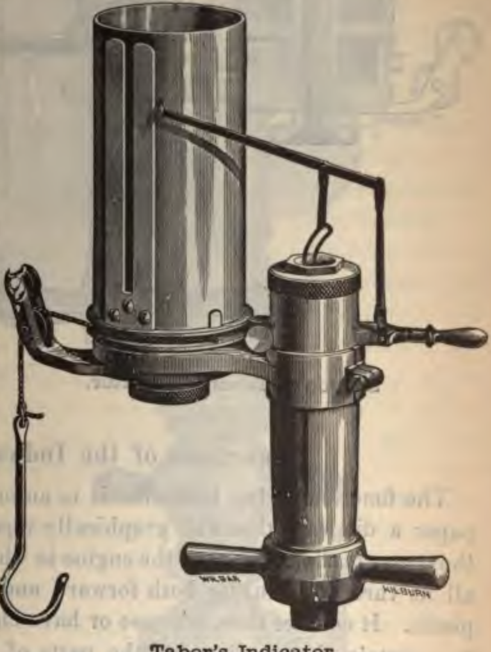
The Thompson Indicator is manufactured by the Americ Steam-Gauge Company, Boston, Mass., who have been eminent successful in the manufacturing of first-class instruments for ma years. The original designs of Mr. Thompson have been som what modified and improved by the American Steam-Gau Company, as will be observed from a comparison of the cut page 495 with those on page 501, the former representing t indicator as originally constructed and the latter the "Thomps Improved Indicator" as it is called by the American Stea Gauge Co.

The important improvements consist in lightening the movi parts, substituting steel screws in place of taper-pins, using a v light steel link instead of a large brass one, reducing the wei of the pencil-lever, also weight of square in trunk of piston lock-nut on end of spindle, and increasing the bearing on con tion of parallel motion By shortening the length and redu the actual weight of the paper cylinder just one-half, and by sh ening the bearing on spindle so that it now carries the drum-sp nearer the base, they have reduced the momentum of the p cylinder to a very small amount. All of these improvements h lessened the amount of friction, which was heretofore very sm but is now reduced to a minimum, and the Thompson Impr Indicator as it is now made is a very excellent instrument.

Tabor's Indicator.

The cuts on pages 503, 504, represent Tabor's Steam-En Indicator. — As will be observed, its most striking features a parallel motion and the plainness of its cylinder. The piston a single capillary packing groove, and its whole action is rem ably nice. The springs, both as to range and general struc are similar to those in the Richards and Thompson Indicator will be noticed that the piston-rod, which is jointed to the p and the pencil-lever, is slotted; this slot is curved, and w *over a guide*-roller set in the cylinder-cap. The rear end o is pivoted to the radius link. The slot-curve is that rve which would be described by the guide-roller as a int while the pencil is being moved in a true line; aimed, insures a correct parallel motion to the pencil. oller is journalled in a free collar held in the cylinder- allows ing parts reely, as brought with the

er drum a steel n which nut is the nut drum is lled head wed on nd of the e recoil- ated in a bracket, nd being vhile the s hooked on the A stop- e cup, engaging with a lug in the drum-base, forms the e recoil motion. If the spindle be slacked somewhat. ase may be revolved over the stop-block, and more or given to the recoil-spring. By simply unscrewing the p, the whole motion work may be removed in one pencil-lever, piston-rod, and radius-link, are all of steel,



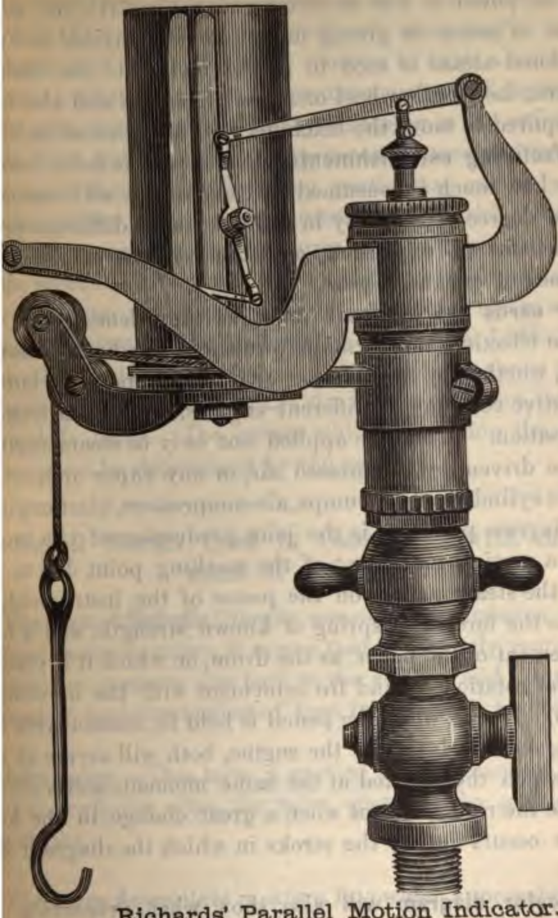
Tabor's Indicator.

Section of Tabor's Indicator.

spring tempered; the small number of moving parts, and their lightness, reduce the error of momentum that exists in instruments of heavier parts, which is frequently a source of uncertainty. The whole instrument is very light, the design simple, and the workmanship neatly done. It is claimed that the diagrams produced are very good.

Functions of the Indicator.

The function of the Indicator is to automatically trace out on paper a diagram that will graphically represent the pressure of the steam in the cylinder of the engine to which it is attached, with all its variations during both forward and return strokes of the piston. It enables those who use or have charge of steam-engines to ascertain the condition of the parts of the engine subject to the direct action of the steam, and to what advantage the steam is applied; whether the valves are properly designed and accurately set, and if the steam-passages or ports are of the proper size to receive and discharge the steam in time to produce the best effect; what pressure of steam there is upon the piston at every position in the cylinder, as well as its average during the stroke; what is the value of the vacuum acting upon the piston of a co engine in all its positions in the cylinder, and when is t



Richards' Parallel Motion Indicator.

average; whether the exhaust passages from the cylinder are sufficiently large to give free exit to the steam, and, if not, what percentage of power is lost in forcibly expelling it; the actual consumption of steam in giving motion to the engine, and also what additional steam is used in giving motion to the shafting and millwark, the paddle-wheel or screw-propeller; and also what power is required to move the machinery, or any part of it.

In manufacturing establishments where power is let to tenants it will show how much is consumed by each, and it will also demonstrate the degree of economy in using steam at different pressures, the benefits of expansion, and the relative efficiency of different kinds of expansion-gear.

Indicator cards are of great value, as they demonstrate the initial, mean effective, and terminal pressures, the back pressure, the cushion, whether by compression or lead; the point of cut-off, and the relative economy of different engines, aside from leakage and condensation. It may be applied not only to steam-engines, but to those driven by compressed air, or any vapor or fluid, as well as to the cylinders of air-pumps, air-compressors, blast-engines, etc. The diagram produced is the joint production of two movements, viz., a vertical movement of the marking point due to the pressure of the steam acting on the piston of the instrument, in opposition to the force of a spring of known strength, and a horizontal movement of the paper, as the drum, on which it is placed, makes partial rotations to and fro coincident with the movement of the piston. Hence, when the pencil is held in contact with the paper during one revolution of the engine, both will arrive at the point from which they started at the same moment, and a closed figure will be the result, except when a great change in the load and pressure occurs during the stroke in which the diagram was taken.

The indicator diagram will also show what proportion of the boiler pressure is contained in the cylinder; how early in
stroke the highest pressure is reached; how well it is main-
l; at what point and at what pressure the steam is cut off;

whether it is cut off sharply, or in what degree it is wire-drawn; at what point, and at what pressure it is released; whether it is freely discharged, or what proportion of it (in excess of the atmosphere or the vacuum in the condenser, according as the engine is condensing or non-condensing) remains to exert a counter or back pressure; whether, before the commencement of the stroke, there is any compression of the vapor remaining in the cylinder, and if so, at what point in the stroke it commences, and to how high a pressure it rises. The foregoing particulars can only be learned by observation, though a scale, corresponding with the spring used, is needed to measure the pressures, and to locate the exact events in the stroke. The points to be calculated in estimating diagrams are the mean or average pressure; the total mean, or the mean effective pressure; the indicated horse-power, I. H. P., and the theoretical water consumption. The indicator shows the pressure at each and every point in the stroke; to represent this faithfully is its sole office. The causes which determine the form of the figure must be determined by the engineer.

Technical Terms Used in Connection with the Employment of the Indicator.

The term Adiabatic literally means no transmission. As applied to an expansion curve, it means that it correctly represents at all points the pressure due both to the volume and the temperature, just as if no transmission of heat to or from it had taken place.

Admission.—This term is applied to the induction of the steam into the cylinder when the valve opens at the commencement of the stroke.

The term Asymptote means a line which approaches nearer and nearer to some curve, but which, though infinitely extended, would never meet it. The clearance and vacuum lines of a diagram are *asymptotes of a true expansion* curve.

The letter B at the end of a diagram means that that end was taken from the bottom end of the cylinder.

A. B. or Aba. is understood to stand for above atmosphere, and B. A. or Bla. below atmosphere.

The term Compression is a term used to express the distance through which the piston moves in the cylinder after the exhaust has closed. Compression takes place between the piston and the cylinder-head at the end of each stroke; and the distance from the end of the cylinder at which it takes place depends on the amount of lap on the valve.

The term Cushion means the resistance offered on the opposite side of the piston induced by the steam shut up in the cylinder.

Cylinder efficiency.—This term is used to designate the amount of work performed in the cylinder of a steam-engine for a given pressure.

The term Clearance is used to express the extent of the space which exists between the piston, the cylinder-head, and the valve-face at each end of the stroke. See page 363.

Displacement.—This term is applied to the cubic contents, or the volume of water, steam, or air displaced by the piston during one stroke. It may be found by multiplying the area of the piston in inches by its stroke in inches. The product will be its displacement in cubic inches.

Duty.—This term is understood by engineers to mean the efficiency of steam-engines, or the number of pounds that an engine is capable of raising one foot high per second with an expenditure or consumption of one hundred pounds of coal.

The term Flexure means bending or curving. The point of flexure in a diagram is the point at which the cut-off closes and *the expansion* curve begins, as shown at C, explanatory diagram

No. 1, page 537. The point of contrary flexure is the point at which the line changes its direction by curving outwards and afterwards inwards, as shown at A, on diagram on page 537.

H. P. cyl. stands for high-pressure cylinder.

H. P. means horse-power, which, when applied to the steam-engine, means 33,000 lbs. raised one foot high; or 150 lbs. raised 220 feet high; or 550 lbs. raised one foot high in one second.

The term Hyperbola means a plane figure which is formed by cutting a portion from a cone by a plane, parallel to its axis or to any plane within the cone, which passes through the cone's vertex. The curve of the hyperbola is such, that the difference between the distances of any point in it from two given points is always equal to a given right line.

The term Isothermal means uniform or same temperature. As applied to an expansion curve, it means that such a curve represents correctly the expansion or compression of the steam when the temperature is uniform.

L. P. cyl. means low-pressure cylinder.

The term Ordinates means the vertical lines drawn across diagrams to facilitate the calculation of their power. See diagram on page 537.

The term Parallelism is generally employed, where two or more straight lines may be extended indefinitely, without any tendency to approach or diverge from one another. See atmospheric and vacuum lines on indicator diagrams.

Release. — This term is understood to mean exhaust. *Residuary* exhaust is that which follows the first release of the terminal pressure. The term *negative exhaust* is sometimes used, though not generally understood in its literal sense. It means compression *or cushion, and absolutely* amounts to the same thing, as it is merely an early product of the exhaust, for the purpose of r ing a portion of steam in the cylinder as the crank appro the centre of the stroke.

Rev. or Rev's is understood to mean revolutions per mi though *rspm* is sometimes used.

I. H. P. means indicated horse-power. It means the nu of H. P. of energy shown by the diagram of an engine, as f by multiplying together the area of the piston in square in its speed in feet per minute, and the mean effective pressure sh and dividing the product by 33,000.

N. H. P. means net horse-power, which is the I. H. P. n the friction of the engine.

The term Initial pressure is generally understood to mea pressure represented in the cylinder between the opening o steam-valve and the closing of the cut-off. More properly s ing, it is the pressure represented in the cylinder at the comm ment of the stroke, as the pressure frequently falls conside before the closing of the cut-off.

M. E. P. means mean effective pressure. It is simply amount by which the average impelling pressure exceeds average resisting or counter-pressure. The M. E. P. on the p of a steam-engine is the measure or exponent of the work formed.

The term Terminal pressure means the pressure at which steam is exhausted from the cylinder, and may be said to b exponent of the consumption of water by the engine.

The term Pipe diagram is applied to diagrams taken fro steam-pipe for the purpose of determining how much of the p ure of the steam in the pipe is lost in passing through the st 's to the cylinder.

The term Scale means the number of pounds of steam per square inch (acting on the piston of an engine) represented by each inch of vertical height on the diagram. Thus a 40 lb. scale means that each inch on the diagram represents 40 lbs. of steam per square inch, and so on.

The term Spring means the spring which is employed on the piston of the instrument, in order to resist the pressure of the steam and the vacuum. The following **table** will give the limit of pressure in the cylinder to which each spring may be subjected. The length of each spring given in the third column is such that each of them would be extended (when subjected to a perfect vacuum) to a length of $2\frac{7}{16}$ inches, which is the approximate ength which would carry the pencil to the lower limit of the range of movement above given.

Scale of Spring.	Limit of Cylinder-Pressure above Atmosphere.	Length of Spring.
15 lbs. per in.	25 lbs.	2·192 ins. = nearly $2\frac{1}{5}$ ins.
20 " "	38 "	2·255 " = a little above $2\frac{1}{4}$ "
30 " "	64 "	2·315 " = " " $2\frac{3}{10}$ "
		or nearer $2\frac{5}{16}$ "
40 " "	90 "	2·345 " = nearly $2\frac{7}{20}$ "
60 " "	143 "	2·376 " = a little over $2\frac{3}{8}$ "
80 " "	195 "	2·391 " = a little above $2\frac{2}{5}$ "

To find the corresponding limit for grades not given, *multiply* the total range of movement, 2·625 inches, by the scale of the spring, and deduct the pressure of the atmosphere.

Example.— Suppose it is desired to find the limit of pressure for a 50 lb. spring: $50 \times 2{\cdot}625 - 14{\cdot}7 = 116{\cdot}55$.

The term String, as used in these pages, means the aggregate length *of the ordinates of* an indicator diagram.

merely an early product of the exhaust, for the purpose ing a portion of steam in the cylinder as the crank the centre of the stroke.

Rev. or Rev's is understood to mean revolutio though *rspm* is sometimes used.

I. H. P. means indicated horse-power. It of H. P. of energy shown by the diagram of by multiplying together the area of the pist its speed in feet per minute, and the mean eff and dividing the product by 33,000.

N. H. P. means net horse-power, which the friction of the engine.

The term Initial pressure is generally pressure represented in the cylinder b steam-valve and the closing of the cut- ing, it is the pressure represented in the ment of the stroke, as the pressure fr before the closing of the cut-off.

M. E. P. means mean effective amount by which the average im average resisting or counter-pressure of a steam-engine is the measure formed.

The term Terminal pressure steam is exhausted from the cy exponent of the consumption of

The term Pipe diagram is ap steam-pipe for the purpose of d *ure of the steam* in the pipe *ports to the cylinder.*

in connection with both ends of
tion is preferable. It is
ams cannot be ob-
ed through a long
nnected to both ends
by experiment, that if
ends, thereby using the
ced as near as possible to
n diagrams so taken, and
ent, is not always noticeable.
on each side of the instrument, a
it, which will allow steam to be
rough the same plug, the difference
no such cock can be had, straight way-
placed as close to the *L* or *T*, to which
ed, as possible, will give sufficiently satis-
ordinary purposes. When, however, it is
agrams separately, two cocks become neces-
must also have two loops or hooks, as far apart
which the instrument is to occupy. Then it
shifted from end to end as desired. If two in-
attached to an engine, diagrams may be taken
y from both ends; but, while such an arrangement
difficulty of equalizing the events of the two ends
rument, it is open to the objection that, if there is any
in the action of the two instruments, or in the strength
springs, this circumstance will interfere with the com-

Motion of the Paper Drum.

g to the almost endless variety of engines, their peculi-
f design, etc., it is impossible to give very definite instruc-
hich will be applicable to all cases. But it must be borne
, that *the motion of* the paper drum must be coincident
t of the piston in respect to its times of stopping

of the expansion line or curve. D is the point of exhaust, which, like that of the cut-off, may be located at the point of contrary flexure, or the point where the expansion line begins to change the direction of its curvature. D E is the exhaust line. It commences at the point of exhaust, and may be considered as terminating at the end of the stroke (though, strictly speaking, it does not terminate till the exhaust port closes at *F*.) *E F* is termed the counter- or back-pressure line, and by some the vacuum or exhaust line; but the former terms are more appropriate, as they are applicable to all diagrams, whether from condensing or non-condensing engines. In the diagrams of non-condensing engines it is above the atmospheric line, *A A*; while in condensing engines it is below; but in both cases it represents some counter-pressure, since a perfect vacuum is unattainable. *F* is the point of exhaust-closure. Its exact location cannot be so readily determined as the points *C* and *D*, as, although like the former, it is anticipated somewhat by a change of pressure, it is not marked by any change in the direction of the curvature of the line. In perfectly working engines it may be located geometrically, but it is seldom necessary to do so, since for all practical purposes it is sufficient to know where the change of pressure due to the closing of the exhaust begins, and its final result. *F G* is the compression curve, and *G B* is the admission line. These constitute all the lines which belong to the diagram proper, and all that are produced by the instrument.

For certain purposes the vacuum line *V V*, and the clearance line *H H*, diagram No. 1, are drawn, the former parallel to the atmospheric line, and at such a distance below it as will represent, according to the scale used, the pressure of the atmosphere
pa or was supposed to be, at the time and place at which
was taken. For this purpose it is usual, when great
desired, to consult a barometer at the time, and
ading on the card; but, in the absence of a barom-
al to assume the pressure at 14.7 lbs. per square

, which is the average at sea level; but, since the pressure
inishes at the rate of $\frac{1}{16}$ lb. for each 189 feet of elevation,
wance should be made for the known or estimated eleva-
of the locality. It should also be remembered that the
ssure will vary nearly ½ lb., and sometimes more, from changes
the weather.

The clearance line *H H*, **diagram No. I,** is drawn perpendicular
he atmospheric and vacuum lines, and at such a distance from
induction end of the diagram, that the space between them
bear the same proportion to the whole length of the latter
he whole volume of clearance bears to the piston displace-
t. When the amount of clearance is unknown, and it is not
ticable either to calculate it or measure it by filling the space
water, it must be approximated as near as possible from the
wn clearance of engines of similar construction. The largest
rance will be generally found in the smaller sized engines of
ordinary single slide-valve type. Five such engines tested at
Cincinnati Industrial Exposition of 1875, had the following
unts 9, 9½, 10, 11⅘, and 12 per cent. of the cubic contents of
cylinder. Next to these will be the larger sizes of the same
, in which the clearance will range from 6 to 10 per cent.
en two slide-valves are used with short, direct ports, but ex-
sting under the valves, the clearance will average from 3 to 6
cent., according to the proportionate length of the stroke, the
est strokes having the smallest per cent. Corliss engines, in
h the stroke is about three times the bore, have about 3 per
. The least amount of clearance is obtained from valves de-
ed to exhaust at both ends of the cylinder, instead of in the
re, as in the case of the ordinary single slide-valve. By such
rrangement of the steam- and exhaust-valves, the clearance
in many instances been reduced to 1¼ per cent. The clearance
oppet-valve engines is more difficult to calculate than in slide-
e engines; but, as a general thing, it does not exceed 5 per cent.
hould be measured with water, when it is desirable to ascertain
rately the cubic contents of the clearance. In poppet-valve

ity in the exhaust-ports or pipes, or both.
6. **The compression curve,** *F G*, owes its form to the
law governs the expansion curve, and its degree of co
ness may be tested by the same methods. The only
between the two are in the quantities of steam ev
production, and the order of their formation; the en
corresponding to the beginning of the other. As to t
required to satisfy the best conditions, some difference
exists. It is ascertained that a certain amount is adv
as a means of arresting the momentum of the reciproc
while changing the direction of the force on the cra
more gentle and quiet manner, than would be done by
sion of steam as an opposing force. If the compressio
properly speaking, the cushion has fulfilled its functi
duction will find the parts already prepared for the
prevent a jar or thump. The maximum pressure reac
cushion should never be greater than the average initia
but within this limit considerable latitude exists, as, whi
ishes the power of the engine, it lessens the consumptio
The less the exhaust-lap, the earlier the exhaust will

other with an easy curve. When a single slide-valve is used, the steam- and exhaust-lap must be provided for in its con- tion, and cannot be subsequently changed without a change roportion. But since it is not the absolute amount of lap, but nount relatively to the travel of the valve, which determines ifluence, it follows that, by reducing the travel, the lap both n and exhaust will be virtually increased, and *vice versâ.* change of travel must be accompanied by such change of lar advance as will maintain the proper lead. The adjust- of the cut-off by the link-motion of the locomotive is an nce of such change of travel and angular advance.

the foregoing description all the capital letters refer to dia- No. 1, on page 537.

hen two slide-valves are used, each performing the functions duction and exhaust at its own end of the cylinder, the steam- nay be increased by setting them farther apart, and dimin- by contracting their connection ; but in such cases steam-lap tained at the expense of the exhaust-lap, and *vice versâ.* ing learned from an engine embodying correct construction performance the general features which should characterize gram, the *engineer* will have no difficulty in recognizing ts as well as deviations from diagram No. 1, on page 537. e conditions should be understood before the slide-valve, tling engine diagram can be intelligently criticised.

Diagrams taken from Automatic Cut-Off Engines.

e points of difference between diagrams from automatic ff engines and those from slide-valve engines will be mainly d in the steam lines, the points of cut-off, and the expansion e. When the automatic cut-off engine is worked in accord- with the theory of its operation, the steam is never throttled e purpose of regulating the speed, but is admitted freely to alves, the speed being regulated solely by means of variations e *point of cut-off.* *Hence,* the steam line should indicate a pressure equal to that in the boiler, whatever the load may be, and would undoubtedly do so, if the proportions were good and the valve-gear in perfect order. The necessary difference, then, between the throttling and automatic cut-off engine diagrams, may be thus stated. In the former, the height of the steam line varies with the load, the length remaining the same; in the latter, the length of the steam line varies with the load and pressure, the height remaining always approximately that of the boiler pressure.

The theoretical diagram.—From what has been said in the foregoing paragraphs, it is clear that a theoretical diagram may be constructed, representing perfect performance on the automatic cut-off principle, which cannot be done in the other case, as the height and conformation of the steam line depends on conditions too numerous and complex for analysis. Thus, with a given boiler-pressure for a steam line, a straight horizontal line may be drawn, corresponding with that pressure, and, from a given point of cut-off, an expansion curve may be drawn having the properties already described, and reaching to the end of the stroke. If the remaining terminal pressure is greater or less than the counter-pressure, a vertical line extending upwards or downwards to the height required by the counter-pressure will represent a perfect exhaust line. Then, for the return stroke, a line coincident with the atmosphere or a perfect vacuum, according as the engine is non-condensing or condensing, will represent the counter-pressure, and a vertical line up to the beginning of the steam line will represent the admission line and complete the figure.

If a compression curve is desired, it may be drawn through the assumed or actual point of exhaust-closure on the counter-pressure line, but such a curve cannot originate from a perfect vacuum. when the diagram is from a condensing engine, and the ompression curve is to be tested by a theoretical one, the st be based on the actual counter-pressure present at the f the port.

theoretical diagram being for the present assumed to be fect, not in the sense of representing the best conditions in an nomical point of view, but only the most perfect performance ssible under given conditions, is nevertheless the standard with ich the actual one is to be compared, and by which it is to be ged. For this purpose it is customary to draw it around the ual, so that the imperfections of the latter may be readily seen their magnitude estimated.

Application of the Theoretic Curve.

n tracing the theoretic curve on diagrams from different ines, a great difference in the degree of theoretical correctness wn in their expansion curves is revealed. The deviation from theoretical is always in the direction of a higher terminal ssure, unless it is caused by excessive piston leakage. This y be explained on two suppositions, viz., leakage of the cut- valves, and evaporation of the spray or water of supersat- tion in the steam during expansion as the pressure decreases. recently the former was the only explanation offered, but, in re modern times, the latter has almost entirely displaced it. ere is no doubt that both causes are in some degree responsible the phenomenon, but the diagram itself seldom furnishes any able indications pointing to either cause to the exclusion of the er; nor does a study of the conditions under which the greatest rrectness shows itself throw much light on the subject. As a eral rule, large engines give more correct expansion curves than ll ones, though numerous exceptions are met with in both es.

ncorrectness is generally less with heavy loads than with light s. But both the foregoing facts can be explained on either ry, since, with equal care in the fitting of the valves, a large ine will leak less in proportion to the amount of steam used n a small one. But the evaporation of the spray will be less fect in the former than in the latter, owing to the longer time *pied in effecting a* given degree of expansion, during which l Pressure,

on of the ste
er pressure i
tion and perfo
ich most near
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at the lowest press
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duce a lower termina
fil the conditions for v
ent to rely on the steam-
as it has been recently tes
changes deteriorate by use, esp
or cold. When practicable, th
blocked, or placed on the centre
full pressure, and a line trac
d a difference of four or five
pressure be detected, how is t
The pipe may be too small, l
dequate; or both these defec
r, a connection should be made
eam-pipe above or below the
able. By means of this connec
ctuations of pressure in the pip
am. A diagram produced in
pressure is due to the po
ss of pressure falls, when it is adm
he initial pressure but little r
the steam is cut off, as t
after the can fill, the pressur
the pipe evidently
ut the middle of the st
boiler pressure. At

stroke it rises again, but this time not so high as it did at its first rise, probably not above boiler pressure. These secondary fluctuations possess no special significance, except as showing that the boiler pressure is to be determined by finding the mean of their extremes. Their frequency during the stroke will depend on the length of the pipe as determining their frequency in time, and on the speed of the engine as determining their relative frequency. The pressure of the steam also affects them, as high-pressure steam is denser than low. The trouble involved in making the necessary connection for such a diagram will of course exclude them in most cases, but their value to the engineer, as a means of arriving at correct proportions for the pipes and ports, will be apparent.

The Mean Effective Pressure.

Whatever uncertainty may attach to the inferences deduced from indicator diagrams, there is every reason to believe that, provided that the spring is correct, the instrument in good working order, and its indications mathematically calculated, the conclusions will be reliable. The usual method of calculating the mean effective pressure is to divide the diagram into any suitable number of equal spaces by lines or *ordinates*, to measure the centre of each space with the proper scale, and to take the average of the several pressures by dividing their sum by their number. But since it is easier to measure on a line than to guess at the centre between two lines, it will be preferable to make the first and last spaces half the width of the rest, which will make the lines stand in the centres of equal spaces. The measurements are then taken on them. Diagram No. 1, page 537, is lined in this manner. The most expeditious and accurate method of obtaining the average of these ordinates is to take a slip of paper, apply its edge to each of them in succession, and mark their combined [illegible] on it. This length in inches multiplied by the scale of the [illegible] used, and the product divided by the number of ordinates [illegible]*d*, will give the desired average. By using a sharp-pointed rument, as the point of a knife, thrusting it into the paper at foot of each ordinate, moving it to the top of the next, and ying the strip with it, the measurement may be taken with at ease and rapidity.

The simplest method is to measure the ordinates between the ect and counter-pressure lines. This will give results accurate ugh for most purposes; in fact, it will give the mean average the two ends with entire accuracy, and this must always be ob- ied as a basis for calculating the power of the engine. But, e a diagram, from either end of the cylinder, represents, by its er line, the pressure which impels the piston during one stroke, by its lower, the counter-pressure which opposes it during the ke in the opposite direction, it follows that, from either diagram ne, a corrrect balance for either of the two strokes which it resents cannot be struck. To do this, the mean counter-pressure he one must be deducted from the mean impelling pressure of the er. To obtain these pressures separately, it is necessary to draw measure the ordinates from the lines representing them to the uum line. This, however, is unnecessary, except for very ac- ate analysis. In general, the counter-pressure of the two strokes be very nearly equal, especially if the exhaust and cushion properly equalized; and even where they are unequal, the final rage of the two ends will be correct.

The number of ordinates may preferably be one-fourth, one- d, one-half, or equal to the number representing the scale used; which case it will only be necessary to multiply the combined gth of the ordinates (or the *string*, as it may be called) by 4, r 2, as the case may be, to obtain the desired result. If the nber is equal to the scale, the multiplier, being 1, need not be d. Thus, suppose the scale to be 40, the number of ordinates and the string 14½ inches. As the scale represents twice the nber of ordinates, the string being multiplied by 2 will give a duct of 29 lbs. mean pressure. Or suppose diagrams to be en from both ends of the cylinder, either on the same paper or rately, and the one to be calculated and averaged with the

[illegible]

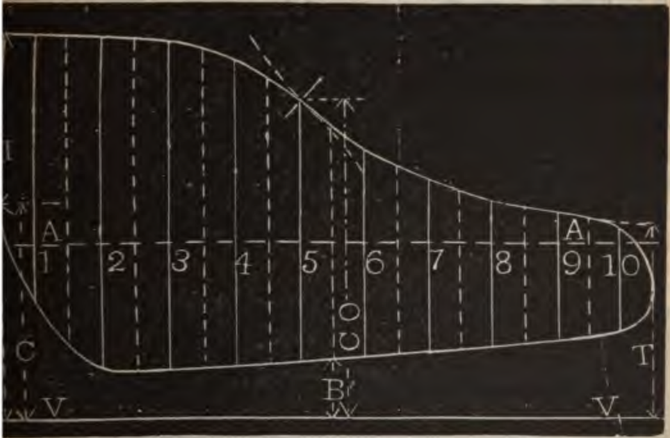
When diagrams are met with in which the exp
sion line crosses the counterpressure line, the tallying should b
the beginning up to the point where the lines cross, a
backwards direction on the strip so as to cancel th
tally already made. When the terminal end is r
remainder of the tallying line made will give the mean ef
see [illegible] in the usual way; or the total mean i
counterpressure above vacuum may be found separat
difference ascertained.

To Space the Ordinates.

Draw vertical lines touching the ends of diagram
E E and apply a rule across them in a more or less o
tion, till some division on the rule, as $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{10}$, $\frac{1}{4}$, or
the distance between the points where the rule cros
an even multiple of the number of ordinates de
the dotted oblique line in diagram No. 1 is $3\frac{3}{4}$ inch
contains the $\frac{1}{16}$ division 60 times; consequently, $\frac{3}{16}$ f
each end, and $\frac{6}{16}$ for the other spaces, will correctl

P. value of each pound. See table on page 566. Then multiply M. E. P. by this value. This method is preferable to multiing by the M. E. P. before dividing, as, when several diagrams n the same engine representing varying loads are to be calcued, the value when once obtained will answer for all, the speed ng practically the same in each case. The area of the piston- is generally ignored in such calculations, though it will diminthe area of one side of the piston about $\frac{1}{40}$.

he custom of dividing the indicator card into ten ordinates been generally adopted by engineers because ten is the most



venient number for a divisor, since the process of dividing by onsists merely of pointing off one decimal. The M. E. P. is ertained by dividing the aggregate length of the ordinates by ir number, and multiplying the quotient by the scale of the gram. The following instructions will be found useful to pers unaccustomed to make the calculation.

irst. — *Divide* the card into ten equal parts, as shown by the ted lines in the above diagram, after which draw a line exactly through the centre of each space, as shown by the full lines 1, 2, 3, etc. Then draw the dotted line *A A*, representing the atmospheric line, also draw the full line *V V*, representing the zero, or vacuum line, which is equal to $14\frac{7}{10}$ pounds, below the atmospheric line; then measure the card at the following points:

The initial-pressure as shown at . . . . . . *I.*
The pressure at the point of cut-off . . . . . *C.O.*
The terminal-pressure at . . . . *T.*
The pressure at the end of the cushion . . . . *C.*

Next measure the full lines, or ordinates 1, 2, 3, etc., with a slip of paper, marking with a sharp pencil or the point of a knife the length of each, until it contains the sum of all their lengths, which in this case will be found to be 11·75 inches; then, from the mean length $\frac{11{\cdot}75}{10} = 1{\cdot}175$ inches, and the mean-pressure $1{\cdot}175 \times 16$ scale of the indicator $= 18{\cdot}80$ pounds; the correct rendering of a card would be as follows:

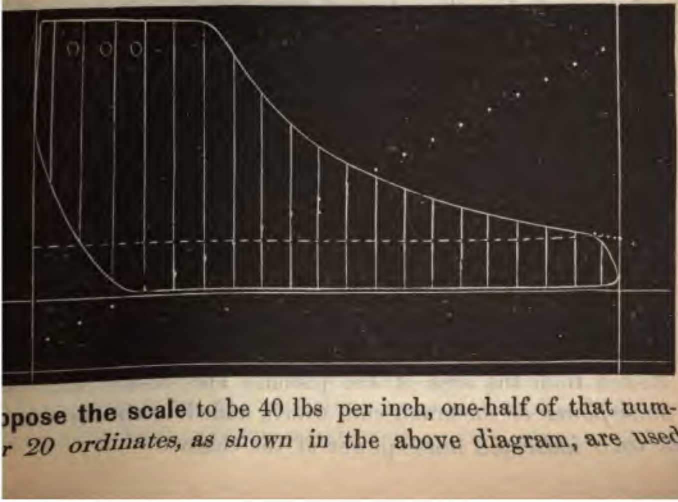
Initial-pressure, (above zero) = *I.* = 32·0lbs.
Pressure at cut-off " " = *C. O.* = 28·0 "
Terminal-pressure " " = *T.* = 17·0 "
Mean back-pressure " " = *B.* = 5·6 "
Pressure at end of cushion (above zero) = *C.* = 18·5 "
Mean effective pressure = 18·8 "

Suppose the diagram to be taken from one end of a cylind 50 inches in diameter (with a stroke of 48 inches), making revolutions per minute, and the area of piston to be 1963·5 squar inches, then $1963{\cdot}5 \times 18{\cdot}8 = 36{,}913{\cdot}8$. This pressure acts the piston throughout the stroke, 48 inches, 50 times a minut and the work done on one side of the piston in each minute woul be $36{,}913{\cdot}8 \times 50 \times \frac{48}{12} = 7{,}382{,}760$. Now, if another diagram wer taken from the other end of the cylinder, and the mea be the same, the total work done by the engine each minu

$\frac{7{,}382{,}760 \times 2}{33{,}000} = 447$ horse-power.

n the analysis of diagrams in this work, the custom of dividing diagram into ten ordinates is sometimes departed from, because, he first place, ten ordinates are not considered enough, in all es, to insure accurate calculation; and, secondly, because, when the nber of ordinates is made the same, or one-half, one-third, or -fourth as many as there are pounds per inch in the scale he diagram, the calculation is, if anything, simpler than the process, since the sum of the ordinates, as measured on the of paper in inches, is the mean effective pressure at once, n the number of ordinates equals the scale, and in other cases ears the same relation to it that the number of ordinates does ie scale. Ten ordinates may be used, however, for such scales re divisible by 10.

ppose the scale to be 60, and the number of ordinates 10, that the sum of their lengths is 7 inches. According to the er process, $\frac{7}{10} = \cdot 7 \times 60 = 42$ lbs.; by the latter method, supg the number of ordinates to be $\frac{1}{6}$ of the scale, the process is ly $6 \times 7 = 42$; that is, the mean effective pressure would be mes the sum of the length of the ordinates, if the scale is six their number.



pose the scale to be 40 lbs per inch, one-half of that numr *20 ordinates, as shown* in the above diagram, are used;

and suppose the sum of their lengths is found by the process of measurement above given to be 15·3 inches, then twice that number will be the mean effective pressure in pounds per square inch, or 15·3×2=30·6 lbs. Suppose the cylinder of an engine is 20 inches in diameter, 40 inch stroke, running at a speed of 75 revolutions, or 500 feet per minute; the area of such a piston would be 314·16 square inches; hence, $\frac{314{\cdot}16\times500}{33000}=4{\cdot}727$ horse-power for each pound of mean effective pressure. The latter being 30·6, then 30·6 × 4·727 = 145,656, the indicated horse-power.

The Indicated Horse-power may be found more accurately by measuring the exact area of the space enclosed by the diagram. This may be done with the aid of the *planimeter*, which is described on pp. 566–569. Having determined the area of the diagram, proceed as follows:

Rule for finding the mean effective pressure from the area of the diagram.

Multiply the area of the diagram in square inches by the scale of the spring and divide the product by the length of the diagram in inches. The quotient will be the mean effective pressure.

Rule for finding the indicated horse-power.

Use the mean effective pressure thus obtained and proceed as above, or more exactly:

Take the area of the head end diagram and multiply it by the scale of the spring, and the ratio of the length of the stroke in feet to the length of the diagram in inches. This product is the work done per square inch of piston area each stroke, and hence it must be multiplied by the piston area in square inches and the number of revolutions per minute and divided by 33,000, to give the horse-power of the head end.

Next, take the area of the crank end diagram and proceed in *the same* way, except that the area of the piston-rod must be de*ducted from* the area of the piston. This result will give the *rse-power* of the crank end, which, added to the first, will giv *total* indicated horse-power of the engine.

xample.—In diagram No. 21, on page 554, suppose that T esents the head and B the crank end, and suppose that the s of these two, as measured by the planimeter, are 4.087 and 5 square inches respectively. The scale of the spring is y pounds to the inch and the piston-rod is four inches in ieter. Required the mean effective pressure and the horse- r of either end and the total indicated horse-power?

nce the length of the diagram is 4½ inches we have

$$\text{M. E. P. (head end)} = \frac{4.087 \times 30}{4.5} = 27.25 \text{ pounds.}$$

$$\text{M. E. P. (crank end)} = \frac{4.275 \times 30}{4.5} = 28.50 \text{ pounds.}$$

$$\text{M. E. P. (average)} \qquad = 27.875 \text{ pounds.}$$

$$\text{I. H. P.} = \frac{27.875 \times 720 \times 1847.45}{33{,}000} = 1123.36$$

f the horse-power is calculated from the diagram direct, tak- into account the area of the piston-rod, the ratio of the length troke to that of the diagram is $\frac{6}{4.5} = 1.333$, and the area of the on-rod is 12.566 square inches, hence

$$\text{I. H. P. (head end)} = \frac{4.087 \times 30 \times 1.333 \times 1847.45 \times 60}{33{,}000}$$

$$= 549.2$$

$$\text{I. H. P. (crank end)} = \frac{4.275 \times 30 \times 1.333 \times 1834.88 \times 60}{33{,}000}$$

$$= 570.5$$

I. H. P. (total) = 549.2 + 570.5 = 1119.70[*]

The *calculation on page 555* for the same engine gives 1123.36 H. P., *d of 1119.70 H. P.* The latter is the more accurate because the diame- *he piston rod is taken into* consideration.

In order to make this calculation more clear let us assume that when the cut-off takes place later in the stroke the engine increases in speed to 80 revolutions per minute and the power increases to 2000 indicated horse-power. Neglecting the influence of the area of the piston-rod, what must be the mean effective pressure under these conditions?

Total work done per minute =

$$33{,}000 \times 2000 = 66{,}000{,}000 \text{ foot-pounds.}$$

Work done per stroke =

$$\frac{66{,}000{,}000}{2 \times 80} = 412{,}500 \text{ foot-pounds.}$$

Space traversed by piston per stroke = 6 feet.

Mean force acting on piston =

$$\frac{412{,}500}{6} = 68{,}750 \text{ pounds.}$$

Area of piston,

$$0.7854 \times 48.5 \times 48.5 = 1847.45 \text{ square inches.}$$

Mean force on each square inch of piston area = mean effective pressure =

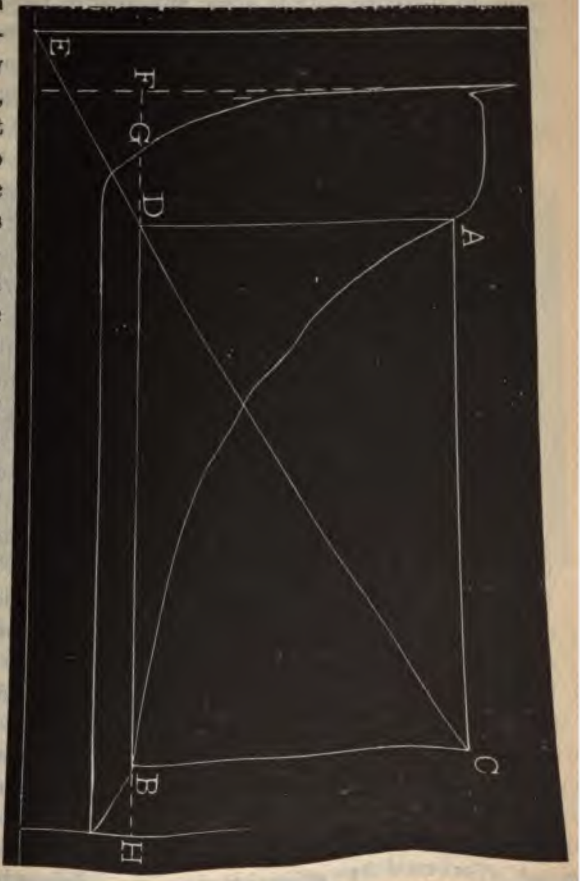
$$\frac{68{,}750}{1847.45} = 37.2 \text{ pounds per square inch.}$$

The net or brake horse-power of a steam engine may be found from the indicator diagram in the following manner:

Take an indicator diagram when the engine is running with full load, and another when it is running with no load except the internal friction. The latter is called the *friction diagram*. Deduct the area of the friction diagram from that of the full load diagram, and from this net area calculate the mean effective pressure. The latter, used in the formula for horse-power, will give the actual horse-power available at the shaft. The horse-
er consumed by any machine which the engine is driving may
und by taking diagrams with the machine on and off, and
ating the horse-power with the difference of the two areas.

Formula for Finding the Theoretical Clearance when the Scale is known.

From two points in the expansion curve, as *A B*, the former
early and the latter as late as possible consistent with the cer-
inty that both
e in the expan-
on curve, draw
e vertical lines,
D and *B C*, at
ght angles to
e atmospheric
d vacuum lines
d the horizon-
lines, *A C* and
D, forming the
rallelogram, *A*
D B. Then,
ough *C D*
w a diagonal
e, continuing
lownwards till
intersects the
cuum line at
and from this
nt draw a ver-
l line, which
l represent the
rance. It will,
the majority
cases, indicate
re clearance
n actually ex-
; but if, as is
etimes the case with large engines of good construction a



Indicator Diagrams.

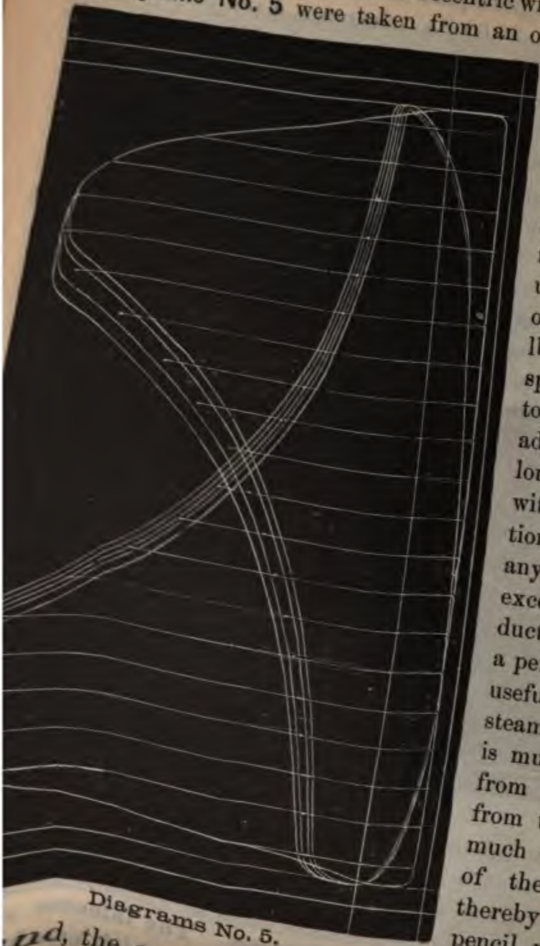
indicator diagrams are the perfect pictures of the perform- of the engines from which they are taken, provided the in- r is in good order. There are two senses in which a diagram to be perfect or imperfect. First, it may be in perfect con- y to existing conditions, as clearance, load, steam-pressure, ough all of these conditions may be far from the best; or, , it may not only conform to the above conditions, but it present the best attainable conditions, which would include rance at all, which is unattainable.

Explanatory Diagram No. 1.

iagram No. I, *B C* shows the steam line; *C*, point of cut-off; xpansion curve; *D*, exhaust; *D E*, exhaust line; *E F*, counter- re line; *F*, point of exhaust-closure; *F G*, compression curve; admission line; *A A*, atmospheric line; *V V*, vacuum line; line representing the clearance; 0 0 0, ordinates for ascertain- e average pressure; *I*, continuation of the expansion curve to stroke, to give the terminal-pressure for the purpose of calcu- theoretical consumption; *J*, the point in the compression curve the pressure equals the terminal; consequently, *I J* is the pro- *of the whole stroke* taken as the measure of the consumption.

the lateral vibration of the connecting-rod, which gives a movement exactly equivalent to that of an eccentric without angular advance.

Diagrams No. 5 were taken from an old Corliss engine that had been running in the penitentiary at Jackson, Michigan, for about 25 years. Scale, 40; clearance about 3 per cent.; mean effective pressure, 47·5 lbs.; mean of the two ends, 47½ lbs. It possesses no special interest, save to show the effects of adjustment due to long wear and use, without the application of an indicator or any other test. The excessively late induction would cause a perceptible loss of useful effect in the steam. The exhaust is much less perfect from one end than from the other, and much of the benefit of the vacuum is thereby lost. The pencil was held on during several revolutions, the governor being over-sensitive and fluctuating, and several lines were drawn at each revolution.



Diagrams No. 5.

nd, the governor being over-sensitive and fluctuating,
ines were drawn at each revolution.

gram No. 6 was taken from a Harris Corliss engine oper-
at the Cincinnati Industrial Exposition of 1875. Size, 16

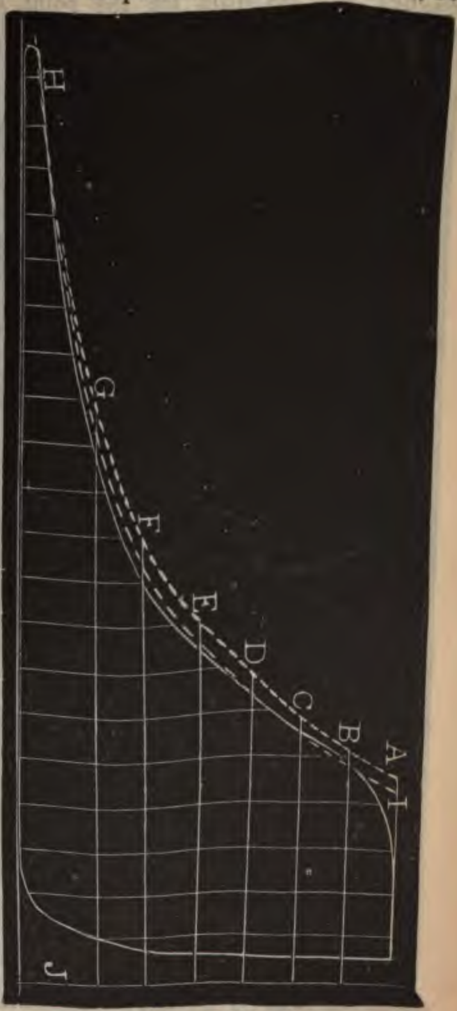


Diagram No. 6.

; speed, 60 revolu-
or 480 feet of piston
per minute. Both
othermal, *I*, and the
tic curves are drawn.
cing the latter, the
ing process was used.
rizontal lines, *A*, *B*,
E, *F*, *G*, represent to-
ssures (above vacu-
, respectively, 90, 80,
50, 40, and 30 lbs.,
lumes of which are
33, 378, 437, 518,
d 838. At the point,
ere the curve termi-
the total pressure is
the volume of which
. Now, it is evident
the distance, *H J*,
is 4·7 inches, repre-
1290, the distance,
representing 838,
olume of 30 lbs.,)
proportionately as
shorter than *H J*
is less than 1290.
the formula, 1290 :
: 838 : 3·05, or
38
— = 3·05, will give

stance (3·05) from
arance line, J, to

Diagrams No. 9 were taken from a **Cummer** slide-valve with riding cut-off, built troit, Michigan. Size, 2 inches; speed, 80 revolu 480 feet per minute; sc mean effective pressure en; clearance is unknow suming it to be 4 per cen is about what its constru quires, the theoretical one end shows correct ance, but that at the oth considerable deviation. a case, taking the size of gine into consideration, planation of this defect tween two suppositions, the cut-off valve leaked end and not at the other that the volume of clea greater at one end than other. If the engine h a small one, the supposi the escape of the expandin from the right-hand end a leaky slide-valve would missible; but the curve end is just what an engin size given should produ out leakage of any kind; the left hand is the one t attention is directed for th of the difference between and the supposition of cut-off valve is the mo [illegible]le one.

Diagrams No. 9.

gram No. 10 was taken from one of a pair of 16 × 30 inch slide-valve engines, which were attached to the same shaft ranks at right angles to each other. The piston speed was et per minute; mean effective pressure, 32·3. The sudden ation of the compression curve with a descending hook sug-

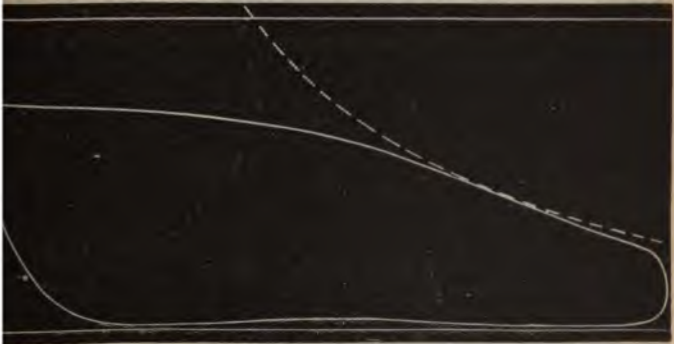
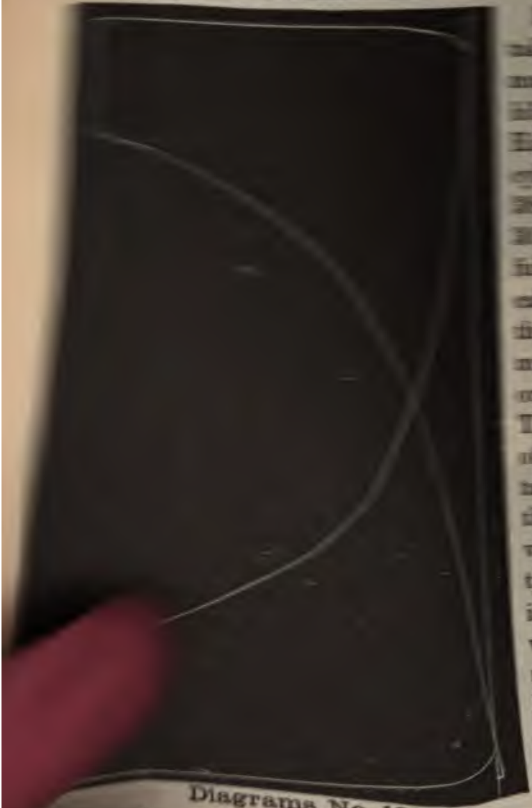


Diagram No. 10.

akage of the piston or valve. The more rapid fall of the ion curve than theory requires, strengthens this supposition, ints to the piston as the source of the trouble. The rise of -pressure in the middle of the return stroke is due to the of the exhaust of the other engine.

Diagram No. 11.

am No. II was taken from an engine, 18 × 36, in a mil [illegible] Diagrams. The cut-off was effected by a special cut-off [illegible] operated by a Kendall's patent governor, [illegible] of an eccentric [illegible] similar to that of the link-motion [illegible]. The most striking defect is the extremely late [illegible] of the eccentric, leading to a [illegible] of the stroke. The exhaust is too late, [illegible].



Diagrams No. 12.

Diagrams No. 12 were taken from a Brown automatic cut-off engine on exhibition at the Centennial Exposition. Diameter of cylinder, 15 inches; stroke, 30; revolutions, 65; scale, 30 lbs. They show wonderful conformity to theoretical requirements, and that the engine and indicat must be in the most per order to produce such The unusually shar off corners are due to tain extent to the fac the induction and valves are of the gr type, and that the ind is of an improved pa with exceptionally moving parts; but neve less there is an air of picion about them, that leave doubts of their uineness in the minds of engineers who understand the action of the val engines.

gram No. 13 was taken from a John Cooper engine, built
the Babcock and Wilcox patent, at Mount Vernon, Ohio.
ter of cylinder, 20 inches; stroke, 36 inches; boiler-press-
5 lbs. per square
speed, 60 revolu-
per minute; scale,
per square inch.
ows no imperfec-
worthy of note, ex-
he imperfect re-
n of the compres-
ressure, owing un-
edly to leakage
of the piston or
alve. Such a de-
a very common
nd may appear
no other evi-
of leakage exist,
h case it is prob-
hat, if the com-
n escapes by the
the leakage ex-
the end of the
or, if it escapes
valve, only the
which retains
ompression-press-
imperfectly. In
resent case the
ession curve com-
s promptly, but
nbs completely, and falls again before admission, show-
hat the leakage commences suddenly near the end of the

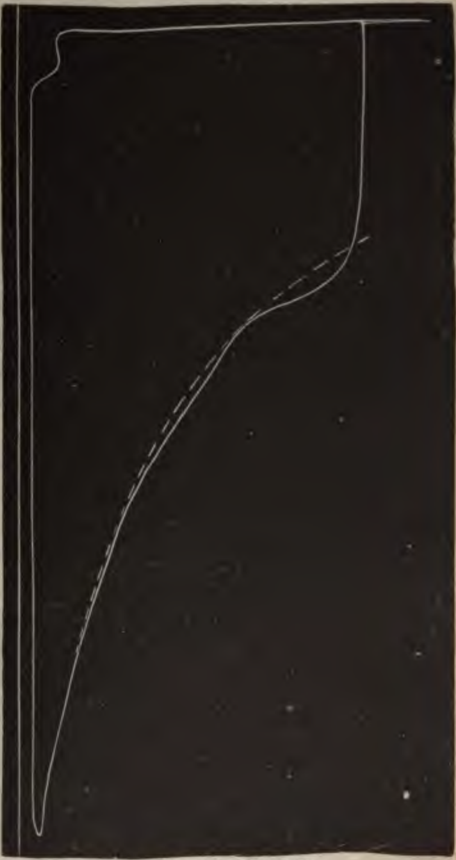


Diagram No. 13.

Diagram No. 14 was taken from a 9 × 15 high-pressure sin lide-valve engine. Speed, 190 revolutions per minute; scale,

Diagram No. 14.

clearance, 6·4 per cent.; mean effective pressure, 41 lbs. It noticed that its events occur late, which defects arise from co pressure, indicating obstructed exhaust and imperfect rise compression-pressure, suggesting leakage of either the va piston by which the compression-pressure has escaped.

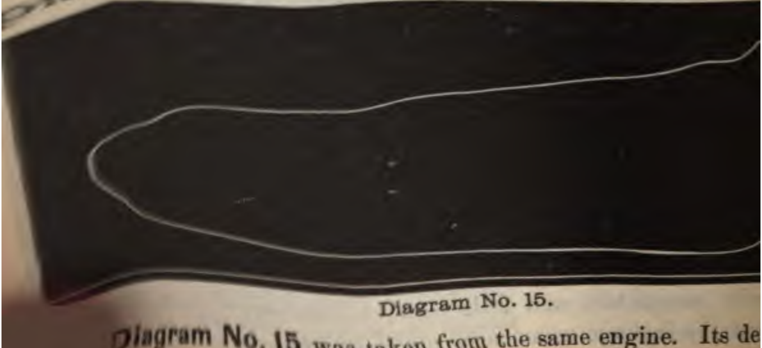


Diagram No. 15.

Diagram No. 15 was taken from the same engine. Its de formance, as shown by its late cut-off, late and insuffici

Diagrams Nos. 17 and 18 were taken respectively from the high- and low-pressure cylinders of the compound engines of the steam-ship Pennsylvania, of the American Line, built by Cramp & Sons, marine engineers and naval architects of Philadelphia speed, 58·3 revolutio per minute. The di grams present no fects; the slight d ference in the me pressure of the t ends of each card in the case of all v tical engines) is to the unbalan weights of the re rocating parts.

Diagram No. 17.

The theoreti clearance is abou per cent.; and, as is probably not from the actual, expansion curves s very correct perfo ance. The amoun vacuum shown is 1 10½ lbs., which is ab the average of mar engines.

As these engines are said to be more economical than a heretofore used on ocean steamers, a calculation of their theor ical economy will not be without interest. Taking the steam

mall cylinder as the measure of consumption, the first
to find for it the equiv-
he mean-pressure acting
rge piston. The area
all cylinder is 2574·1975
ches, and that of the
e is 6379·4238 square
The M. E. P. of the
inder is 33·25 lbs., and
e other 9·25 lbs. The
multiply the area of
piston by the mean-
acting on it, and divide
uct by the area of the
ton. But, in the pres-
it will involve less labor
m the division first,
divide the area of the
on by that of the small
multiply the quotient
. E. P. of the large one.
9·4238 ÷ 2574·1975 ×
·33 lbs., which, added
E. P. of the small cyl-
3·25 + 19·33 = 52·58
s for it the equivalent
52·58. Then the vol-
e average terminal (28
g 895, the calculation
s follows: $\frac{859·375}{895 \times 52·58}$
s. From this the de-
or compression will be
per cent., or ·48 lbs., leaving (16·2 — ·48) 15·70 lbs. per
per hour, which justifies theoretically the claim made

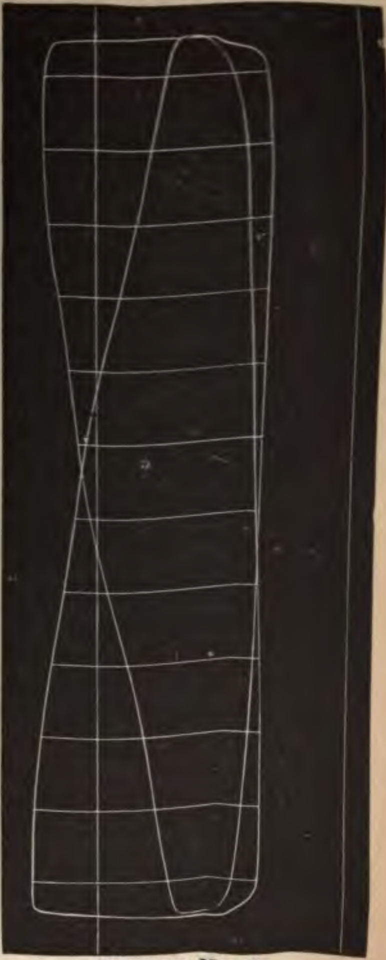


Diagram No. 18.

essure of both ends of the high-pressure cylinder is 47
vacuum); volume, 550. Of the low-pressure cylinder is
bove vac-
me, 2100.
lents for
er of the
power of
follows:
gh-press-
r, 43 125
= 86·765.
-pressure
14·25 +
28·332.
data, the
of the
rates of
umption
ach cyl-
ws: For
ressure
59·375
65×550
per indi-
e-power
For the
cylin-
75
2100 =
ndicated
er per

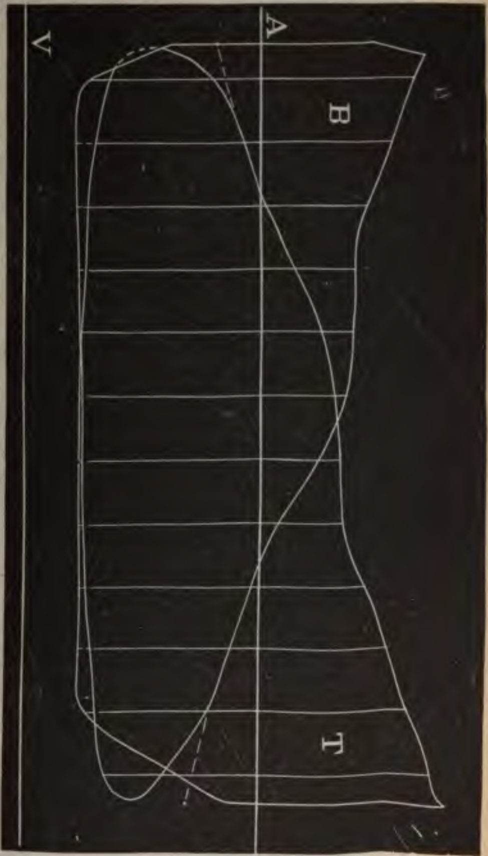
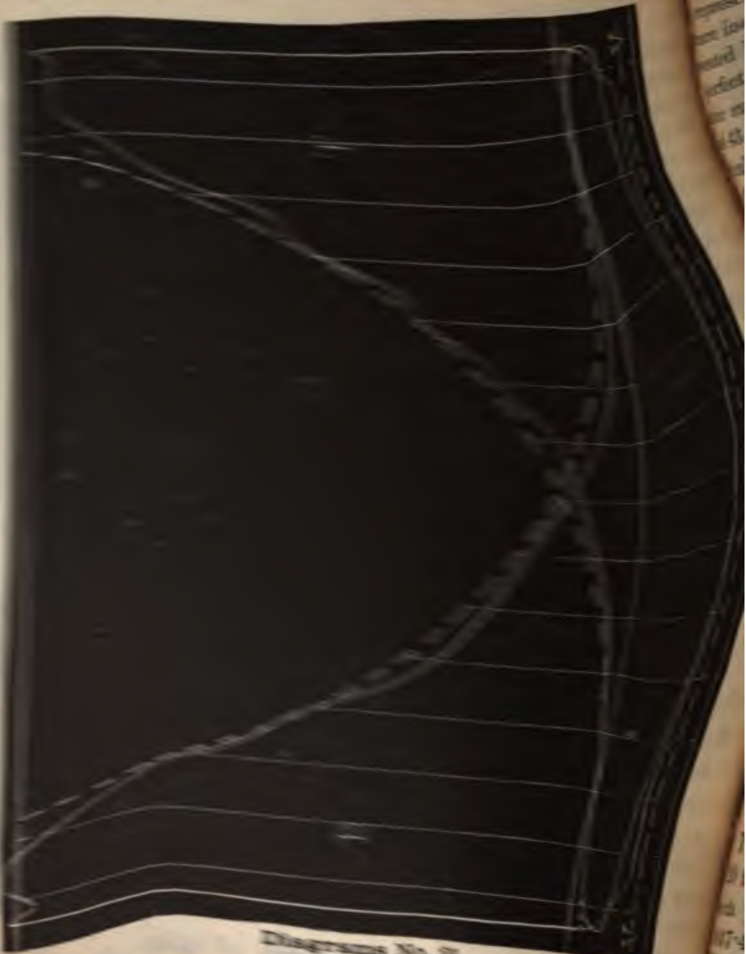


Diagram No. 20.

imum **compression-pressures** of each are so nearly
terminal, that no correction for clearance and cushion
de. *The diagrams indicate good performance in all*

am, the lack of smoothness in the lines being presumably to the [illegible] motion of the vessel.



Diagrams No. 21.

grams No. 21 were taken from the simple surface-condensing of the steamship Vera Cruz, of Alexander's Line, on her

Diagrams No. 22 were taken from the same engine as diagra No. 21, on the steamer's forty-fourth return voyage to New York from Havana. It represents considerably lighter load than diagram No. 21, and shows the attainment of a better vacuum, is more perfect in its lines, and is equally correct in its expansion curves. The line above the diagrams represents the boiler-pressure. The calculations are as follows: Mean effective pressure of diagram *B*, 17 lbs. Mean effective pressure of diagram *T*, 19·5 lbs. Mean of the two, 18·25 lbs.

Diagrams No. 22.

Terminal-pressure of bottom diagram, . . .	6· lbs.
Terminal-pressure of top diagram, ...	7· lbs.
Mean of the two, ...	6·5 lbs.

Taking 3600 as *approximately* the volume of 6·5 lbs. pressu *the rate of water consumption* will be 13·08 lbs. per indi *horse-power* per *hour*, which, if equalled, has never been exceeded by any other engines in this country, either simple or compound.

Diagrams Nos. 23 and 24 were taken from the simple surface-condensing engines of the steamship Knickerbocker, of Cromwell's line, and running between New York and Boston. Many of the conditions could not be ascertained, but the mean effectiv

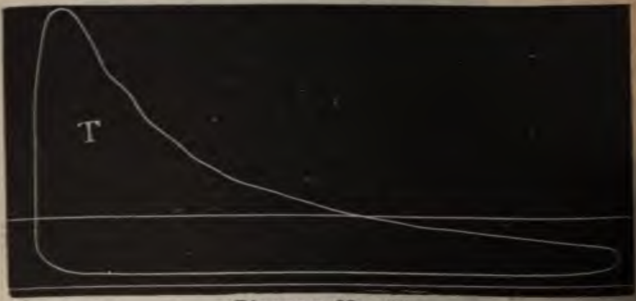


Diagram No. 23.

Diagram No. 24.

pressure of *B* appears to be about 29 lbs., and of *T*, 19 lbs. The calculations of the rate of water consumption give for the card, *3·74 lbs.*, and for *T*, 15·55. These very low rates are to some *t due to* the very perfect vacuum attained. With the excep actual pressure on the piston, the most probable cause of the rise in the curve is, that the steam was admitted during the entire stroke to *E*, but not with sufficient freedom to maintain the pressure when the piston travel was greatest, or that the connecting-pipe between the cylinder and the indicator was long and tortuous. The right hand diagram is not so peculiar, as it shows a horizontal steam-line and a tolerably well defined point of cut-off, *C*, and expansion curve. In both the exhaust is much more free and prompt than the induction. The best vacuum was obtained at the beginning of the return stroke, *F F*, after which the lines undulate in a manner not easily accounted for, without an intimate knowledge of the construction of the engine and the conditions attending it.

Diagrams Nos. 26 and 27 were taken from the simple condensing engine of the steamboat Mary Powell, plying between New York city and Albany, which had exceeded in point of speed any other steam craft on American waters, or in Europe, so far as can be ascertained, making 25 miles per hour between those points with perfect ease.

Diameter of cylinder,	72 in.
Stroke of piston,	12 ft.
Diameter of piston-rod,	8 in.
Diameter of air-pump,	40 in.
Stroke of the air-pump,	62 in.

Very few data could be ascertained, but it seems that the M. E. P. of the top diagram was . . . . . . 22·02 lbs.

Of the bottom,	22·23 "
Mean of both,	22·13 "
Terminal of top,	13·5 "
Of bottom,	18· "
Mean of both,	15·75 "
Theoretical clearance of top,	12 per cent.
Theoretical clearance of bottom,	17 " "

The water consumption appeared to be about 24·62 lbs. per horse-power per hour. The bottom card has the more compres-

The size and speed of the engine could not be ascertained.

owell is a splendid specimen of the American beam en-
-boat which some years ago were so great favorites on

ram No. 26.

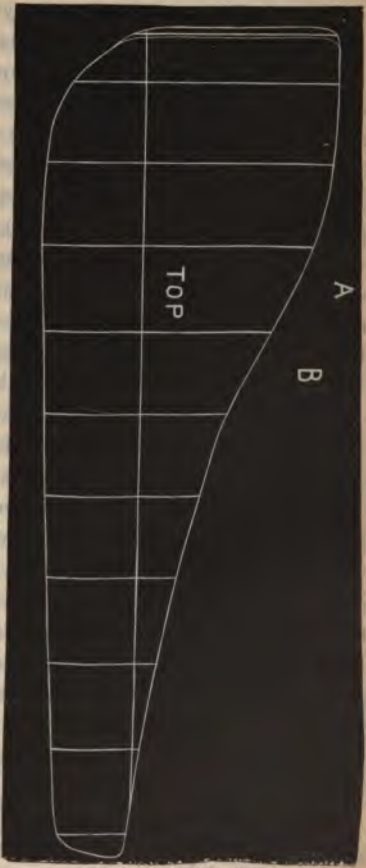


Diagram No. 27.

the great speed they were capable of developing, but
ast disappearing, and being superseded by another
n account of inherent defects in their arrangem

Theoretical Economy.

If the steam used by an engine were known to be saturated, and at the same time free from any excess of water, and if it both entered and left the engine in that condition, it would be easy to calculate from the diagram the amount of water which the engine would use in a given time, supposing it to be practically free from leakage. Under such conditions the expansion and compression curves would conform rigidly to exact theory, and the total piston displacement for one stroke, divided by the volume of terminal pressure, and the displacement up to any point in the curve divided by the volume of the pressure at that point, would give the same result wherever the point was taken, which result would be the number of cubic inches of water used during that stroke. Unfortunately, the nature of steam is such that no exact calculations of water consumption can be made. Even if its exact condition as it enters the engine is known, as it may be by the calorimeter test, its capacity for receiving and parting with heat is so great that its condition changes immediately upon entering the cylinder, so that, after deducting the water of supersaturation, known to be present before it enters the cylinder, the diagram will still fail to account for all of the remainder. Nevertheless such calculations are frequently made, and as a means of ascertaining the relative economy of different engines, and of different loads, pressures, and adjustments in the same engine, they possess great value, since, whatever uncertainty may exist as to the unindicated consumption, it may, so far as the engine is concerned, be assumed to be the same in each of the cases under comparison.

When it is desired to approximate as nearly as possible to the ual consumption by calculation, a certain amount must be dded to the theoretical result. This amount varies from 10 to 50 r cent., according as the conditions are more or less favorable; when they are so unfavorable as to require an addition of 50 ent., they are obviously so bad as to call for repairs and changes, rather than elaborate calculations. When the conditions are generally good, a careful examination of them will make it possible to fix the margin of uncertainty within tolerably narrow limits. A large engine, with well-jacketed cylinder and tight-fitting valves and piston, will generally require at least 10 per cent. addition, independent of the percentage of unevaporated spray, which may exist in the steam with which it is supplied, and this, unless the boiler is so set as to superheat the steam, will require from 10 to 25 per cent. more. In fact, the margin of uncertainty due to the boiler is much greater than that due to the engine, as not only will differently constructed boilers vary greatly in the amount of unevaporated water given off, but great difference will be found to exist with the same boiler, according to the height the water is carried, the rapidity with which it is evaporated, the amount of impurities present in the feed-water, or which have accumulated in the boiler, and many other conditions. Thus a rapidly fired generator, containing a large area of heating surface in proportion to the amount of water and little steam room and superheating surface, may, and often will, give off nearly or quite as much unevaporated water as is contained in the steam. The only fair way to test the performance of an engine is to test the steam as it enters it, both as to moisture and heat. It should also be borne in mind that, according to Trowbridge's tables, the difference between the economy of engines of over ten cubic feet capacity of cylinder and those under one cubic foot, is about 12 per cent. in favor of the larger size.

How to Calculate Theoretical Rate of Water Consumption.

The total displacement per stroke in cubic inches divided by the volume of the steam at release pressure, and the quotient multiplied by the number of strokes per hour, will give the total cubic inches used per hour. This, divided by 27·648, the number *of cubic inches of water* per pound, will give the total of pounds used per hour, which, if divided by the I. H. P., will give the result in pounds per I. H. P. per hour. This is the usual method; but, when the *rate only* is desired, a shorter process may be adopted, based on the fact that, from a given diagram, the result would be the same, whether the calculations are based on the actual size of the engine, or some other size is assumed, say a smaller size; as, although the total consumption would be changed, the divisor would also be proportionately changed.

Suppose the engine to be of such displacement as to develop one horse-power with one pound pressure, and that it is driven by that pressure of water instead of steam. It being but one horse-power, its total consumption per hour and per horse-power per hour will be the same. Being driven by water, its displacement will be its water consumption, which will be obtained as follows: A horse-power is 33,000 lbs. lifted one foot high per minute, or 33,000 × 60 = 1,980,000 lbs. per hour, or 1,980,000 × 12 = 22,760,000 lbs. lifted one inch per hour, which would be the displacement of such an engine in cubic inches, and consequently its consumption in cubic inches of water when driven by water. Then, taking 27·648 cubic inches of water per lb., we have 22,760,000 ÷ 27·648 = 859,375 as its rate of consumption in lbs. of water per H. P. per hour. Then, if the pressure were greater than one lb., the amount used would be as many times less than the above, as the pressure was greater than one lb.; and also, if it were driven by steam instead of by water, the amount used would be as much less, as the volume of steam at the terminal pressure was greater than an equal weight of water. It follows that if we divide 859,375 by the product of the mean effective pressure, and the volume of the total terminal pressure of the diagram under analysis, the quotient will be the desired rate, whatever the size and speed of the engine. The use of this constant number renders
peration more easy and short, and, except in the case of the
ound engine, entirely independent of all data except those fur-
by the diagram itself, the scale of indicator being known.

terminal pressure for this and subsequent rules is found.

when the exhaust takes place before the end of the stroke is reached, by continuing the expansion curve to the end of the stroke. In other words, it is not what the pressure may be at the moment of release, but what it would have been if it had not been released until the end of the stroke.

How to apply the rule to diagrams taken from compound engines when the strokes of the two cylinders are equal. Multiply the M. E. P. of the low-pressure cylinder diagram by the area of its piston, and divide the product by the area of the piston of the high-pressure cylinder. The quotient will be the pressure, which, acting on the low-pressure piston, will be equivalent in energy to that acting on the high-pressure piston. Then add this quotient to the M. E. P. of the high-pressure cylinder, and with its mean pressure so augmented treat it in all respects as an ordinary diagram. Or the process may be reversed, *i. e.*, the diagram from the low-pressure cylinder, with its M. E. P. augmented by the quotient of the product of the area and M. E. P. of the horse-power cylinder divided by the area of the low-pressure cylinder, may be treated as an ordinary diagram; but the result by this method will be less than by the first.

When the two cylinders have different strokes as well as different piston areas, multiply together the M. E. P. piston area, and stroke of the high-pressure cylinder, and divide the product by the product of the piston area of the low-pressure cylinder multiplied by its stroke. The quotient will be the amount to augment the M. E. P. of the horse-power cylinder before treating it as a simple diagram.

The same calculations may be more conveniently made by means of the following table; to use it, proceed according to the following rule:

Find under P the number which corresponds nearest to the terminal pressure of the diagram, and multiply the terminal pressure by the number opposite it to the right under W, and divide the *product by the* M. E. P.; the quotient will be the rate of *water consumption in* lbs. per 1 horse-power per hour.

P.	W.	P.	W.	P.	W.	P.	W.	P.	W.
5	37·95	27	34·37	49	33·18	71	32·46	93	31·96
6	37·54	28	34·29	50	33·14	72	32·43	94	31·94
7	37·22	29	34·22	51	33·10	73	32·40	95	31·92
8	36·93	30	34·15	52	33·06	74	32·38	96	31·90
9	36·67	31	34·08	53	33·02	75	32·36	97	31·88
10	36·44	32	34·01	54	32·98	76	32·34	98	31·86
11	36·24	33	33·95	55	32·94	77	32·32	99	31·84
12	36·06	34	33·89	56	32·91	78	32·30	100	31·82
13	35·89	35	33·83	57	32·88	79	32·28	101	31·80
14	35·73	36	33·77	58	32·85	80	32·26	102	31·78
15	35·59	37	33·72	59	32·82	81	32·23	103	31·77
16	35·46	38	33·67	60	32·79	82	32·20	104	31·75
17	35·34	39	33·62	61	32·76	83	32·18	105	31·73
18	35·22	40	33·57	62	32·73	84	32·16	106	31·71
19	35·10	41	33·52	63	32·70	85	32·14	107	31·69
20	34·99	42	33·47	64	32·67	86	32·12	108	31·67
21	34·89	43	33·42	65	32·64	87	32·09	109	31·65
22	34·79	44	33·38	66	32·61	88	32·07	110	31·63
23	34·70	45	33·34	67	32·58	89	32·05	111	31·61
24	34·61	46	33·30	68	32·55	90	32·03	112	31·59
25	34·53	47	33·26	69	32·52	91	32·00	113	31·57
26	34·45	48	33·22	70	32·49	92	31·98	114	31·55

Example from same diagram. The terminal pressure is 25·5 lbs., and the mean of the numbers under *W*, opposite to 25 and 26 (34·50 and 34·41), is 34·45. The mean effective pressure being 30·5, the operation is as follows: 25·5 × 34·45 ÷ 30·5 = 28·8 lbs. per horse-power per hour.

As a matter of course, the theoretical rule of water consumption, as deduced from indicator diagrams, can never be fully realized in practice. It can only be approximated.

The Planimeter.

The Planimeter is an instrument by which the area of irregular surfaces may be accurately measured. The original instrument, which was invented by Amsler, consisted of two arms hinged together as shown, the other ends being the one fixed as at *A* in diagram, the other *B*, movable. The arm with the movable

carries a roller wheel, *C*, which is graduated and which by its
tion measures the area of the diagram traced out by the
vable end *B*. The theory of the apparatus is rather complex
cannot be explained without the aid of the higher mathemat-
but its use in connection with the measurement of the area of
icator diagrams is extremely simple.

o use the instrument, fasten the figure to be measured on a
oth board, and insert the point, *A*, in the board at any con-
ient location; then make a mark on the diagram, as at *D*;
t fix the movable point, *B*, at the place selected for starting;
turn the index-roller, *C*, round until *O*, on its periphery,
esponds with the O on the fixed vernier; then move it round

the figure to the right, or in the direction of the hands of a wat. After it passes round the entire figure, note how many wh numbers and subdivisions have passed the *O* on the vernier. Th whole numbers will indicate the square inches, and the subdivisi tenths of square inches. If the *O* on the vernier falls betwee two subdivisions marked on the roller, read the number of squar inches and tenths; then look on the vernier from *O* to 10, and find a mark which coincides with one on the rollers; the number of such mark, counting from *O*, will be the hundredths or second decimal place.

Thus suppose that, in the figure measured, six subdivisions and part of another one have passed, and that the fourth mark on the vernier coincides with a mark on the roller, the area of the figure will be either 3·64, 13·64, or 23·64 square inches, according to whether the roller has made less than one, more than one, and less than two, or between two and three revolutions. The eye can readily decide as to the number of revolutions the roller has made, as it would be impossible to make a mistake of ten square inches in estimating the area of a figure within the capacity of the instrument. If the figure measured is an indicator diagram, it will nearly always be of less area than ten square inches, or at most only a trifle more, as the utmost capacity of the indicator 5½ by 2¾ inches, or 15⅛ square inches; and they are very seldo worked beyond 4 by 2½ inches.

The area of a figure may be taken without placing the *0* the roller opposite the *O* on the vernier; but in such cases i necessary to take the reading before and after the tracing is ma the difference between the two readings will be the area of fi [illegible]et it is preferable to place the *O*'s together. The f the instrument may also be turned to the left, the reading must be subtracted from 10 to give

Each of the figures stamped on the roller indic n of area, and if a figure contains 10 square in g-point, the roller will revolve once, and the *O*'s at the start.

CHAPTER XXIII.

CONDENSERS.

ct of using a condenser in connection with a steam
remove the back pressure, or a large portion of it,
atmosphere, by condensing
steam and thus producing
cuum on that side of the
h is open to the exhaust.
necessary adjunct of the
engine, and its use in that
as well as with the low-
inders of multiple expan-
is the main source of econ-
nes of this class. The con-
invented by James Watt,
in connection with the first
es.

inds of condensers in gen-
known as the jet and sur-
surface condenser consists
ox, in which brass or copper
serted in tube sheets, simi-
of a tubular steam-boiler,
ich the water is forced by
ing pump, for the purpose
g the steam. In some cases
is effected by bringing the
m in contact with the out-
ubes, the circulating water
inside; while in others the
hausted into the tubes, and the circulating water
n the outside of them. There is no especial

End View of a Surface Condenser with the Bonnet removed.

A snifting-valve is fixed on the condenser to allow the air and water to escape when the condenser is blown through. The vacuum in the condenser keeps it closed, and, in the event of a great head of water, or pressure in the condenser, the valve will rise up and allow it to escape.

TABLE

SHOWING THE FORCE WITH WHICH THE UNCONDENSED STEAM ARISING FROM THE WATER IN THE CONDENSER RESISTS THE ASCENT OR DESCENT OF THE PISTON, ACCORDING TO ITS TEMPERATURE.

Temperature, Fahrenheit.	Force in Inches of Mercury.	Pounds per Square Inch.	Temperature, Fahrenheit.	Force in Inches of Mercury.	Pounds per Square Inch.
32	0·200	0·100	130	4·36	2·17
40	0·250	0·128	135	5·07	2·52
50	0·360	0·181	140	5·77	2·88
55	0·416	0·215	145	6·60	3·28
60	0·516	0·260	150	7·53	3·74
65	0·630	0·311	155	8·50	4·22
70	0·726	0·361	160	9·60	4·76
75	0·860	0·428	165	10·80	5·37
80	1·01	0·505	170	12·05	6·04
85	1·17	0·585	175	13·55	6·75
90	1·36	0·680	180	15·16	7·58
95	1·58	0·805	185	16·90	8·47
100	1·86	0·900	190	19·00	9·50
105	2·10	1·07	195	21·10	10·58
110	2·53	1·26	200	23·60	11·81
115	2·82	1·43	205	25·90	13·01
120	3·30	1·50	210	28·88	14·43
125	3·83	1·902	212	30·	15·

The temperature of the water in the hot wells of surface-co densing engines is generally about 100° to 110° Fah. A highe erature would affect the vacuum and injure the air-pum alves, while a lower temperature would cool the cylinder, and use a waste of fuel by the condensation of the steam. A very w temperature causes increased consumption of fuel, while a very igh one causes a loss of power, owing to the back pressure inuced by the uncondensed vapor in the condenser, which will be own by the vacuum-gauge.

In the jet condenser, when the bilge-injection is opened, the air-imp draws off the air from the pipe, when the air in the ship, essing on the surface of the bilge-water, forces it up the pipe to the condenser. In the surface condenser the circulating imp creates the vacuum, and the air presses the water up.

In a jet condenser, if the injection-water is not shut off when e engines are stopped, the condenser will be filled with water, d, if not cleared before the engine is started, may cause serious mage to the cylinder or condenser.

elative Quantity of Injection-Water Required to Condense a Certain Volume of Steam.

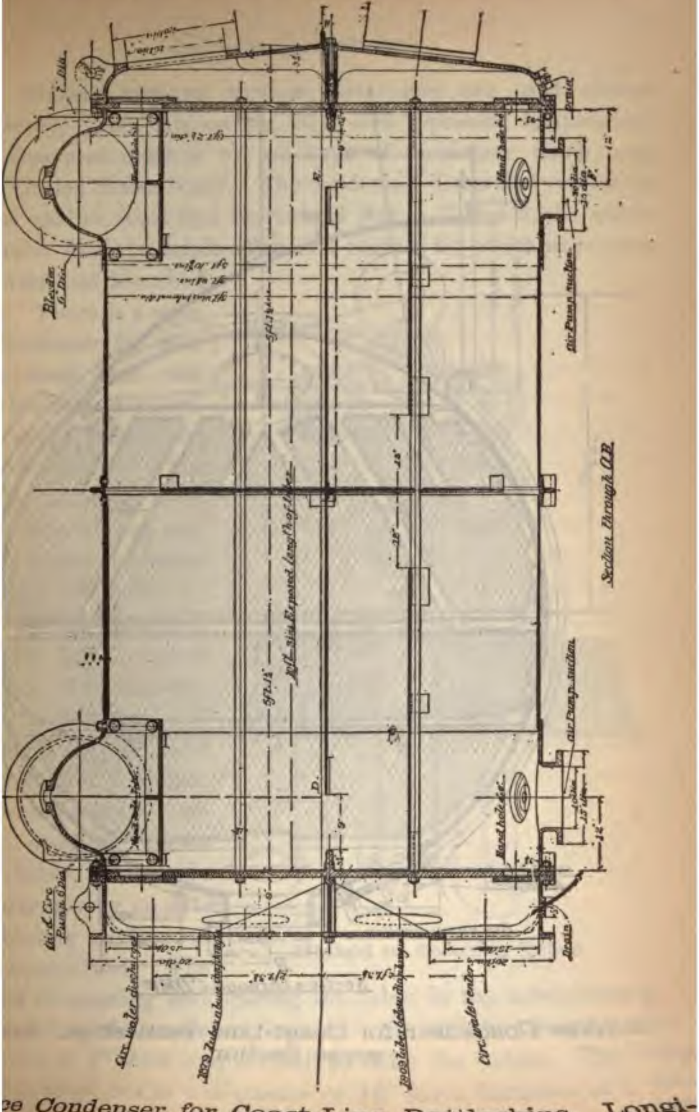
The weight or quantity of injection- or condensing-water reiired for a given weight or volume of steam depends upon veral conditions: 1. The pressure at which the steam is exusted. 2. The absolute pressure existing in the condenser after e vacuum has been formed. 3. The temperature at which the jection-water enters the condenser. While the first and second nditions vary but slightly with uniform load and steam pressure, e third will vary with the season, and even with the weather; nsequently, more condensing-water is required in summer than winter. But the average amount may be illustrated as lows:

Example.—Suppose the pressure in the cylinder at release or haust be 5 lbs. above atmosphere, and the absolute pressure in condenser, after vacuum is formed, be 2 lbs., corresponding to vacuum of 26 inches of mercury. Each pound of steam ex-*sted at 5 lbs. above atmosphere* contains 1183 thermal units, or 80°, supposing there be an abundant supply of cold water. It may be explained in this way. A better vacuum due to a temperature of 70° or 80° requires so much cold water in the condenser, (which must afterwards be pumped out against the pressure of the atmosphere,) that the gain in the vacuum does not equal the loss of power caused by the additional load on the pump. There is, therefore, a clear loss by the reduction of the temperature below 100°, if such reduction be caused by the admission of an additional quantity of water.

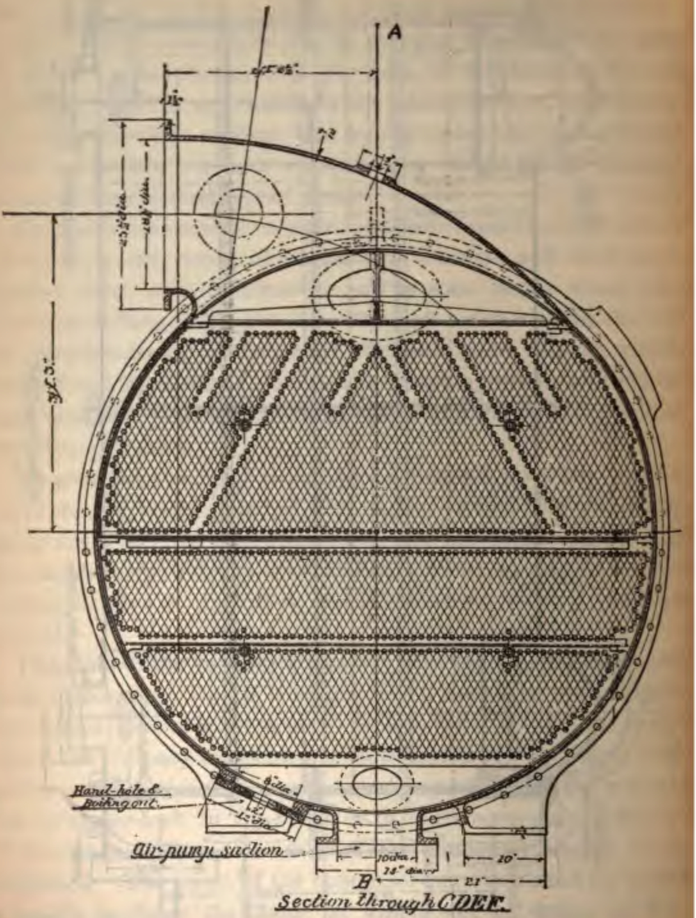
To produce a vacuum in a jet condenser, open the blow-through valve, when the steam, in its passage through, will blow out all air and water in the condenser; and as soon as the steam issues from the snifting-valve the blow-through valve may be shut, and the injection-cocks opened, when the cold water mixing with the steam forms a vacuum. When the gauge shows a sufficient vacuum, shut the injection-cocks, in order to prevent the condenser from being flooded.

To produce a vacuum in a surface condenser, open the injection-valve shortly before starting the engine, so that the circulating-water may enter the condenser tubes, and cool them. Then, when the engine is started, the exhaust steam comes in contact with the cooling surface of the tubes, and is condensed when a vacuum is formed.

The state of the vacuum is shown by the vacuum-gauge attached to the condenser; and, if it be imperfect, the cause must be ascertained and the fault corrected. If the water in the hot well be above the ordinary temperature, more injection water must be admitted; and, if the vacuum continues imperfect, the cause may be due to an air-leak in the valve or cylinder-cover, or in the joint of the eduction pipe. The door of the condenser should also be examined. The joints of the condenser may be tested by holding a candle to them, the flame of which will be drawn in if the joints are leaky.



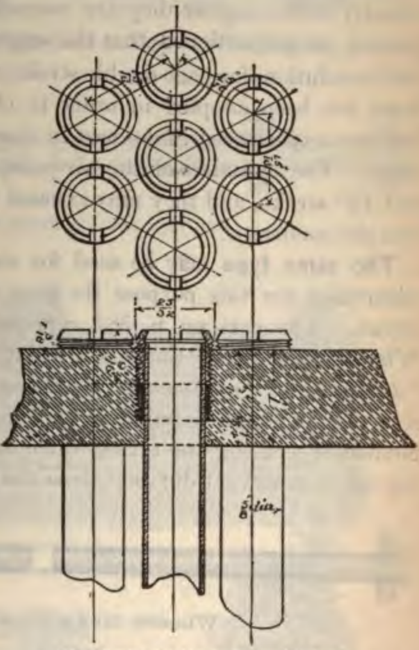
ce Condenser for Coast-Line Battleships. Longitudinal Section.



Surface Condenser for Coast-Line Battleships. Transverse Section.

Surface Condensers.

marine engines surface condensers are used almost ively. The cuts on pp. 577, 578 represent longitudinal ransverse sections of the type of condenser much used United States Navy. The condenser illustrated represents e used on coast-line battleships Nos. 1, 2, and 3, the auxiloiler and the triple-expansion engines for which have been ated and described

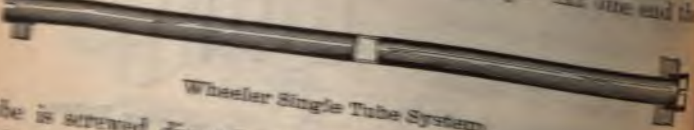


Method of Securing Tubes.

There is a separate ondenser for each , made with castheads and rolledshell, bolted and d together. The gs are $\frac{7}{16}''$ thick ntain all the nozr steam and water gs. The shell is $\frac{1}{4}''$ bolted, strapped, d, and soldered er. The diameter eet 9 inches and gth between tube 10 feet 3 inches. ondenser contains seamless drawn tubes, $\frac{5}{8}''$ outside er, giving an outoling surface of quare feet. The l of securing and spacing the tubes in the tube sheets is ted in the accompanying cut. As will be observed, the heet is 1″ thick and drilled to take the tubes. The holes n *reamed out to a diameter of* $\frac{25}{32}''$ for a distance of $\frac{3}{4}''$ from

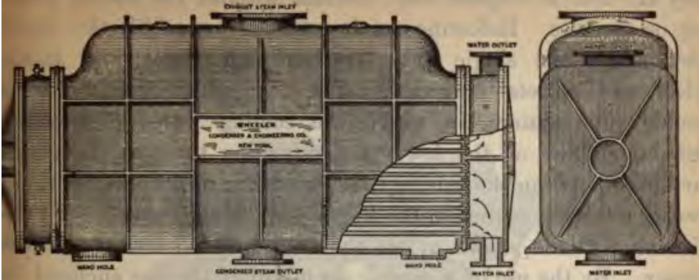
of the sheet and tapped, after which
ing is inserted around the tube and a screw ferrule
force the packing against the tubes. The tubes are sp
centre to centre. The condensing water is taken from t
or bilge by a separate centrifugal circulating pump f
condenser. These pumps are each capable of discharging
gallons per minute. The air pumps for each engine are
vertical single-acting lifting pumps, having cylinders
ameter and 18" stroke, and instead of attaching the pump
directly to the engines they are connected together through g
gearing so proportioned that the engine will make two and a
half revolutions for each double stroke of the pump. This arrang
ment has been adopted in order to obviate the difficulty th
has been experienced in the past in running these engines at a l
speed. The cylinders of the air-pump engines are 9" diame
and 12" stroke, and they may exhaust either into the receiver o
into the condenser.

The same type may be used for stationary engines, althoug
when used for this purpose the design is usually somewhat dif-
ferent. The cuts on p. 581 represent two different types of
Wheeler condensers, the one a "single tube" and the other a
"double tube" condenser. Referring to the former, it will be
seen that its design is similar to that illustrated on page 564. The
method of securing the tubes, which is shown in the accompanying cut, is somewhat different from the ordinary. At one end the

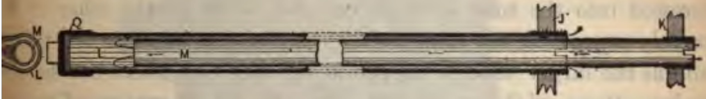


Wheeler Single Tube System.

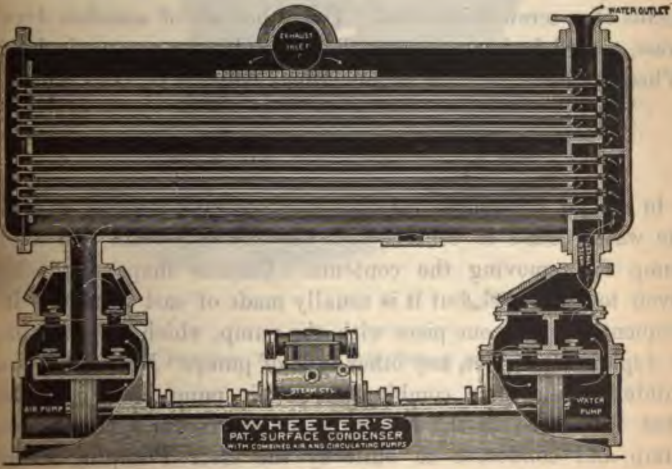
tube is screwed direct into the tube sheet, its thickness at that end being somewhat greater, so that cutting the thread will not weaken the tube. The other end is secured by means of packing and ferrule, the same as in the marine-engine condenser described bove. In the double tube system the tubes are so arranged that



Wheeler Surface Condenser. Single Tube System.



Wheeler Double Tube System.



Wheeler Surface Condenser. Double Tube System (pumps attached).

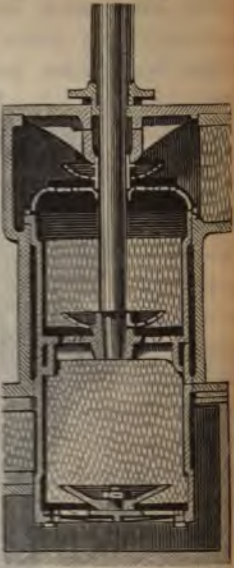
they are free to expand and contract without the use of packing or ferrules. Referring to the cuts on page 581, the upper view shows the single tube system, with water and steam inlets and outlets indicated. The two other cuts show the double tube system, in which the cooling water first enters the inner tubes of the lower set, returning through the annular space between the tubes; then enters the upper chamber, following a similar course in the upper set; finally escaping by the discharge nozzle shown at the upper right-hand end of the condenser. By the use of a double set of tubes, the one enclosed in the other, the ferrules and packing are dispensed with. As will be seen in the enlarged view of a pair of tubes, the outer tube is screwed into the tube sheet at one end, while at the other it is merely supported, the same being true for the small inner tube, and as the larger tube is capped at the free end, there can be no leakage there, while at the same time the whole system of tubes has ample room for expansion and contraction. To remove a tube it is only necessary to remove the head and unscrew the tube by means of a screw-driver tool. The tubes are of seamless drawn-brass, tinned inside and out. These condensers are made by the Wheeler Condenser and Engineering Company of New York.

Jet Condensers and Air Pumps.

In the jet condenser all that is necessary is a vessel in which the water comes in contact with the exhaust steam and an air pump for removing the contents. Various shapes have been given to this vessel, but it is usually made of cast iron and it is frequently cast in one piece with the pump, which may be single or duplex, or, in fact, any other type of pump. Nearly all pump builders make some combination of air pump and condenser. That illustrated in the following cut represents a twin pattern pump and condenser as built by the Barr Pumping Engine *ompany* of Philadelphia for engines of 60 to 4000 horse-power *city.*

Barr Twin Pattern Vertical Air Pump and Condenser.

All condensing engines have of necessity to be provided with an air-pump, for the purpose of extracting the air, injection-water, and the water of condensation from the condenser, in order to maintain a vacuum. There does not appear to be any uniform, recognized rule, among marine engineers or manufacturers of surface-condensing compound engines, for proportioning the air-pumps to the steam-cylinder, as, while some builders make the capacity of their air-pumps one-eighth of that of the low-pressure cylinder, others make it one-tenth, and others one-eleventh; the average of the number examined being about one-ninth.

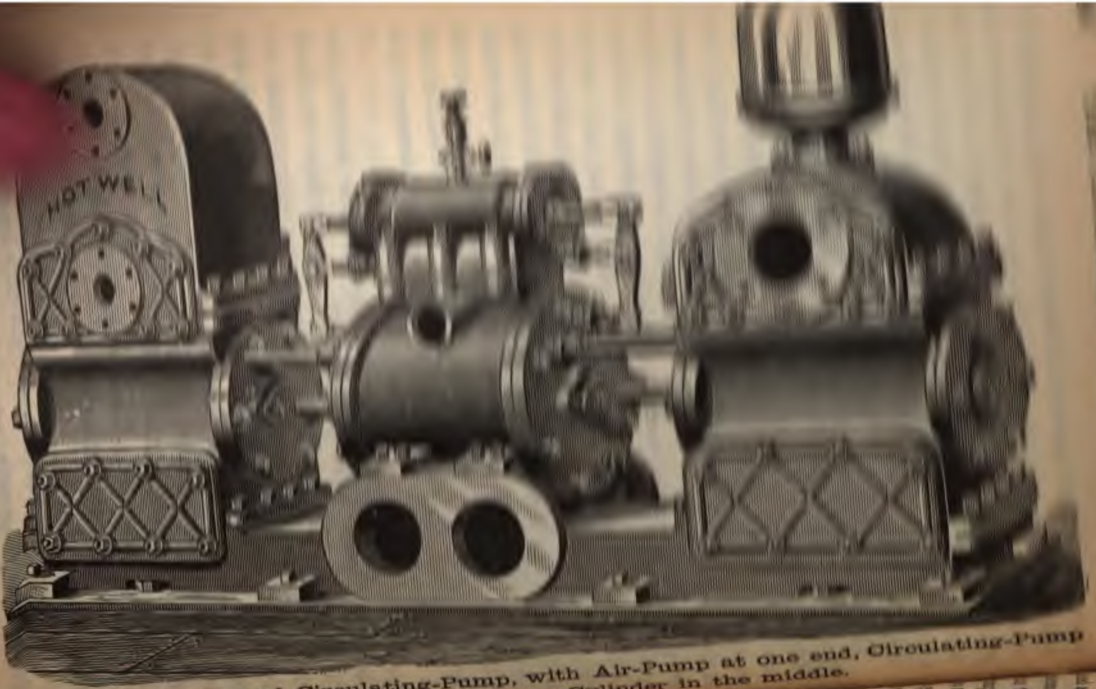

Section of a Marine Air-Pump.

The air-pumps of the steamships Pennsylvania, Ohio, Indiana, and Illinois, of the American Line, are one-eleventh the capacity of the low-pressure cylinder. And, as these engines have the reputation of being very economical, it should be presumed that their proportions are good; nevertheless, they are evidently too large, as one-fifteenth would be nearer to a correct proportion. The tendency among marine engineers is to overdo the thing in the case of air-pumps, perhaps under the impression that a large air-pump creates a better vacuum, and, as a result, air-pumps of enormous diameter and long stroke are attached to marine engines; whereas, the air-pump has very little to do with the vacuum, its functions being simply to clear the condenser of water and air. Any proportion that will accomplish this will fulfil all the necessary requirements. An air-pump too large for the purpose for which it is intended, can have no other effect than to absorb much of the power which might be utilized in increasing the speed of the engine and economizing the fuel. The air-ump piston, being resisted by the pressure of the atmosphere, ab sorbs from four to five per cent. of the power of ordinary simple condensing engines, and from two to three per cent. in the better class of compound marine engines; the power required to work it being greatest when the vacuum is most perfect, and least when the vacuum is impaired. A good deal also depends on the mechanical arrangement employed to work it, as well as on the condition of its packings, bearings, proportions, etc.

The capacity of the air-pumps of condensing engines using a jet or spray, ranges from one-fifteenth to one-twentieth the capacity of the cylinder. As it requires from 22 to 30 times as much water to condense steam as there is water in it (according to the pressure and temperature), the air-pumps ought to be proportioned to meet the maximum demands. The right proportions of air-pumps for both jet- and surface-condensing engines may be found by *calculating* the displacement of the steam-piston, and that of the air-pump for one minute, and *dividing* the former by the latter. The use of the air-pump in connection with condensing engines, as before stated, is not an absolute necessity in all cases, as, with a head of water having a fall of about 13 feet, a vacuum can be formed and maintained in the condenser without an air-pump, providing the end of the delivery-pipe is submerged in a tank of water.

Vertical air-pumps, with valves in their pistons or buckets, give the best satisfaction, as, in that case, the air and vapor are lifted and forced out of the condenser, relieving the exhaust and increasing the vacuum. The capacity of the openings through the valve-seats of air-pumps should be such that the maximum flow of the water through them will not exceed 10 feet per second. For instance, suppose a pump of 12 ins. stroke to make 50 strokes per minute, the maximum travel of the bucket at midstroke will be about 2·6 feet per second. Then, as $10 \div 2{\cdot}6 = 3{\cdot}84$, the capacity of the opening should not be less than one-fourth the area of the pumps.

Air-pumps *are frequently* very injudiciously located, bei



Air- and Circulating-Pump, with Air-Pump at one end, Circulating-Pump
Steam-Cylinder in the middle.

aced above the condenser; whereas, if placed below it, their re- iirements would be fewer, as the water would fall by gravity om the condenser into the air-pump. In some cases the air- imp extends down through the condenser, so that the openings e nearly on a level with the bottom of the condenser, which is good arrangement in every respect, except that it necessitates a ng stroke, which has a tendency to absorb power.

Independent air-pumps, a cut of which may be seen on page 86, having an air-cylinder at one end, the circulating-water cyl- ider at the other, and the steam-cylinder in the middle, are being ery generally adopted on ocean steamers. The claim set up for iem is, that, as they are independent of the engine, they can be orked faster or slower, according to the circumstances of the ase; that they absorb none of the power of the engine, and are eer from liability to accident in stormy weather, or whenever the ngine races, than air-pumps attached to the main engine; that hey can be started, and a vacuum formed, before the engine com- iences to work; that the injection-water can be more easily reg- ilated; that they require no expensive foundation; that, in con- equence of the water- and air-pistons being on each end of the team-piston, they have a more steady and uniform motion than he ordinary air-pump has, and that, in consequence of all their arts being accessible, they can be easily examined, and any de- angement remedied or readjusted, without interfering with the working of the engine.

In a surface-condensing engine, the air-pump has only to extract the water resulting from the condensed steam and the uncondensed vapor from the condenser. In a jet-condensing engine, the air-pump has to withdraw both the injection-water and the water of condensation; the work to be performed by the latter being from 25 to 30 times greater than that of the former.

An air-valve is sometimes fitted to a circulating, reciprocating, or double-acting pump, for the purpose of admitting air to the

[illegible]

A bucket air-pump is a single-acting pump, [illegible] [illegible] fitted to it, which closes on the [illegible] [illegible] a quantity of water equal [illegible] at each stroke of the engine.

A piston air-pump is a double-acting pump, the [illegible] It is fitted with suction- and delivery-valv [illegible]

A plunger air-pump is a double-acting pump, re [illegible] air-pump, except that it has no head-valves, [illegible] is fitted with a plunger. The effect of thi [illegible] owing to its displacement, discharges on bot [illegible] the down-stroke.

The double-acting air-pump has both suction- [illegible] valves; but it is possible with the single-acting pu [illegible] cases, to dispense with either the one or the othe [illegible] generally made with pistons, though sometimes with

An air-pump with a foot-valve and no discharge- [illegible] be most affected by a leaky stuffing-box; and, while t [illegible] remains, the pump will draw water, but if removed, [illegible] work.

An air-pump trunk is a hollow cylinder attached [illegible] or piston, and working through a stuffing-box. Such [illegible] ment is rendered necessary when the pump is worke [illegible] the crank-shaft, or where it is located so close to [illegible] through which the motion is transmitted from the [illegible] appliance of an intervening cross-head a [illegible] difference in the discharge is equal to [illegible] ween the displacement caused by an [illegible] that caused by the trunk.

The air-pump pet cock or valve is generally placed below the head-valve and above the bucket. It opens with the down stroke of the pump, and admits air to act as a cushion on the water. When the delivery-valve is opened, the engineer can tell by its action whether the pump is working properly or not.

An air-pump bucket is a hollow piston, generally made of brass, with a grating in the top, and a boss (water-tight) which receives the rod in its centre, from which strengthening ribs run to the rim of the bucket. The outside of the bucket is grooved to receive water-tight packing. The valves, which are generally of India-rubber, and whose lift is regulated by a guard secured by a nut, and against which the valve is pressed when the bucket is on the down stroke, are on the top of the grating.

Air-pump rods are generally made of wrought-iron, and covered with a skin of Muntz metal, or brass, to prevent the oxidization to which wrought- or cast-iron rods are exposed.

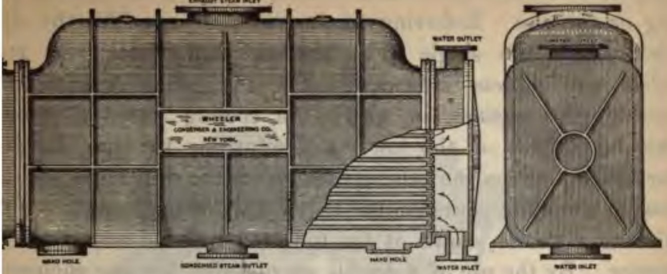
A ship's side air-pump discharge-valve is generally a mitred valve, with its spindle passing through a gland in the cover, on which a weight is placed to keep it shut. It differs from a stop-valve in having a lift and weight.

There are numerous contrivances in use for dispensing with the air-pump, such as the injector condenser, which produces a sheet of water in the exhaust-pipe; but the necessary arrangements for operating them generally cost more than a good reliable air-pump, though the first cost of the former is less than that of the latter. Besides, the vacuum is never so perfect when produced by any such arrangement as when created by a close condenser and air-pump. This becomes obvious, since we know that, even with the most perfect mechanism, it is almost impossible to attain a perfect vacuum, and maintain it for any length of time, as nature abhors a vacuum, as the atmosphere on the outside of a vessel is constantly endeavoring to equalize any unbalanced pressure that *may exist on the inside.*

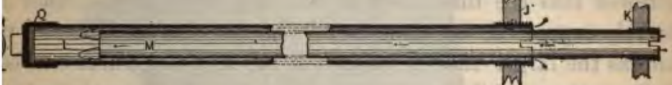
the outside of the sheet and tapped, after which a suitable packing is inserted around the tube and a brass ferrule screwed in to force the packing against the tubes. The tubes are spaced $\frac{15}{16}''$, centre to centre. The condensing water is taken from the sea or bilge by a separate centrifugal circulating pump for each condenser. These pumps are each capable of discharging 9000 gallons per minute. The air pumps for each engine are two vertical single-acting lifting pumps, having cylinders 20″ diameter and 18″ stroke, and instead of attaching the pump rods directly to the engines they are connected together through spur-gearing so proportioned that the engine will make two and one-half revolutions for each double stroke of the pump. This arrangement has been adopted in order to obviate the difficulty which has been experienced in the past in running these engines at a low speed. The cylinders of the air-pump engines are 6″ diameter and 12″ stroke, and they may exhaust either into the receivers or into the condenser.

The same type may be used for stationary engines, although when used for this purpose the design is usually somewhat different. The cuts on p. 581 represent two different types of Wheeler condensers, the one a "single tube" and the other a "double tube" condenser. Referring to the former, it will be seen that its design is similar to that illustrated on page 568. The method of securing the tubes, which is shown in the accompanying cut, is somewhat different from the ordinary. At one end the tube is screwed direct into the tube sheet, its thickness at that end being somewhat greater, so that cutting the thread will not weaken the tube. The other end is secured by means of packing *and ferrule,* the same as in the marine-engine condenser described *above. In the* double tube system the tubes are so arranged that

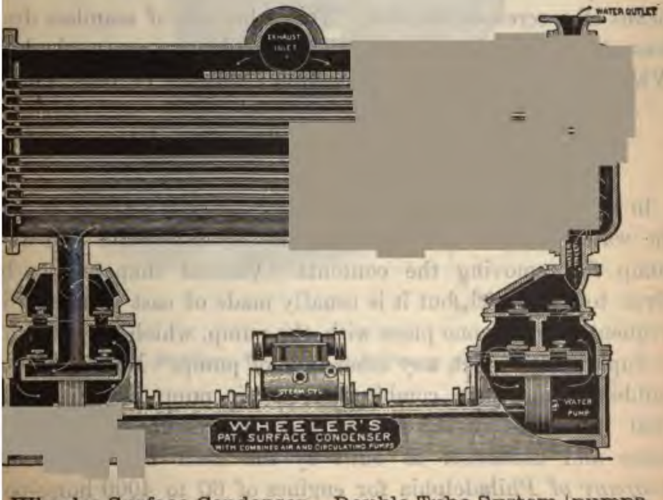
Wheeler Single Tube System.



Wheeler Surface Condenser. Single Tube System.



Wheeler Double Tube System.



Wheeler Surface Condenser. Double Tube System (pumps attached).

Define the term zero when applied to indicator diagrams.

ive the formula for finding the horse-power of an engine from cator diagrams.

Vhat are the functions of the planimeter?

xplain the most correct method of using the planimeter.

Vhat is the exponent of the work performed by a steam-engine? the meaning of the term mean effective pressure, see page

Vhat is the best criterion of the most economical results which eam-engine is capable of producing?

Vhat is the object of attaching a condenser to a steam-engine?

ive the names, and the advantages and disadvantages of the kinds of condensers in most general use, with a description he same.

xplain how the injection-water enters and escapes from surface jet condensers.

tate what relative proportion the jet condenser should bear to steam-cylinder of a condensing engine.

tate what relative proportion the cooling surface in a surface denser should bear to the cubic contents of the steam-cylinder.

tate the respective advantages and disadvantages of having densers too large or too small.

Vhat is the most advantageous temperature at which to keep water in hot wells? and what effect does too high or too low mperature exert on the economical working of the engine?

xplain the arrangements by which the bilge injection-water troduced into jet and surface condensers.

Vhat would be the effect of not shutting off the injection-water n the engine is stopped?

tate the quantity of water necessary to condense steam, with rmula.

ive the rule for finding the cooling surface in the tubes of ace condensers.

PART VII.

GAS AND GASOLINE ENGINES.

CHAPTER XXIV.

ALTHOUGH gas and gasoline engines are made up of parts having a general similarity to those of the steam engine and with like functions, they have one fundamental point of difference—namely, in the medium whose expansive property is made use of to transform heat energy into the kinetic energy of mechanical motion. In the case of the steam engine heat energy is imparted to the vapor of water in another apparatus, the boiler, and the steam is brought into the engine and allowed to expand and do mechanical work. In the gas engine it is air whose expansion is made use of. Moreover, the heating of the air is performed in the cylinder of the engine itself, so that the gas engine takes the place of a steam engine and boiler. The heating of the air is performed by admitting into the cylinder a quantity of gas, gasoline, petroleum or other inflammable oil, mixing it at the same time with air and igniting the mixture at the proper moment. The intense heat produced raises the air to a high temperature. It therefore expands and pushes over the piston as does steam in the steam engine. At the end of the stroke suitable valves open to allow the exhaust of the products of combustion from the cylinder, and other valves in turn open to let in new charges of air and fuel.

The fuels principally used are gas, either natural or artificial, gasoline, and petroleum, the quantity per horse-power required *depending* upon the quality of the fuel; that is, upon the num- *of* heat units in each pound. With ordinary illuminating the quantity per indicated horse-power per hour will vary n 17 to 20 cubic feet. With Pittsburg natural gas it has en as low as 11 cubic feet; using 74° gasoline, known as *stove oline*, the consumption per horse-power hour is about one-tenth one gallon. The amount of petroleum used would be about same. By taking gas obtained from coal in a producer and asuring the number of pounds of coal per horse-power hour re- red, it has been found that the gas engine exceeds the steam ine and boiler considerably in economical use of coal, the tests Professor H. W. Spangler, of the University of Pennsylvania, a 100 horse-power gas engine showing that an indicated horse- ver was produced with a consumption of about one pound of l per hour. A producer plant and gas engine are much more ensive than a steam engine and boiler, so that the price of l at any place will determine as to whether, on the whole, the of a gas engine is desirable.

he Otto Cycle.—Most steam engines are double-acting; that ake steam alternately at each end of the cylinder, although e of them, like the Westinghouse and Willans, are single- ng and take steam at only one end. Nearly all gas engines single-acting and, moreover, take in a charge of gas and air *y second* revolution, instead of *every* revolution, as in the case ingle-acting steam engines. The complete cycle of operations which nearly all gas engines operate is known as the Otto le, and is as follows:

forward stroke.—Admission by suction into the cylinder of a charge consisting of air mixed with some combustible gas or vapor.

return stroke.—Compression of the charge. At the end of this stroke the charge is ignited.

forward stroke.—Expansion of the charge which has been heated by combustion.

return stroke.—Expulsion through the exhaust openings of the mixed gases which have been cooled by expansion.

he temperature produced by rapid combustion of the ignited charge is very high, probably about 3000° F., so that it is necessary to cool the cylinder by means of a jacket supplied with running water. Otherwise the packings would be destroyed, premature ignition would take place, and lubrication would be impossible. The heat imparted to the water jacket is in general wasted and amounts to about 40 per cent. of the total heat energy of the gas. Were it not therefore for the necessity of cooling the cylinder the efficiency of the gas engine would be much greater even than is now the case.

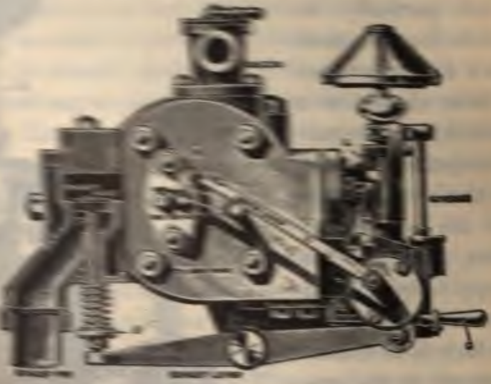
Methods of Igniting the Charge.—The earlier method of igniting was by means of a flame produced by burning a jet of gas or vapor with which the ignited charge was brought into contact at the proper moment. A great improvement was made by using, instead of the flame, a tube kept red-hot by a flame of gas or vapor burning outside of the cylinder. Such devices are rather sensitive to variations in the proportions of air to fuel and have largely given way to electric igniting devices. The first forms of these made use of a platinum strip heated white hot; but were found unsatisfactory, as the platinum had to be kept so near its fusing-point, in order to produce certain ignition, that it was soon destroyed. At present electric igniters operate with a spark produced by breaking an electric circuit which has a current flowing through it. They may be divided into two classes, *fixed-spark gap* and *break-spark gap*. In the former, two electrodes, insulated from each other, are placed in the end of the cylinder at a distance from each other of a small fraction of an inch. The secondary circuit of an induction coil is connected to these electrodes. In series with the battery and primary circuit of the induction coil is placed a contact operated by the engine, which makes circuit and promptly breaks it again just at the moment when ignition should take place. A spark passes across the gap between the two electrodes and causes the gas to ignite. In the break-
ap-igniter one electrode is fixed and the other moves so as
to contact with it at the proper time. A battery and
are connected in series with the two electrodes.

verning.—The speed of gas engines is generally regulated by g off the supply of fuel partially or entirely when the num- f revolutions is too great. The regulating device usually ts of a ball governor of the Waters type (see page 409), operates a suitable valve. Such a method is open to the vantages of fly-ball governing which obtain with steam en- Further, it operates less quickly from the fact that gas is in only once in four strokes in the normal running of the e, whence it happens that a much longer time elapses between ovement of the fly-balls and the changing of speed than is se with steam engines. Although gas engines are provided xceedingly heavy fly- s, their variations in are several per cent. r than those of good engines.

e Otto Engine, being arliest successful gas e, and partially on ccount the one most used at the present as been chosen as a entative for more par- r description. In the ut, which shows a view g at the rear end of linder, *B* is the gas el supply-pipe; *D*, a ; *C*, a rubber bag, the of which is to dimin- ctuations in the gas- re; *A* is a valve cor- ding to the throttle of a steam engine; *F* *xhaust pipe; and G* is a cast-iron pot which serves to deaden ness of the cylinder. The second, third, and fourth cu

Side View of Cylinder End.

w the mechanism in greater detail. When the throttle le
is open gas gets as far as the gas valve. This is opened at t



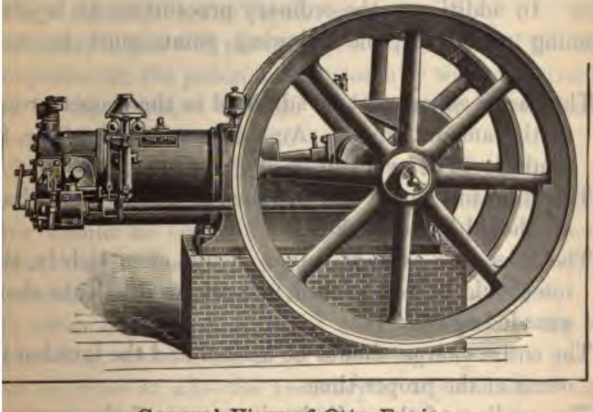
End View of Cylinder End.

e every second forward stroke by the lever-arm W
time which is controlled by the governor. Air i

at the same time through the valve *M*, which is operated atically by suction produced by the advance of the piston.

Top View of Cylinder End.

e return stroke the air valve closes and the mixture of air and the cylinder is compressed to a pressure of some 70 pounds uare inch. Just after the second forward stroke commences *nition takes place.* The heated gaseous mixture expands,



General View of Otto Engine.

ignition. The first impulse succeeding a cut off should be slightly weaker than the succeeding ones. If it is notably weaker, there is a deficiency of gas. If it is as strong or even stronger than the succeeding ones, there is an excess of gas.

Admission and Exhaust of Air.—Air is as essential to the engine as the fuel. The more air is admitted the more fuel can be used, and (other things being equal) the more power the engine will develop.

The inlet valve should not only afford a sufficient opening, but it should be properly timed so as not to shut off the entrance too early or too late, as in the latter case a part of the charge is expelled after having been admitted into the cylinder. The charge is also apt to be reduced if there is an excessive back pressure in the exhaust pipes, due to insufficient size, extreme length, or accumulation of water from condensed moisture in a long pipe.

Leaks.—Any leaks by which the pressure is allowed to escape from the cylinder result in a reduction of power and a waste of fuel. Leaks toward the water jacket or around the cylinder are easy to detect. The exhaust valve is the part that is most likely to become leaky by reason of the high temperature to which it is submitted. It is generally of the poppet type, with conical seat, and so disposed as to be easily inspected and reground to its seat with powdered emery and oil.

When the inlet valve leaks the result is more pronounced than for any other leak of the same magnitude, because the gases not only leave the cylinder, but they accumulate in the space or passage through which the air and the fuel are admitted and substitute themselves for pure air in each subsequent charge, thus disturbing the proper adjustment of air and fuel.

A small leak toward the water jacket does not do much harm [illegible] the engine is kept running at full power. At a reduced [illegible] cooling[illegible]ly on starting the engine, the entrance of water [illegible] would be through the leak is likely to be much more dis[illegible] It is possible to use the engine temporarily in such [illegible] by draining the water from the jacket just before

a slight pressure. In gasoline engines the fuel is vapor of
ne carried by air sucked in through a vaporizer containing
asoline. In petroleum engines the fuel is sprayed into the
n of air which enters the cylinder.

the case of gas engines the gas pipe near the engine is pro-
with a rubber bag or receiver with rubber diaphragm. The
rance of this flexible wall shows plainly, when the engine is
ng, whether the head of gas keeps fairly uniform; that is,
ier the supply is sufficient without being at times excessive.

e valve which regulates the admission of gas during the
ssion of air to the cylinder should close tightly every time.
does not, there is danger of having an excess or deficiency
s admitted as the gas-pressure may rise and fall, especially
e engine is run at a varying speed. There is also danger of
ng gas on light loads. An irregularly leaking valve is apt
oduce puzzling behavior, as excessive and deficient charges
be mixed promiscuously with proper ones. Any considerable
s of gas will produce a smell and smokiness of the exhaust
ll as a failure to ignite regularly.

deficiency of gas will produce slow combustion of the charge,
impulses on the piston, and eventually weak or strong ex-
ons in the passages through which the air is admitted. It
also cause failure to ignite regularly.

after having found the gas valve to be tight, there exists
loubt as to the admission of the proper amount of gas, an
ator should be employed if one is available. If not, the
tment may be made approximately by varying the quantity
r admitted until the best result seems to be obtained.

ith those engines whose speed governor acts on the hit-or-
plan—*i. e.*, which allow either a full opening of the gas valve
cur or none at all—the accuracy of adjustment of the gas
ssion can be determined as follows:

t such a load on the engine that it will take several charges
ccession, then *cut off one* and then take several more. Then
the strength of the individual impulses following each

Advantages and Disadvantages.—As already stated, the
and gasoline engine, considered as a machine for transforn
the latent energy of fuel into useful mechanical work, is
superior in point of economy to the steam engine. This is es
ially the case where producer gas is used—that is, a gas mad
the so-called Dowson apparatus, which can be made very chea
and, while unfit for illuminating purposes, is an excellent fuel
use in connection with the gas engine. In small units—that
up to about 100 horse power—it may be said in general
power may be had more cheaply from gas or gasoline eng
than from steam engines. Furthermore, there being no boile
fire, the attendance required is less. Where city gas is used i
only necessary to turn on the gas-cock and start the engine, w
with a producer the coal may be fed automatically into a hop
On the other hand, where a heating-system is to be operated
connection with the power plant, the advantages possessed by
gas or gasoline engine, in point of economy, disappear, as the h
contained in the exhaust from a steam engine may be rea
utilized for heating purposes. If the exhaust by itself is
sufficient for the purpose, it may be augmented by some
steam from the boilers, and so the [illegible] heating [illegible] redu
to a very small amount. Aside [illegible] th [illegible] rat
gas engines is often greater [illegible]
is true that the fireman [illegible]
other hand, the gas [illegible]
than the steam [illegible]
It is much mor [illegible]
gent machin [illegible]
quently [illegible]
the boil [illegible]
which [illegible]
to h [illegible]

t kept idle until the trouble is removed, the saving referred
ill soon disappear entirely.

he method of starting up gas and gasoline engines has always
a weak point. After the gas has been turned on, or the
line injected into the cylinder, it becomes necessary to turn
engine over several times rapidly before the normal action
ns. This may be done, readily enough, by hand in the smaller
s, while in the larger ones some auxiliary device, such as a
pressed-air tank or a small starting engine, is provided for
ing the engine over. In medium-sized engines, however, the
ense of such a device would be out of proportion to the cost
he engine, and in such cases the turning over of the engine
mes an exceedingly laborious and often exasperating opera-
. This has always been a serious drawback to the use of gas
nes, and one which, up to the present time, has not been
rely removed.

Vith regard to regulation, it has already been pointed out that
gas engine, owing to the fact that it receives only one-fourth
any impulses, is far inferior to the ordinary steam engine.
desideratum is partially overcome by the use of extra heavy
vheel ; but even then the regulation of the speed is not suffi-
t the demands of certain kinds of power service. For
for example, the variations in the speed of the
arly always perceptible in the lamps, except
ttery is used in connection with the generator.
gas engine, dynamo, and storage battery, in
vantages as a lighting plant for large resi-
pressure is kept uniform by the storage
ed up at any instant, without preparation,
as a motor with the aid of current from
ng the tedious operation of turning over
furthermore, the cost of fuel and attend-
ll, so that for large residences and simi-
plant is both convenient and inexpen-
kind of a plant under special conditic

is advantageous also in larger buildings. For example, in the large office building of the United Gas Improvement Co., in Philadelphia, which at the present writing is nearly completed, the lighting is done both by gas and by the electric current. The company being engaged in the manufacture of gas, this is naturally the cheapest kind of fuel, and consequently the electric plant is driven by gas engines, and a storage battery is used in connection with the generators to accomplish the results above recited.

In general, it may be said, that gas and gasoline engines can be used to advantage (*a*) where power is required at irregular intervals, because they are always ready to start without preparation; (*b*) where the amount of power is very small, because of the comparative economy both in first cost and cost of operation; (*c*) in locations where coal is expensive or fuel must be carried a considerable distance, because gasoline may be more cheaply transported than coal, and consequently the gasoline engine would be cheaper to operate. The agricultural gasoline engine, for use on farms and plantations located far from a railroad, is a good example of this. There might be many other special conditions to make the gas or gasoline engine preferable, and no exact rules can be given in this matter. The data which have been given in the present chapter, together with a careful study of all existing conditions, will guide the intelligent engineer in choosing the kind of engine best adapted to each individual case.

PART VIII.

MATERIALS AND THEIR PROPERTIES.

CHAPTER XXV.

COMPOSITION AND GENERAL PROPERTIES.

We are accustomed to think of air and water as elements, but emists easily prove that air is a mixture of various gases and at water is a combination of two gases. They have been unable, wever, to decompose these two gases and have therefore con- ded that they are fundamental or elementary forms of matter. y analyzing and decomposing a large number of materials they ve discovered a large number of substances which they are unable decompose further. These substances, some of which are solids, hers liquids, and still others gases, under ordinary conditions, ey call elements. Each element has definite and peculiar prop- ties. By their combination with each other they produce all e different substances with which we are familiar. They always mbine with each other in certain definite proportions, which oportions are multiples of the atomic weights given in the table posite.

Atoms and Molecules.—If we take a piece of iron and divide into small fragments, we still find that these fragments retain l the properties which were characteristic of the original piece. we divide these pieces still further up to the limit of observa- on by the microscope, they still retain these properties. It is nceived, however, that a point might be reached such that if *vision were carried still further* the particles produced by this *division would lose some or all of the properties of the origi- material.* *It is further* believed that beyond this there can b no further division. These last final particles are spoken of as the **atoms** of an element. The smallest particle which can exist and still retain the distinctive peculiar properties of a substance is called the **molecule**.

TABLE OF ELEMENTS.

Elements.	Symbol.	Atomic Weight.	Elements.	Symbol.	Atomic Weight.
Aluminium,	Al	27.08	Molybdenum,	Mo	95.9
Antimony (Stibium),	Sb	120.3	Nitrogen,	N	14.041
Arsenic,	As	75	Nickel,	Ni	59
Barium,	Ba	137	Niobium,	Nb	94.2
Beryllium,	Be	9.1	Osmium,	Os	192
Bismuth,	Bi	208	Oxygen,	O	16
Boron,	B	11.01	Palladium,	Pd	106
Bromine,	Br	79.963	Phosphorus,	P	31.03
Cadmium,	Cd	112.1	Platinum,	Pt	194.8
Cesium,	Cs	132.9	Potassium (Kalium),	K	39.14
Calcium,	Ca	40	Rhodium,	Rh	103
Carbon,	C	12	Rubidium,	Rb	85.4
Cerium,	Ce	140.2	Ruthenium,	Ru	101.7
Chlorine,	Cl	35.453	Samarium,	Sa	150
Chromium,	Cr	52.2	Scandium,	Sc	44.1
Cobalt,	Co	59	Sulphur,	S	32.06
Copper,	Cu	63.3	Selenium,	Se	79.1
Didymium,	Di	142.3	Silver (Argentum),	Ag	107.66
Erbium,	Er	166	Silicon,	Si	28.4
Fluorine,	Fl	19	Sodium (Natrium),	Na	23.06
Gallium,	Ga	69.9	Strontium,	Sr	87.5
Germanium,	Ge	72.3	Tantalum,	Ta	183
Gold (Aurum),	Au	197.2	Tellurium,	Te	125
Hydrogen,	H	1.003	Thallium,	Tl	204.1
Indium,	In	113.7	Thorium,	Th	232.4
Iodine,	I	126.86	Tin (Stannum),	Sn	118.1
Iridium,	Ir	193.2	Titanium,	Ti	48.1
Iron (Ferrum),	Fe	56	Tungsten (Wolfram),	W	184
Lanthanum,	La	138.5	Uranium,	Ur	239.4
Lithium,	Li	7.03	Vanadium,	Vd	51.2
Lead (Plumbum),	Pb	206.91	Ytterbium,	Yb	173.2
Magnesium,	Mg	24.38	Yttrium,	Y	88.7
Manganese,	Mn	55	Zinc,	Zn	65.5
Mercury,	Hg	200.4	Zirconium,	Zr	90.7

olmium and thulium (the element X of Soret) might also be mentioned, h the latest researches seem to indicate that they and also erbium, didymium arium are not simple substances, but rather mixtures of several elements.

ights given are not the actual weights of the atoms, as are inconceivably minute, but the relative weights. oxygen atom weighs about sixteen times as much as the atom. As the latter is the lightest of all, it is taken as rd of atomic weight.

substance is now supposed to be composed of an immber of molecules, which, even in the solid state, are irely at rest, and in the gaseous form are in a state of violent commotion, rushing about in straight lines in all with inconceivable rapidity.

ficulty of proving or disproving the molecular theory inability to determine the size or shape of a molecule eans in our power. The most powerful microscope fails show them, and should some material for lenses be disfinitely superior to glass or other material at present in ould fall far short of appreciating a molecule through .

incipal properties of different metals are their *malleaapability* to stand hammering; their *ductility*, or power rawn into wire-form; their *tenacity*, or strength; their their *fusibility*, or ease of melting under the application nd their *specific gravity*. (For melting-points see Chap-

lowing table gives an idea of the order in which some mon metals stand:

ability.	Ductility.	Tenacity.	Fusibility.
,	Platinum,	Iron,	Tin,
r,	Silver,	Copper,	Lead,
inum,	Iron,	Aluminum,	Zinc,
er,	Copper,	Platinum,	Aluminum,
	Gold,	Silver,	Silver,
,	Aluminum,	Zinc,	Gold,
	Zinc,	Gold,	Copper,
num,	Tin,	Tin,	Iron,
	Lead.	Lead.	Platinum.

Gravity, Specific.—The specific gravity of a body is the ratio of its weight to the weight of an equal volume of some other body assumed as a conventional standard. The standard usually adopted for solids and liquids is rain or distilled water at a common temperature. In bodies of equal magnitudes the specific gravities are directly as their weights or as their densities. In bodies of the same specific gravity their weights will be as the magnitudes. In bodies of equal weights the specific gravities are inversely as the magnitudes. The weights of different bodies are to each other in the compound ratio of their magnitudes and specific gravities. Hence, it is obvious that, speaking of the magnitude, weight, and specific gravity of a body, if any two of them are given, the third may be found. A body, immersed in a fluid, will sink if its specific gravity be greater than that of the fluid; if it be less, the body will rise to the top and be only partly immersed; and if the specific gravity of the body and fluid be equal, it will remain at rest in any part of the fluid in which it may be placed. When a body is heavier than a fluid it loses as much of its weight when immersed as is equal to a quantity of the fluid of the same bulk or magnitude. If the specific gravity of the fluid be greater than that of the body, then the quantity of fluid displaced by the part immersed is equal to the weight of the whole body. The specific gravities of equal solids are as their parts immersed in the same fluid.

To Find the Specific Gravity of a Substance.—If it is heavier than water, weigh it in air and then weigh it suspended in water. The difference in weight is the weight of an equal bulk of water. Divide the weight in air by the weight of the equal bulk of water and the quotient is the specific gravity.

If the body floats put just the weight on it that is necessary to make it sink even with the surface of the water. Then from the sum of this weight and the weight in air subtract the weight in water. The difference is the weight of an equal bulk of water. *Divide the* weight in air by this and the quotient will be the *specific gravity.*

SPECIFIC GRAVITIES OF METALS.

	Specific gravity.	Weight per cu. in.
um	2.56 to 2.71	.0963
y	6.66 to 6.86	.2439
	9.74 to 9.90	.3544
opper + Zinc 80 20	7.8 to 8.6	.3103
70 30		.3031
60 40		.3017
50 50		.2959
Copper, 95 to 80 Tin, 5 to 20	8.52 to 8.96	.3195
n	8.6 to 8.7	.3121
	1.58	
m.	5.0	
	8.5 to 8.6	
re	19.245 to 19.361	.6949
	8.69 to 8.92	.3195
	22.38 to 23.	.8076
st.	6.85 to 7.48	.2604
rought	7.4 to 7.9	.2779
	11.07 to 11.44	.4106
ese	7. to 8.	.2887
um	1.69 to 1.75	.0641
32°	13.60 to 13.62	.4915
60°	13.58	.4900
212°	13.37 to 13.38	.4828
	8.279 to 8.93	.3175
n	20.33 to 22.07	.7758
m	0.865	
	10.474 to 10.511	.3791
	0.97	
	7.69* to 7.932†	.2834
	7.291 to 7.409	.2652
n	5.3	
n	17. to 17.6	
	6.86 to 7.20	.2526

he first column of figures the lowest are usually those of cast metals.

ific Gravity of Liquids.—The most obvious method of ing the specific gravity of any liquid is to take a vessel ith it and weigh it. Then weigh the same vessel filled ater. Divide the weight of the substance by the weight of er and the quotient will be the specific gravity.

hydrometer used for testing the specific gravity of liquids *of a graduated* tube of small diameter attached to a bulb containing air enough to make it float. Just below this air chamber is a small bulb containing enough mercury to keep the apparatus upright. The graduations on the tube give the specific gravity of the liquid in which the hydrometer is placed.

SPECIFIC GRAVITIES OF LIQUIDS AT 60° F.

Acid, Muriatic	1.200	Oil, Olive	.92
“ Nitric	1.217	“ Palm	.97
“ Sulphuric	1.849	“ Petroleum	.78 to .88
Alcohol, pure	.794	“ Rape	.92
“ 95 per cent.	.816	“ Turpentine	.87
“ 50 “	.934	“ Whale	.92
Ammonia, 27.9 per cent.	.891	Tar	1.
Bromine	2.97	Vinegar	1.08
Carbon disulphide	1.26	Water	1.
Ether, Sulphuric	.72	“ sea	1.026 to 1.03
Oil, Linseed	.94		

SPECIFIC GRAVITIES OF GASES AT 32° F.

Compared with air, pressure 1 atmosphere, 1 cu. ft. air weighs at this temperature and pressure .08071 pound.

Air	1.000	Hydrogen	.070
Ammonia (gas)	.597	Hydrogen sulphide	1.191
Carbonic acid gas	1.529	Marsh gas	.559
Carbon monoxide	.967	Nitrogen	.972
Chlorine	2.422	Nitrous oxide	1.527
Coal gas from	.340	Oxygen	1.105
“ to	.450	Sulphurous acid gas	2.247
Hydrochloric acid gas	1.250	Steam (at 212°)	.469

Use of Tables.—*Example.*—A certain vessel contains when full 10 pounds of water. How many pounds of linseed oil will it contain? By looking in the table we find the specific gravity of linseed oil is $\frac{94}{100}$. Therefore the vessel will contain 10 × .94, or 9.4 pounds of linseed oil.

Example.—1 gallon of alcohol weighs at 60° F. 8.3 pounds. What will 1 gallon of linseed oil weigh? Divide 8.3 by the *specific gravity* of alcohol and multiply by the specific gravity *seed oil.* $8.3 \div .794 \times .94 = 9.88$ pounds.

WEIGHT OF A CUBIC FOOT OF SUBSTANCES.

NAMES OF SUBSTANCES.	Average Weight. Lbs.
Aluminum,	162
Anthracite, solid, of Pennsylvania,	93
" broken, loose,	54
" " moderately shaken,	58
" heaped bushel, loose,	(80)
Ash, American white, dry,	38
Asphaltum,	87
Brass, (Copper and Zinc,) cast,	504
" rolled,	524
Brick, best pressed,	150
" common hard,	125
" soft, inferior,	100
Brickwork, pressed brick,	140
" ordinary,	112
Cement, hydraulic, ground, loose, American, Rosendale,	56
" " " " " Louisville,	50
" " " " English, Portland,	90
Cherry, dry,	42
Chestnut, dry,	41
Clay, potters', dry,	119
" in lump, loose,	63
Coal, bituminous, solid,	84
" " broken, loose,	49
" " heaped bushel, loose,	(74)
Coke, loose, of good coal,	62
" " heaped bushel,	(40)
Copper, cast,	542
" rolled,	548
Earth, common loam, dry, loose,	76
" " " " moderately rammed,	95
" as a soft flowing mud,	108
Ebony, dry,	76
Elm, dry,	35
Flint,	162

WEIGHT OF SUBSTANCES *continued*).

NAMES OF SUBSTANCES.	Average Weight. Lbs
Glass, common window,	157
Gneiss, common,	168
Gold, cast, pure, or 24 carat,	1204
" pure, hammered,	1217
Granite,	170
Gravel, about the same as sand, which see.	
Gypsum (plaster of paris),	142
Hemlock, dry,	25
Hickory, dry,	53
Hornblende, black,	203
Ice,	58.7
Iron, cast,	450
" wrought, purest,	485
" " average,	480
Ivory,	114
Lead,	711
Lignum Vitæ, dry,	83
Lime, quick, ground, loose, or in small lumps,	53
" " " " thoroughly shaken,	75
" " " " per struck bushel,	(66)
Limestones and Marbles,	168
" " loose, in irregular fragments,	96
Magnesium,	109
Mahogany, Spanish, dry,	53
" Honduras, dry,	35
Maple, dry,	49
Marbles, see Limestones.	
Masonry, of granite or limestone, well dressed,	165
" " mortar rubble,	154
" " dry " (well scabbled,)	138
" " sandstone, well dressed,	144
Mercury, at 32° Fahrenheit,	849
Mica,	183
Mortar, hardened,	103
Mud, dry, close,	80 to 110

WEIGHT OF SUBSTANCES (*continued*).

NAMES OF SUBSTANCES.	Average Weight. Lbs.
Mud, wet, fluid, maximum,	120
Oak, live, dry,	59
" white, dry,	50
" other kinds,	32 to 45
Petroleum,	55
Pine, white, dry,	25
" yellow, Northern,	34
" " Southern,	45
Platinum,	1342
Quartz, common, pure,	165
Rosin,	69
Salt, coarse, Syracuse, N. Y.,	45
" Liverpool, fine, for table use,	49
Sand, of pure quartz, dry, loose,	90 to 106
" well shaken,	99 to 117
" perfectly wet,	120 to 140
Sandstones, fit for building,	151
Shales, red or black,	162
Silver,	655
Slate,	175
Snow, freshly fallen,	5 to 12
" moistened and compacted by rain,	15 to 50
Spruce, dry,	25
Steel,	490
Sulphur,	125
Sycamore, dry,	37
Tar,	62
Tin, cast,	459
Turf or Peat, dry, unpressed,	20 to 30
Walnut, black, dry,	38
Water, pure rain or distilled, at 60° Fahrenheit,	62⅓
" sea,	64
Wax, bees,	60.5
Zinc or Spelter,	43.7

Green timbers usually weigh from one-fifth to one-half more than dry.

WEIGHT OF VARIOUS MATERIALS.

1 bushel, heaped, bituminous coal	weighs	80 lbs.,	approximately.
1 " " coke	"	37 "	"
1 " " lime	"	75 "	"
1 " (2748 cu. in.) charcoal	"	20 "	"
1 " struck, Rosendale cement	"	68 "	"
1 " " salt, coarse	"	56 "	"
1 " " wheat	"	60 "	"
1 " " corn	"	56 "	"
1 " " oats	"	30 "	"
1 barrel petroleum, 42 gallons,	"	275 "	"

Brick.—The sizes of bricks of different makers vary considerably, as do also bricks from the same maker, owing to the different heats to which they are subjected. The following are some common dimensions, as given in the handbook of the New Jersey Steel and Iron Company:

Description.	Inches.	Description.	Inches.
Baltimore front	8¼×4⅛×2⅜	Maine	7½×3⅜×2⅜
Philadelphia front		Milwaukee	8½×4⅛×2⅜
Wilmington front		North River	8 ×3½×2¼
Trenton front		Trenton	8 ×4 ×2¼
Croton	8½×4 ×2¼	Ordinary	7¾×3⅝×2¼ 8 ×4⅛×2½
Colabaugh	8¼×3⅝×2⅜		

FIRE BRICK—
Valentine's (Woodbridge, N. J.) . . . . 8⅞×4⅜×2½ ins.
Downing's (Allentown, Pa.) . . . . 9 ×4½×2½ ins.

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 ¼ inch thick?

$\underline{8+\frac{1}{4}}\times\underline{2\frac{1}{4}+\frac{1}{4}}=20.62$; $144\div 20.62=7$; $7\times 3=21$ bricks per sq. ft.

BRICK-WORK AND MASONRY.

Stone work is estimated by the perch of 25 cubic feet. Brick-work is estimated by the thousand, and for various thicknesses of wall runs:

9 in. wall or 1 brick in thickness, 14 bricks per superficial foot.
13 " " 1½ " " 21 " " "
18 " " 2 " " 28 " " "
22 " " 2½ " " 35 " " "

CHAPTER XXVI.

METALS IN COMMON USE.

Iron is the most important of all the metals known to man, as ell as the most useful. It has been one of the principal agents n the civilization of the human race, and is at the present day ore extensively employed in the mechanical arts than any other etal. It is found in different conditions, but always in the state f oxides, or as iron ore, that is, a sort of rusty metallic state. The ost common kind — the hematite or blood-stone — may be decribed as iron-rust solidified, or rendered concrete by water. After eing taken from the ground in the condition of ore, it is placed n a blast-furnace and smelted, after which it is rendered fibrous nd ductile by puddling. Spiegel iron or specular cast-iron is, as s name implies, largely crystalline, presenting bright, mirror-like, leavage planes.

Wrought-iron varies in specific gravity from 7·8 to 7·6; taking he mean at 7·7, a cubic foot will weigh 479·8721664 lbs., or nearly 80 lbs. Cast-iron varies in specific gravity from 7·5 to 6·9, the verage being 7·2.

	Wrought-Iron, Lbs.	Cast-Iron, Lbs.
A cubic foot…………	479·872	439·800
A cylindrical foot…..	376·891	344·407
A spherical foot…….	251·261	230·279
A cubic inch……….	0·2777	0·2845
A cylindrical inch….	0·2181	0·1999
A spherical inch……	0·1454	0·1333

Cast-iron is composed of about 91 per cent. of iron, 5 of caron, 2 of silicon, and 2 parts of sulphur, phosphorus, and other mpurities. It also contains manganese, nickel, cobalt, chromium, anadium, titanium, and tungsten in minute quantities. The arts of steam-engines *generally* made of wrought-iron are the *ink, eccentric-rods and straps,* valve- and piston-rods, connecting-*ds, air-pump levers,* cross-heads for pumps, arms, etc.

Rust.—The red powder that falls from iron which has been subjected to the action of moisture is the oxide of the m and is termed rust.

Steel is one of the chemical modifications of iron, a comb tion of iron and carbon. It is composed of different percen of each according to the purpose for which it is used. The containing the least carbon is the softest, and that containin most is the hardest.

Cast-iron, wrought-iron, and steel can be distinguished each other by the difference in the grain — wrought-iron being in the grain than cast, and steel finer than wrought; cast-iro ing short and brittle, wrought-iron fibrous, and steel void of

Steel and cast-iron are fusible; wrought-iron is malleable, tile, tough, fibrous, and possesses the quality of welding; also, is capable of being welded. From this it will be seen steel possesses properties in common with both wrought- and iron. Malleable iron is composed of 99·5 per cent. of iron, of carbon, 0·076 of silicon, and the rest is sulphur and phorus. Its principal value consists in its property of resi the chemical action of salt water or steam.

TABLE

SHOWING THE PERCENTAGE OF CARBON IN THE VARIOUS GRADES IRON AND STEEL.

Iron semi-steelified contains	1–150	% Carbo
Soft steel capable of welding	1–120	"
Cast steel for common purposes	1–100	"
Cast steel requiring more hardness	1–90	"
Steel capable of standing a few blows, but quite unfit for drawing	1–50	"
First approach to a steely, granulated fracture	1–40	"
White cast-iron	1–25	"
Mottled cast-iron	1–20	"
Carbonated cast-iron	1–15	"
Super-carbonated crude iron	1–12	"

TABLE

SHOWING THE ACTUAL EXTENSION OF WROUGHT-IRON AT VARIOUS TEMPERATURES.

Deg. of Fah.	Length.	
32°	1·	
212	1·0011356	
392	1·0025757	Surface becomes straw-colored, deep-yellow, crimson, violet, purple, deep-blue, bright-purple.
672	1·0043253	
752	1·0063894	
932	1·0087730	Surface becomes dull, and then bright-red.
1,112	1·0114811	
1,652	1·0216024	Bright-red, yellow, welding heat, white heat.
2,192	1·0348242	
2,732	1·0512815	
2,912	Cohesion destroyed. Fusion perfect.	

Linear Expansion of Wrought-Iron. — The linear expansion which a bar of wrought-iron undergoes, according to Daniell's pyrometer, when heated from the freezing- to the boiling-point, or from 32° to 212° Fah., is about $\frac{1}{880}$ of its length; at higher temperatures the elongation becomes more rapid. Thus, it will be seen how sensible a change takes place when iron undergoes a variation of temperature. A bar of iron 10 feet long, subject to an ordinary change of temperature of from 32° to 180° Fah., will elongate more than $\frac{1}{8}$ of an inch, or sufficient to cause fracture in stone-work, strip the thread of a screw, or endanger a bridge, floor, roof, or truss, or even push out a wall if brought in contact with it.

The expansion of volume and surface of wrought-iron is calculated by taking the linear expansion as unity; then, following the geometrical law, the superficial expansion is twice the linear, and the cubical expansion is three times the linear.

Cast-iron expands $\frac{1}{162000}$ of its length for one degree of heat; the greatest change in the shade, in this climate, is $\frac{1}{1170}$ of its *length; exposed to the* sun's rays, $\frac{1}{1000}$.

Cast-iron *shrinks,* in cooling, from $\frac{1}{85}$ to $\frac{1}{98}$ of its length.

TABLE

DEDUCED FROM EXPERIMENTS ON IRON PLATES FOR STEAM-BOILERS, BY THE FRANKLIN INSTITUTE, PHILADA.

Iron boiler-plate was found to increase in tenacity, as its temperature was raised, until it reached a temperature of 550° above the freezing-point, at which point its tenacity began to diminish.

At 32° to 80°	tenacity is	56,000 lbs.,	or ⅐ below its maximum.
" 570°	" "	66,000 "	the maximum.
" 720°	" "	55,000 "	the same nearly as at 30°.
" 1050°	" "	32,000 "	nearly ½ the maximum.
" 1240°	" "	22,000 "	nearly ⅓ the maximum.
" 1317°	" "	9,000 "	nearly ⅐ the maximum.

It will be seen by the above table that if a boiler should become overheated by the accumulation of scale on some of its parts, or an insufficiency of water, the iron would soon become reduced to less than one-half its strength.

TABLE

SHOWING THE STANDARD WEIGHTS OF CAST-IRON WATER-PIPE.

3 inch,	15 lbs. per foot	= 180	lbs. per length of 12 feet.
4 inch,	22 " "	= 264	" " " "
6 inch,	33 " "	= 400	" " " "
8 inch,	42 " "	= 500	" " " "
10 inch,	60 " "	= 720	" " " "
12 inch,	75 " "	= 900	" " " "

TABLE

SHOWING THE STANDARD WEIGHTS OF CAST-IRON GAS-PIPE.

3 inch,	12½ lbs. per foot	= 150	lbs. per length of 12 feet.
4 inch,	17 " "	= 204	" " " "
6 inch,	30 " "	= 360	" " " "
8 inch,	40 " "	= 480	" " " "
10 inch,	50 " "	= 600	" " " "
12 inch,	70 "	= 840	" " " "

TABLE

WING THE WEIGHT OF CAST-IRON PIPES, 1 FOOT IN LENGTH, FROM ¼ CH TO 1½ INCHES THICK AND FROM 3 INCHES TO 24 INCHES DIAMETER.

in Inches.	Thickness in Inches.								
	¼ Lbs.	⅜ Lbs.	½ Lbs.	⅝ Lbs.	¾ Lbs.	⅞ Lbs.	1 Lbs.	1⅛ Lbs.	1½ Lbs.
3	8½	12½	17¼	22¼	27½	......	......	......	......
3½	9¼	14¼	19½	25¼	31¼	......	......	......	......
4	10	16¾	22	28½	35	......	......	......	......
4½	11¾	18	24½	31½	38¾	......	......	......	......
5	13	19¾	27	34½	42¼	50½	59	......	......
5½	15	21½	29½	37½	46	54¾	63¾	......	......
6	......	23½	32	40¾	49¾	59	68¾	78¾	88¾
6½	......	25¼	34½	43¾	53½	63½	73½	84¼	95
7	......	27¼	36¾	46¾	56¾	67¾	78½	89¾	101¼
7½	......	29	39	50	60¾	72	83½	95¼	107½
8	......	30¾	41¾	53	64½	76¼	88½	100¾	113½
8½	......	33	44½	56¼	68¼	80¾	93½	106½	120
9	......	34½	46½	59	71¾	84¾	98½	111¾	125¾
9½	......	36¼	49	62	75½	89	103	117½	132
0	......	38¼	51½	65¼	79¼	93½	108	122¾	138
0½	......	......	54	68¼	82¾	97¾	112¾	128½	144¼
1	......	......	56½	71¼	86½	102	117¾	134	150¼
1½	......	......	59	76¼	90	106¼	122¾	139½	156½
2	......	......	61¼	77½	93½	110½	127½	145	162½
3	......	......	......	82¾	101¼	118¼	137½	154	173½
4	......	......	......	89¼	108¼	126½	146¼	165¼	185¼
5	......	......	......	95¼	115¾	135¼	156¼	176¼	198
6	......	......	......	......	123¼	143	166	187½	211¼
7	......	......	......	......	130¼	152½	178½	198¼	223½
8	......	......	......	......	137	161¼	185¼	209	235¼
9	......	......	......	......	......	169¼	195¾	222¼	247
0	......	......	......	......	......	178	205¼	233¼	259
1	......	......	......	......	......	......	214	243½	273¼
2	......	......	......	......	......	......	223½	244¾	285¼
3	......	......	......	......	......	......	233½	265½	298¼
4	......	......	......	......	......	......	245¼	277½	310½

TABLE

SHOWING THE WEIGHT OF CAST-IRON BALLS FROM 3 TO 13 INCHES IN DIAMETER.

iam. in Inches..	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6	6¼	6½	6¾	7	7¼	7½	7¾
Vt. in Pounds...	3¾	4¾	5¾	7¼	8¾	10½	12½	14¾	17	20	23	26	29¾	33½	37¾	42¼	47¼	52½	58	64

Diam. in Inches...	8	8¼	8½	8¾	9	9¼	9½	9¾	10	10¼	10½	10¾	11	11½	12	13
Wt. in Pounds.....	70½	77¼	84¼	92½	100¼	109	118	127½	137¾	148¼	159½	171	183¼	209½	238	302

To find the weight of any cast-iron ball, cube the diameter, and multiply by the decimal ·5236; the product will be the number of cubic inches in the ball, which, if multiplied by the decimal ·2607, will give the weight of the ball in pounds.

WEIGHT OF CAST-IRON PLATES PER SUPERFICIAL FOOT AS PER THICKNESS.

Thickness in Inches..........	⅛		¼		⅜		½		⅝		¾		⅞		1	
Weight..........................	lbs. 4	oz. 13	lbs. 9	oz. 10	lbs. 14	oz. 8	lbs. 19	oz. 5	lbs. 24	oz. 2	lbs. 29	oz. 0	lbs. 33	oz. 13	lbs. 38	oz. 10

TABLE

SHOWING THE WEIGHT OF ROUND-IRON FROM $\frac{1}{2}$ AN INCH TO 6 INCHES IN DIAMETER, 1 FOOT LONG.

For Calculating the Weight of Shafting, etc.

Diameter in Inches........	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2	$2\frac{1}{8}$
Weight in Pounds.........	$\frac{3}{4}$	1	$1\frac{1}{2}$	2	$2\frac{3}{4}$	$3\frac{1}{2}$	$4\frac{1}{4}$	5	6	7	8	$9\frac{1}{2}$	$10\frac{1}{4}$	12

Diameter in Inches.......	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{1}{2}$	$2\frac{5}{8}$	$2\frac{3}{4}$	$2\frac{7}{8}$	3	$3\frac{1}{8}$	$3\frac{1}{4}$	$3\frac{3}{8}$	$3\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{3}{4}$	$3\frac{7}{8}$
Weight in Pounds.........	$13\frac{1}{2}$	15	$16\frac{3}{4}$	$18\frac{1}{4}$	20	22	24	26	28	$30\frac{1}{4}$	$32\frac{1}{2}$	35	$37\frac{1}{4}$	40

Diameter in Inches........	4	$4\frac{1}{8}$	$4\frac{1}{4}$	$4\frac{3}{8}$	$4\frac{1}{2}$	$4\frac{5}{8}$	$4\frac{3}{4}$	$4\frac{7}{8}$	5	$5\frac{1}{4}$	$5\frac{1}{2}$	$5\frac{3}{4}$	6
ight in Pounds.........	$42\frac{1}{2}$	$45\frac{1}{4}$	48	$50\frac{3}{4}$	$53\frac{3}{4}$	$56\frac{3}{4}$	60	63	$66\frac{3}{4}$	$73\frac{1}{4}$	$80\frac{1}{4}$	$87\frac{3}{4}$	$95\frac{1}{2}$

TABLE

SHOWING THE WEIGHT OF BOILER-PLATES 1 FOOT SQUARE AND FROM 1/16TH TO AN INCH THICK.

Thick. in Ins..	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
Wt. in Lbs. per ft. sq.	2½	5	7½	10	12½	15	17½	20	22½	25	27½	30	32½	35	37½	40

TABLE

SHOWING THE WEIGHT OF SQUARE BAR-IRON, FROM ½ AN INCH TO SIX INCHES SQUARE, 1 FOOT LONG.

Square.........	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2	2⅛	2¼	2⅜	2⅝	2½	2¾	2⅞	3	3⅛
Wt. in Lbs....	8/10	1¼	2	2½	3½	4¼	5¼	6½	7½	9	10½	12	13½	15¼	17	19	22	23¼	25½	28	30½	33

Square.........	3¼	3⅜	3½	3⅝	3¾	3⅞	4	4⅛	4¼	4⅜	4½	4⅝	4¾	4⅞	5.	5¼	5½	5¾	6
Wt. in Lbs....	35¾	38½	41½	44½	47½	50¾	54	57½	61	64¾	68⅓	72⅓	76¼	80⅓	84½	93¼	102¼	111¾	121¾

WROUGHT IRON WELDED STEAM, GAS AND WATER PIPE

Table of Standard Dimensions, as manufactured by National Tube Works Company.

	DIAMETER.		Thick-ness.	CIRCUMFERENCE.		TRANSVERSE AREAS.			Length of Pipe per sq. ft. 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	1.677	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

TABLE

HE WEIGHT OF BOILER-PLATES 1 FOOT SQUARE AND FROM $\frac{1}{16}$TH TO AN INCH THICK.

s..	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1
. in Lbs. per ft. sq.	2½	5	7½	10	12½	15	17½	20	22½	25	27½	30	32½	35	37½	4

TABLE

SHOWING THE WEIGHT OF SQUARE BAR-IRON, FROM ½ AN INCH TO SIX INCHES SQUARE, 1 FOOT LONG.

Square........	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2	2⅛	2¼	2⅜	2½	2⅝	2¾	2⅞	3	3⅛
Wt. in Lbs....	$\frac{8}{10}$	1¼	2	2½	3½	4¼	5¼	6½	7½	9	10½	12	13½	15¼	17	19	22	23¼	25½	28	30½	33

are.........	3¼	3⅜	3½	3⅝	3¾	3⅞	4	4⅛	4¼	4⅜	4½	4⅝	4¾	4⅞	5.	5¼	5½	5¾	6
Wt. in Lbs....	35¾	38½	41½	44½	47½	50¾	54	57½	61	64¾	68½	72½	76¼	80¼	84½	93¼	102¼	111¾	121¾

WROUGHT IRON WELDED STEAM, GAS AND WATER PIPE

Table of Standard Dimensions, as manufactured by National Tube Works Company.

DIAMETER.			Thickness.	CIRCUMFERENCE.		TRANSVERSE AREAS.			Length of Pipe per sq. ft. 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
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1¼	1.66	1.38	.14	5.215	4.335	2.164	1.496	.668	2.301	2.768	96.25	2.244	11½
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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

Alloys and Compositions.

	Copper.	Zinc.	Tin.	Antimony.	Lead.	Nickel.	Bismuth.
Brass for locomotive bearings	87·	2·5	5·	———	5		
Brass for glands	66·	0·5	9·				
Brass engine bearings	87·	7·4	6·5				
Yellow brass for turning	48·	20·					
Brass solder	50·	10·					
Bar metal	90·	10·					
Red brass	70·	10·	....	....	5		
Flanges to stand brazing	62·	2·			2		
Tough brass engine work	100·	15·	15·				
Tough brass for heavy bearings	160·	5·	25·				
Muntz metal	90·	60·					
White metal	11·	11·	42·6	85·2			
White metal, hard	104·7	38·7	6·6				
Bronze red	130·5	29·5					
Bronze yellow	100·8	48·8	2·4				
Gun metal for bearings	90·3	9·67	6·3				
Bell metal for large bells	80·		20·				
Britannia metal	1·	2·	81·	16·			
Brass for sheets	84·7	15·3					
Nickel-silver, English	60·	17·8	....	....	.....	22·2	
Nickel-silver, Parisian	66·	13·6	....	....	.....	19·3	
German silver	50·	25·	....	....	.....	25·	

Brass or gun-metal is used for main-bearings of marine-engines and propeller-shafts, link-blocks, air-pump buckets, head- and foot-valves, stern-tube bushes, propellers, and steam- and water-cocks. White metal is frequently used as a lining for main propeller-shaft and tunnel-bearings. Its chief value consists in its anti-friction and lubricating properties, while its disadvantages are that, if it becomes overheated, it will melt and run out of the bearing. Muntz metal is used for surface-condenser tubes, air- lating-pump rods, and surface-condenser tube-plates. It le, has a high tensile strength, is very durable, and not orrosion.

Babbitt's Metal. — Its composition is as follows: Four pounds copper, eight pounds of regulus of antimony, and eighty-eight ınds of tin. The copper is first melted; the tin and the regu- of antimony are then added. After the metals have been ed a short time, and brought to a dull red heat, it is fit for use.

nother durable alloy for the journal-boxes of steam-engines is pper, 84; zinc, 8; tin, 2; lead, 4; and iron, 5 parts.

Bronze Alloy. — Copper, 80; tin, 18; zinc, 2. If, after cast- , and while still red hot, cold water is poured over it, it becomes rder, and finer in grain, and tougher, as the tin, instead of sepa- ing, as happens when the bronze cools slowly, remains mixed, l the alloy retains its compactness.

Solder.—The following solder will braze steel or iron, and may found very useful in case of a valve-stem or other light portion an engine or machine breaking at a time when it is important t the engine or machine should continue work: Silver, 19 rts; copper, 1 part; brass, 2 parts.

Silver solder is generally composed of 4 parts silver and 2 rts yellow brass. Pure copper, in thin strips, is generally used soldering-irons. Plumbers' solder is composed of 2 parts tin l 4 parts lead. This solder melts at about 450° Fah. Tin- iths' solder is composed of 4 parts tin and 2 parts lead. This der melts at about 350° Fah. Bismuth solder is composed 7 parts bismuth, 5 parts lead, and 3 parts tin. This solder melts about 225° Fah. All tin and lead solders become more fusible more tin they contain. Thus, 1 part tin and 10 parts lead lt at about 550° Fah.; while 6 parts tin and 1 part lead melt about 375° Fah. All the tin, lead, and bismuth solders become re fusible the more lead and bismuth they contain.

Delta metal, which is a tough, strong metal capable of being ged, cast, and receiving a high polish, consists of approximately per cent. copper, 30 per cent. zinc, and 5 per cent. iron. has a tensile strength about three-quarters that of wrought n.

TABLE OF WEIGHTS PER LINEAL FOOT OF BRASS AND COPPER ROD.

	BRASS.		COPPER.	
INCHES.	ROUND.	SQUARE.	ROUND.	SQUARE.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*
1-16	.011	.014	.01155	.0147
⅛	.045	.055	.047	.060
3-16	.100	.125	.106	.13497
¼	.175	.225	.189	.241
5-16	.275	.350	.296	.377
⅜	.395	.510	.426	.542
7-16	.540	.690	.579	.737
½	.710	.905	.757	.964
9-16	.90	1.15	.958	1.22
⅝	1.10	1.40	1.182	1.51
11-16	1.35	1.72	1.431	1.82
¾	1.66	2.05	1.703	2.17
13-16	1.85	2.40	1.998	2.54
⅞	2.15	2.75	2.318	2.95
15-16	2.48	3.15	2.660	3.39
1	2.85	3.65	3.03	3.86
1 1-16	3.20	4.08	3.42	4.35
1 ⅛	3.57	4.55	3.831	4.88
1 3-16	3.97	5.08	4.269	5.44
1 ¼	4.41	5.65	4.723	6.01
1 5 16	4.86	6.22	5.21	6.63
1 ⅜	5.35	6.81	5.723	7.24
1 7-16	5.86	7.45	6.255	7.97
1 ½	6.37	8.13	6.811	8.67
1 9-16	6.92	8.83	7.39	9.41
1 ⅝	7.48	9.55	7.993	10.18
1 11-16	8.05	10.27	8.45	10.73
1 ¾	8.65	11.00	9.27	11.80
1 13-16	9.29	11.82	9.76	12.43
1 ⅞	9.95	12.68	10.642	13.55
1 15-16	10.58	13.50	11.11	14.15
2	11.25	14.35	12.108	15.42
2⅛	12.78	16.27	13.668	17.42
2¼	14.32	18.24	15.325	19.51
2⅜	15.96	20.32	17.075	21.74
2½	17.68	22.53	18.916	24.09
2⅝	19.50	24.83	20.856	26.56
2¾	21.40	27.25	22.891	29.05
2⅞	23.39	29.78	25.019	31.86
3	25.47	32.43	27.243	34.69
3¼	30.45	38 77	31.972	40.71
3½	35.31	44.96	37.081	47.22
4	46.124	58.73	48.433	61.67

To find the weight of Octagon Rod, take the weight of Round Rod of a given size and multiply by 1·084.

To find the weight of Hexagon Rod, take the weight of Round Rod of a given size and multiply by 1·12.

These tables are theoretically correct, but variations must be expected in practice.

TABLE OF WEIGHTS PER LINEAL FOOT OF SEAMLESS BRASS AND COPPER TUBING.

IRON PIPE SIZES.

Same as Iron Pipe.	Exact O. D.	Nominal Outside Diameter.	APPROXIMATE WEIGHT PER LINEAL FOOT.	
			Brass.	Copper.
Inches.	Inches.	Inches.	Lbs.	Lbs.
⅛	.405	3-8	.25	.26
¼	.540	9-16	.43	.45
⅜	.675	11-16	.62	.65
½	.840	13-16	.90	.95
¾	1.05	1 1-16	1.25	1.32
1	1.315	1 5-16	1.70	1.79
1¼	1.66	1 5-8	2.50	2.63
1½	1.90	1 7-8	3.	3.16
2	2.375	2 3-8	4.	4.21
2½	2.875	2 7-8	5.75	6.05
3	3.50	3 1-2	8.30	8.74
3½	4.00	4	10.90	11.47
4	4.5	4 1-2	12.70	13.37
4½	5.00	5	13.90	14.63
5	5.563	5 9-16	15.75	16.58
6	6.625	6 5-8	18.31	19.23

TABLE OF WEIGHTS PER LINEAL FOOT OF SEAMLESS DRAWN BRASS AND COPPER TUBING.

STANDARD SIZES.

CARRIED IN STOCK IN 12-FEET LENGTHS.

Outside Diameter.	B. & S. Gauge.	Stubs' Gauge.	WEIGHT PER FT.		Outside Diameter.	B. & S. Gauge.	Stubs' Gauge.	WEIGHT PER FT.	
			Brass.	Copper.				Brass.	Copper.
″			Lbs.	Lbs.				Lbs.	Lbs.
1-8	20	21	.034	.036	1 5-8	12	14	1.49	1.56
3-16	20	21	.057	.060	1 3-4	11	13	1.82	1.91
1-4	18	20	.086	.092	2	11	13	2.09	2.20
5-16	18	20	.113	.119	2 1-4	10	12	2.70	2.83
3-8	17	19	.161	.169	2 1-2	10	12	3.01	3.16
7-16	17	19	.193	.203	2 3-4	10	12	3.33	3.51
1-2	16	18	.255	.268	3	9	11	4.00	4.20
9-16	16	18	.291	.305	3 1-4	8	10	4.84	5.06
5-8	16	18	.325	341	3 1-2	8	10	5.22	5.49
3-4	15	17	.46	.49	4	8	10	5.98	6.28
7-8	15	17	.55	.58	4 1-4	8	10	6.38	6.69
1	14	16	70	.73	4 1-2	8	10	6.77	7.11
1 1-8	14	16	.78	.82	4 3-4	8	10	7.15	7.51
1 1-4	13	15	.99	1.04	5	8	10	7.55	7.93
1 3-8	12	14	1.22	1.29	6	8	10	9.10	9.55
1 1-2	12	14	1.36	1.44	6 3-6	5	7	12.93	13.60

SHOWING NUMBER OF BELT RIVETS AND BURS TO THE POUND.

No.	¼	5-16	⅜	7-16	½	9-16	⅝	¾	⅞	1	1⅛	1¼	1⅜	Burs
3	.....	.....	.....	.....	.....	.....	.....	.....	.....	....	...	.. .	....	70
4	.....	.....	.....	.....	.....	.....	.....	.....	.....	....	...	....	....	78
5	....	.....	.....	.....	64	60	53	48	46	44	39	36	32	85
6	.....	.....	105	100	96	90	74	68	61	56	54	50	46	180
7	211	189	171	160	150	140	132	110	97	91	79	72	63	368
8	266	248	227	200	172	157	147	136	116	100	93	88	71	417
9	365	330	261	248	228	220	184	169	156	133	124	113	99	600
10	411	376	336	305	257	249	223	206	180	162	...	....	....	830
11	416	400	360	338	320	.....	.....	.....	.....	....	...	....	....	944
12	545	475	400	342	325	308	292	257	221	190	...	....	....	1167
13	799	640	547	502	448	400	392	316	. ...	....	...	....	....	1442
14	104	995	816	784	616	550	528	.....	.....	....	...	....	....	1620
15	.....	.....	.....	.....	.....	.....	.....	.....	.....	....	...	....	....	3512

d, which is widely employed in the arts, differs radically properties from iron and copper. It melts at a fairly low rature (about 600° F.), is very soft and malleable, and is t entirely inelastic. It is only slightly soluble in water, the tion of a coating of lead carbonate preventing the further ess of solution. It is not attacked by most acids and is ore used largely for vessels employed in their manufacture. constituent of paints in the forms of white lead (lead care) and red lead (lead oxide) its use is enormous.

electrical work it has two chief uses: 1. In storage batte- ie frames of the plates are formed of pure lead and the active ials of lead compounds. 2. For conductors to be used in ground or submarine work it is drawn over the insulation conductor so as to enclose it in a water-proof lead pipe for irpose of keeping the insulation of the conductor dry.

id is used largely in sheets and pipes to convey or hold s. Its small tensile strength renders it unfit for use where reat strain is to be put upon it; but, on the other hand, its om from attack by oxygen and many oxidizing agents s it exceedingly useful.

eet lead is regularly made with weights per square foot of unds, 3 pounds, 3½ pounds, 4 pounds, 4½ pounds, 5 pounds, nds, 7 pounds, and upward.

id pipe for use as water pipe is made in regular sizes and *ts as given in the table following.*

LEAD AND TIN-LINED LEAD PIPE.

Calibre of Pipe.	Weight per Rod and Foot	Average length of Coils.	Calibre of Pipe.	Weight per Foot.
⅜ in.	7 lbs. per rod		1½ in.	3½ lbs. per foot
"	10 oz. per foot	100 feet	"	4¼ lbs. "
"	1 lb. "	125 "	"	5 lbs. "
"	1¼ lbs. "	100 "	"	6½ lbs. "
"	1½ lbs. "	85 "	"	8 lbs. "
½ in.	9 lbs. per rod	150 "	1¾ in.	4 lbs. "
"	¾ lbs p. foot	135 "	"	5 lbs. "
"	1 lb. "	125 "	"	6½ lbs. "
"	1¼ lbs. "	100 "	"	8½ lbs. "
"	1½ lbs. "	140 "	2 in.	4¾ lbs. "
"	1¾ lbs. "	120 "	"	6 lbs. "
"	2 lbs. "	100 "	"	7 lbs. "
"	2¼ lbs. "	90 "	"	8 lbs. "
"	2½ lbs. "	85 "	"	9 lbs. "
"	3 lbs. "	70 "	2½ in.	8 lbs. "
⅝ in.	14 lbs. per rod		"	11 lbs. "
"	1 lb. per foot	125 "	"	14 lbs. "
"	1½ lbs. "	85 "	"	17 lbs. "
"	2 lbs. "	100 "	3 in.	9 lbs. "
"	2¼ lbs. "	95 "	"	12 lbs. "
"	2½ lbs. "	85 "	"	16 lbs. "
"	2¾ lbs. "	75 "	"	20 lbs. "
"	3 lbs. "	70 "	3½ in.	12½ lbs. "
"	3½ lbs. "	60 "	"	15 lbs. "
¾ in.	16 lbs. p. rod.		"	18½ lbs. "
"	1¼ lbs. per foot	100 "	"	22 lbs. "
"	1½ lbs. "	80 "	4 in.	12 lbs. "
"	1¾ lbs. "	75 "	"	16 lbs. "
"	2 lbs. "	65 "	"	21 lbs. "
"	2½ lbs. "	85 "	"	25 lbs. "
"	3 lbs. "	70 "	4½ in.	14 lbs. "
"	3½ lbs. "	60 "	"	18 lbs. "
"	4½ lbs. "	45 "	5 in.	20 lbs. "
1 in.	24¾ lbs. p. rod.		"	31 lbs. "
"	2 lbs. per foot	65 "		
"	2½ lbs. "	50 "		
"	3¼ lbs. "	65 "		
"	4 lbs. "	50 "		
"	4¾ lbs. "	45 "		
1¼ in.	2 lbs. "	50 "		
"	2½ lbs. "	50 "		
"	3 lbs. "	45 "		
"	3¾ lbs. "	55 "		
"	4¾ lbs. "	45 "		
"	6 lbs. "	35 "		

WEIGHT OF LEAD PIPE FOR A GIVEN HEAD OF W

Head or Number of Feet Fall.	Pressure per sq. inch.	Calibre and Weight per Foot.					
		Letter.	⅜ inch.	½ inch.	⅝ inch.	¾ inch.	1 inc
30 ft.	15 lbs.	D	10 oz.	¾ lb.	1 lb.	1¼ lbs.	2
50 ft.	25 lbs.	C	12 oz.	1 lb.	1½ lbs.	1¾ lbs.	2½
75 ft.	38 lbs.	B	1 lb.	1¼ lbs.	2 lbs.	2¼ lbs.	3¼
ft.	50 lbs.	A	1¼ lbs.	1¾ lbs.	2½ lbs.	3 lbs.	4
	75 lbs.	AA	1½ lbs.	2 lbs.	2¾ lbs.	2½ lbs.	4¾
		AA	1¾ lbs.	3 lbs.	3½ lbs.	4¾ lbs.	6

CHAPTER XXVII.

BOLTS, NUTS, SCREWS, ETC.

ws—Standard Thread.—There are three different threads , the **V** thread, the Whitworth, and the Sellers or U. S. rd, the proportions of which are given below.

“pitch” of a thread is the distance which it travels length-or one revolution of the screw.

thickness or depth of a nut, to give equal strength, must al to the outside diameter of the screw or bolt.

TABLE

THE PROPORTIONS OF THE UNITED STATES OR SELLERS' STANDARD THREADS FOR SCREWS, NUTS, AND BOLTS.

Number of Threads per Inch.	Diameter of Screw at the Root of the Thread in Decimals of an Inch.	Width of Top and Bottom of Thread in Decimals of an Inch.	Outside Diameter of Screw in Inches.	Number of Threads per Inch.	Diameter of Screw at the Root of the Thread in Decimals of an Inch.	Width of Top and Bottom of Thread in Decimals of an Inch.
20	·185	·0062	**2**	4½	1·712	·0277
18	·240	·0074	**2¼**	4½	1·962	·0277
16	·294	·0078	**2½**	4	2·176	·0312
14	·344	·0089	**2¾**	4	2·426	·0312
13	·400	·0096	**3**	3½	2·629	·0357
12	·454	·0104	**3¼**	3½	2·879	·0357
11	·507	·0113	**3½**	3¼	3·100	·0384
10	·620	·0125	**3¾**	3	3·317	·0413
9	·731	·0138	**4**	3	3·567	·0413
8	·837	·0156	**4¼**	2⅞	3·798	·0435
7	·940	·0178	**4½**	2¾	4·028	·0454
7	1·065	·0178	**4¾**	2⅝	4·256	·0476
6	1·160	·0208	**5**	2½	4·480	·0500
6	1·284	·0208	**5¼**	2½	4·730	·0500
5½	1·389	·0227	**5½**	2⅜	4·953	·0526
5	1·491	·0250	**5¾**	2⅜	5·203	·0526
5	*1·616*	*·0250*	**6**	2¼	5·423	·0555

Weight of Bolts per 100.

SQUARE HEADS.

Diam.	¼	5/16	⅜	7/16	½	9/16	⅝	¾	⅞	1
Length.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1½ in.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37.	56.	....	....
2 "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39.9	60.2	95.7	[illegible]
2½ "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44.1	66.	105.6	[illegible]
3 "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48.3	75.4	113.8	[illegible]
3½ "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	52.5	82.4	122.	[illegible]
4 "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	56.7	87.5	130.2	[illegible]
4½ "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60.9	93.8	138.4	[illegible]
5 "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	65.1	100.	146.6	[illegible]
5½ "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	69.3	106.1	154.9	[illegible]
6 "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	73.5	112.2	163.2	[illegible]
6½ "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	77.8	118.3	171.5	[illegible]
7 "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	81.9	124.4	179.8	[illegible]
7½ "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	86.	130.5	187.1	[illegible]
8 "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	90.	136.6	195.4	[illegible]

Breaking Strain of Bolts.

⅜ in.	7/16 in.	½ in.	9/16 in.	⅝ in.	11/16 in.	¾ in.	⅞ in.	1 in.
4,575 lbs.	4,900 lbs.	7,700 lbs.	9,000 lbs.	11,225 lbs.	15,000 lbs.	18,200 lbs.	23,500 lbs.	30,00 lbs.
1⅛ in.	1¼ in.	1⅜ in.	1½ in.	2 in.	2¼ in.	2½ in.	2¾ in.	3 in.
[illegible] lbs.	[illegible] lbs.	[illegible] lbs.	[illegible] lbs.	[illegible] lbs.	[illegible] lbs.	[illegible] lbs.	[illegible] lbs.	[illegible] lbs.

U. S. Tapped Nuts.

NUMBER IN 100 POUNDS.

Size of Bolt.	Threads to Inch.	Square Nuts, Capped.	Hexagon Nuts, Capped.
3/16 inch.	24	17,000	20,500
¼ "	20	7,500	9,000
5/16 "	18	4,500	5,500
⅜ "	16	2,750	3,300
7/16 "	14	1,900	2,170
½ "	13 or 12	1,250	1,500
9/16 "	12	980	1,150
⅝ "	11	700	850
"	11	425	545
	10	400	520
	9	250	340
	8	180	

LENGTHS OF THREADS CUT ON BOLTS.

th of Bolts.	¼ & 5/16	⅜ & 7/16	½ & 9/16	⅝	¾	⅞	1	1⅛	1¼
o 1½ in.	¾	⅞	1	1¼	...	...	...	...	...
" 2 "	⅞	1	1	1¼	1½	1¾	...	...	...
" 2½ "	1	1	1	1¼	1½	1¾	1¾	...	...
" 3 "	1	1	1	1¼	1½	1¾	2	2¼	...
" 4 "	1	1¼	1¼	1½	1½	1¾	2	2½	2½
" 8 "	1	1¼	1¼	1½	1¾	2	2¼	2¾	3
" 12 "	1	1¼	1½	1¾	2	2¼	2½	3	3¼
" 20 "	1	1½	2	2	2	2½	3	3¼	3½

ts longer than 20 inches and larger than 1¼ inches in diameter will be led about 3 times the diameter of the rod.

WEIGHT OF NUTS AND BOLT-HEADS IN POUNDS.

FOR CALCULATING WEIGHT OF EXTRA LONG BOLTS.

n. Bolt in Inches.	¼	⅜	½	⅝	¾	⅞	1	1¼	1½	1¾	2	2½	3
ht of—													
onal nut and head.	.017	.057	.128	.267	.43	.73	1.10	2.14	3.78	5.6	8.7	17.	29.
" "	.021	.069	.164	.320	.55	.88	1.31	2.56	4.42	7.0	10.5	21.	36.
h of bolt, additional	.015	.03	.054	.085	.121	.165	.22	.34	.48	.66	.88	1.36	1.98

WEIGHT AND SIZE OF CAST WASHERS.

WEIGHT PER 100.

	Bolt or Rod . .	⅜ in.	½ in.	⅝ in.	¾ in.	⅞ in.	1 in.
d	Dimensions .	1½ x 5/16	2 x ⅜	2½ x ½	3 x ⅝	3½ x ¾	4 x ⅞
rs	Weight . . .	9½ lbs.	21 lbs.	43 lbs.	70 lbs.	113 lbs.	175 lbs.
	Bolt or Rod . .	1⅛ in.	1¼ in.	1⅜ in.	1½ in.	1¾ in.	2 in.
1	Dimensions .	4½ x 1	5 x 1⅛	5½ x 1¼	6 x 1⅜	7 x 1½	7½ x 1⅝
rs	Weight . . .	256 lbs.	332 lbs.	455 lbs.	610 lbs.	865 lbs.	1,115 lbs.

astings.—Iron and some of the other metals, like brass, lead, , and tin, can be cast in moulds. On cooling they shrink, and vance must be made for this. The following tables will be ul for this purpose:

TABLE

WING THE WEIGHT OF CASTINGS BY WEIGHT OF THE PATTERNS.

ultiply the weight of the pattern by the multiplier opposite material.

White Pine	× 16	Cast-iron.
"	× 17·1	Wrought-iron.
"	× 17·3	Steel.
"	× 18	Copper.
"	× 25	Lead.

TABLE

SHOWING THE SHRINKAGE OF CASTINGS OF DIFFERENT METALS.

st-iron, $\frac{1}{8}$ inch per lineal foot.	Tin, $\frac{1}{12}$ inch per lineal foot.
ass, $\frac{3}{16}$ " "	Zinc, $\frac{5}{16}$ " "
ad, $\frac{1}{8}$ " "	

ule *for finding the approximate weight of iron castings from pat- s.*—Multiply the weight of the pattern by the figures corre- nding to the material in the table. Very accurate results can- be expected, as the specific gravity of wood as well as of iron ies.

Pine wood	14·0
Oak "	9·0
Beech "	9·7
Linden "	13·4
Birch "	10·6
Alder "	12·6
Pear-tree wood	10·0

trength of Wrought-iron.—The tensile strength of wrought-iron, while much larger than that of cast iron, varies almo much with different specimens as that of cast iron, as will be in the table. Good wrought iron should exhibit a tensile br ing strength, however, of about 50,000 pounds per square

TABLE

SHOWING THE TENSILE STRENGTH OF VARIOUS QUALITIES OF AME WROUGHT-IRON.

	Breaking we a square inc
From Salisbury, Conn.,	6
" Pittsfield, Mass.,	5
" Bellefonte, Pa.,	5
" Maramec, Mo.,	4
" " "	5
" Centre County, Pa.,	5
" Lancaster County, Pa.,	5
" Carp River, Lake Superior,	8
" Mountain, Mo., Charcoal bloom,	9
American hammered,	5
Chain-iron,	4
Rivets,	5

Its compressive strength is about the same as its tensile stre An important point in the testing of iron and steel with a to determining their quality, is the amount of elongation the piece will stand before it breaks. Good wrought iron sh show an elongation of 18 to 25 per cent.

Strength of Steel.—The tensile and compressive strength steel may be made to vary from 50,000 to 200,000 pounds square inch by altering the percentage of carbon and other n rials in its composition. Mild steel for boilers is usually spec to be between 55,000 and 65,000 pounds per square inch te strength, and to show an elongation before breakage of 20 t ent.

ariations in tensile strength of various kinds of steel the table below.

	Breaking weight of a square inch bar.
,	52,250
r-plates,	50,000
age boiler-plates,	55,000
joints, double-riveted,	35,000
" single "	28,600
ne steel, highest strength,	198,910
" lowest "	163,760
" average "	180,000
ogeneous metal,	105,732
" " 2d quality,	81,663
mer steel,	148,324
"	154,825
"	157,881

TENSILE STRENGTH OF METALS.

Name of Metal.	Tensile Strength in pounds per sq. in.
inum wire,	30,000–40,000
wire, hard-drawn,	50,000–150,000
ze, phosphor, hard-drawn,	110,000–140,000
silicon "	95,000–115,000
er wire, hard-drawn,	60,000–70,000
wire,	38,000–41,000
cast,	13,000–29,000
wire, hard-drawn,	80,000–120,000
" annealed,	50,000–60,000
, cast or drawn,	26,000–33,000
dium	39,000
num, wire,	50,000
r wire	42,000
mild, hard-drawn,	100,000–200,000
hard, "	150,000–330,000
cast or drawn,	4000–5000
cast,	7000–13,000
drawn,	22,000–30,000

[illegible] which melts at a tempera-

[illegible] approximate weight of iron cast-

[illegible] the process of

[illegible] in cubic feet,

[illegible] at various tem-

[illegible] up to a certain tem-

[illegible] by the application

[illegible] conductor for preventing [illegible] cylinders, pipes, etc.

[illegible] electrical work?

[illegible]

TABLE SHOWING SIZE, WEIGHT, &c., OF WIRE.

Number by Wire Gauge.	Diameter in Decimals of 1 inch.	Feet to the pound.	Weight of 1 foot, in pounds.	Weight of 1 mile, in pounds.	Length of 1 bundle (63 lbs.), in yards.	Area of section, in decimals of 1 square inch.	Actual breaking weig't of bright market wire, in lbs.	Tensile strength of bright market wire per square inch of section, in lbs.
00000	.450	1.863	.5366	2833.148	39.12	.15904	12,598	78,903
0000	.400	2.358	.4240	2238.878	49.52	.12566	9,955	79,326
000	.360	2.911	.3435	1813.574	61.13	.10179	8,124	79,813
00	.330	3.465	.2886	1523.861	72.77	.08553	6,880	80,437
0	.305	4.057	.2465	1301.678	85.20	.07306	5,926	81,110
1	.285	4.645	.2153	1136.678	97.55	.06379	5,226	81,925
2	.265	5.374	.1861	982.555	112.85	.05515	4,570	82,873
3	.245	6.286	.1591	839.942	132.01	.04714	3,948	83,756
4	.225	7.454	.1342	708.365	156.53	.03976	3,374	84,862
5	.205	8.976	.1114	588.139	188.50	.03301	2,839	86,000
6	.190	10.453	.09566	505.084	219.51	.02835	2,476	87,349
7	.175	12.322	.08115	428.472	258.76	.02405	2,136	88,802
8	.160	14.736	.06786	358.3008	309.46	.02011	1,813	90,153
9	.145	17.950	.05571	294.1488	376.95	.01651	1.507	91,276
10	.130	22.333	.04477	236.4384	468.99	.01327	1,233	92,890
11	.1175	27.340	.03658	193.1424	574.14	.01084	1,010	93,194
12	.105	34.219	.02922	154.2816	718.60	.00866	810	93,530
13	.0925	44.092	.02268	119.7504	925.93	.00672	631	93,917
14	.080	58.916	.01697	89.6016	1237.24	.00503	474	94,299
15	.070	76.984	.01299	68.5872	1616.66	.00385	372	96,703
16	.061	101.488	.00985	52.008	2131.25	.00292	292	99,922
17	.0525	137.174	.00729	38.4912	2880.65	.00216	222	102,740
18	.045	186.335	.00537	28.3378	3913.04	.00159	169	106,343
19	.040	235.084	. . .	22.3872	4936.76	.0012566	137	109,362
20	.035	308.079	. . .	17.1389	6469.66	.0009621	107	111,184

HOISTING ROPES (19 WIRES TO THE STRAND).

	IRON.							CRUCIBLE STEEL.			
Trade Number	Diameter in ins.	Circumference in inches.	Weight per foot, in lbs., with hemp center.	Breaking Stress, in Tons of 2,000 lbs.	Proper Working Load, in Tons of 2,000 lbs.	Circumference of Hemp Rope of Equal Strength.	Min. Size of Drum or Sheave, in ft.	Breaking Stress, in Tons of 2,000 lbs	Proper Working Load, in Tons of 2,000 lbs.	Circumference of Hemp Rope of Equal Strength.	Min. Size of Drum or Sheave in feet.
1	2¼	7	8.	74	15	15½	8	164.69	32.9	.	9
2	2	6¼	6.3	65	13	14½	7	132.37	26.5	.	8
3	1¾	5½	5.25	54	11	13	6½	108.13	21.63	.	7½
4	1⅝	5	4.1	44	9	12	5	97.17	19.44	. . .	6
5	1½	4¾	3.65	39	8	11½	4¾	86.38	17.3	16½	5½
5½	1⅜	4¼	3.	33	6.5	10¼	4½	61.00	12.2	15	5
6	1¼	4	2.5	27	5.5	9½	4.	50.17	10.	12¼	″
7	1⅛	3½	2.	20	4.	8	3½	38.00	7.7	11	4½
8	1	3⅛	1.58	16	3.	7	3	29.2	5.8	9	4
9	⅞	2¾	1.2	11.5	2.5	6	2¾	21.55	4.	8	3¾
10	¾	2⅜	.88	8.64	1.75	5	2½	14.99	3.	6½	3½
10¼	⅝	2	.7	5.13	1.25	4½	2	12.53	2.5	5¾	3
10½	9/16	1¾	.44	4.27	.75	4	1¾	8.81	1.75	5¼	2¾
10¾	½	1½	.35	3.48	.5	3½	1½	7.52	1.5	4¾	2

CHAINS.

WEIGHT AND PROOF STRENGTH OF CHAIN MANUFACTURED BY THE NEW JERSEY STEEL AND IRON COMPANY.

STUD CHAIN.			SHORT LINK CHAIN.			X. B. CRANE CHAIN.
Size.	Average Weight per fathom.	Proof.	Size.	Average Weight per fathom.	Proof.	Proof.
Inches.	Pounds.	Tons.	Inches.	Pounds.	Tons.	Tons.
¾	33	10	3/16	2¾	¼	. . .
13/16	38	12	¼	5	½	. . .
⅞	43	14	5/16	7	1	. . .
15/16	50	16	⅜	9½	2	3
1	58	18	7/16	12	2½	4
1 1/16	65	20	½	15	3½	4½
1⅛	72	23	9/16	19	4½	5½
1 3/16	80	26	⅝	25	5½	7
1¼	88	28	11/16	30	7	8½
1 5/16	98	31	¾	35	8	10
1⅜	110	34	13/16	40	9½	11½
1 7/16	114	37	⅞	47	11	13
1½	127	41	15/16	54	12½	14½
1 9/16	138	44	1	61	14	16
1⅝	150	48	1 1/16	69	16	19
1 11/16	157	52	1⅛	76	18	21
1¾	170	56	1 3/16	85	20	23
1 13/16	184	60	1¼	95	22	25
1⅞	200	64	1 5/16	103	24	27
1 15/16	214	68	1⅜	113	26	29
2	230	72	1 7/16	123	28	31
2⅛	250	80	1½	133	30	33
2¼	290	88				

GALVANIZED WIRE ROPES, FOR SHIPS' RIGGING, GUYS FOR DERRICKS, &c.

TRENTON IRON CO.'S LIST.

Circumference in inches.	Weight, per fathom, in lbs.	Circumference of Hemp Rope of equal strength, in ins.	Breaking Stress, in tons of 2,000 lbs.	Circumference in inches.	Weight, per fathom, in lbs.	Circumference of Hemp Rope of equal strength, in ins.	Breaking Stress, in tons of 2,000 lbs.
5½	26½	11	43	3	8	6	12
5¼	24½	10½	40	2¾	6¾	5½	10
5	22	10	35	2½	5½	5	8½
4¾	20½	9½	33	2¼	4¼	4½	7
4½	18	9	30	2	3½	4	6
4¼	16	8½	26	1¾	2½	3½	5
4	14¾	8	23	1½	2	3	3½
3¾	12	7½	20	1¼	1½	2½	2½
3½	10¾	7	16	1	¾	2	2
3¼	9½	6½	14	⅞	½	1½	1

Strength of rope will be found under the chapter on transmis- n of power.

Factors of Safety.—In making use of tables on the strength materials engineers do not make the size of the piece just large ugh to support its load, but make it several times larger, so as be on the safe side. The number of times larger depends on nature of the load to which it is to be subjected, and is called factor of safety. The following represent good practice: Where load is steady with no vibration, such as in roofs, the factor safety is 3. Where load is fairly uniform but causing vibration, in shafting hung from roof, the roof material sizes would be cal- lated with a factor of safety of 4.

When the load is reversed in direction the factor is 6.

Beams—Wooden.—The load which a beam will support de- nds upon its depth, width, length between points at which it is pported, the kind of wood and the way in which it is loaded. A am is uniformly loaded when the weight per square inch rest- on and supported by it is the same at all parts of its length. beam so loaded will support more pounds than if the weight re all concentrated and hung from a hook in the middle.

The table on the opposite page, taken from the Carnegie hand- ok, is calculated with a factor of safety of 4:

If the load is suspended from one point between the points of port of the beams, the safe load may be taken as one-half that en in the table.

Example.—Suppose it is desired to lift an engine fly-wheel ghing 1500 pounds by a block and tackle suspended from a den beam. The beam supports only a light floor and is itself ported by the walls of the building, the distance between the nts of support being 12 feet deep. The beam is 12″ deep by wide, of white pine. Will it safely support the pulley, and by much margin?

From the table a beam 12 feet long, 12″ deep, and 1″ wide uni- mly loaded will support 1000 pounds with a factor of safety of *Loaded at one point its* safe load will be 500 pounds. Therefore a 4″ beam will support 2000 pounds, and if the pulley were to be attached to an eye-bolt screwed into the beam, since the eye-bolt would be about ¾″ diameter, and would take ¾″ from the width of the beam, this beam would just do the work safely.

SAFE LOADS, UNIFORMLY DISTRIBUTED, FOR RECTANGULAR SPRUCE OR WHITE PINE BEAMS.

ONE INCH THICK.

Calculated with factor of safety = 4.
(For oak, increase values in table by ⅓.)
(For yellow pine, increase values in table by ⅔.)

Span in feet.	DEPTH OF BEAM.										
	6″	7″	8″	9″	10″	11″	12″	13″	14″	15″	16″
5	600	820	1070	1350	1670	2020	2400	2820	3270	3750	4270
6	500	680	890	1120	1390	1680	2000	2350	2730	3120	3560
7	430	580	760	960	1190	1440	1710	2010	2330	2680	3050
8	380	510	670	840	1040	1260	1500	1760	2040	2340	2670
9	330	460	590	750	930	1120	1330	1560	1810	2080	2370
10	300	410	530	670	830	1010	1200	1410	1630	1880	2130
11	270	370	490	610	760	920	1090	1280	1490	1710	1940
12	250	340	440	560	690	840	1000	1180	1360	1560	1780
13	230	310	410	520	640	780	930	1080	1260	1440	1640
14	210	290	380	480	590	720	860	1010	1170	1340	1530
15	200	270	360	450	560	670	800	940	1090	1250	1420
16	190	260	330	420	520	630	750	880	1020	1180	1330
17	180	240	310	400	490	590	710	830	960	1100	1260
18	170	230	290	370	460	560	670	780	910	1040	1190
19	160	210	280	360	440	530	630	740	860	990	1130
20	150	200	270	340	420	510	600	710	820	940	1070
21	140	190	260	320	390	480	570	670	780	890	1020
22	140	190	240	310	380	460	540	640	740	850	970
23	130	180	230	290	360	440	520	610	710	810	920
24	130	170	220	280	350	420	500	590	680	780	890
25	120	160	210	270	330	410	480	560	660	750	860
26	110	160	210	260	320	390	460	540	630	720	820
27	110	150	200	250	310	370	440	520	610	690	790
28	110	140	190	240	300	360	430	500	580	670	760
29	110	140	180	230	290	350	410	490	560	640	740

To obtain the safe load for any thickness: Multiply values for 1 inch by thickness of beam.

To obtain the required thickness for any load: Divide by safe load for 1 inch.

The table under bolts gives some tests showing how many pounds weight is necessary to pull out screws from yellow pine. This table shows that a ¾″ screw sunk 5″ into the wood required 7,685 pounds to pull it out. Using a factor of safety of 4, this would support nearly 1900 pounds, or 400 pounds more than the amount of its load.

Steel beams are made with a shape like the letter I, and are hence called I beams. The top and bottom pieces are called the flanges and the vertical piece running between and connecting them is called the web. By the table on p. 654 taken from the catalogue of the Stillwell-Pierce & Smith-Vaile Company, we can calculate what load a beam will carry if uniformly loaded, using a factor of safety of 4. If the load is concentrated at one point, only one-half the result given by the table should be used.

Example.—What load at its centre can be safely suspended from a 6″ I beam whose thickness of web is .23 and whose flanges are 3½″ wide, if the span between points of support is 10 feet? From the table the coefficient for a 6″ beam of these dimensions is 83,500. Dividing this by 10 we get 8,350 pounds as the safe distributed load, and half this, or 4175 pounds, can be suspended at one point.

A uniformly loaded beam has the greatest tendency to break at its middle point, and a smaller weight will break a beam if applied at its middle than at any other point. So that the examples given above as applying to a weight suspended at any point are not strictly correct; but as they are on the safe side and greatly simplify the calculations, it was considered best to give them in this shape.

Columns.—The values for crushing or compressive strength given in the tables are not safe to use where the length of the piece subjected to the crushing force is more than four times its diameter, as with longer pieces a bending action comes in which causes them to give way long before the load given in the tables is reached. The calculation of sizes of columns is beyond the scope of this book, but will be found in treatises on applied mechanics and strength of materials.

Experiment 7.—Suppose we have the same coil of wire as in Experiment 6, which we will call coil No. 1, connected to a galvanometer, and near it a second coil attached to a battery. A current is flowing through coil No. 2, but not through coil No. 1, of course. Now suddenly disconnect the battery from coil No. 2. The needle of the galvanometer will give a sudden jump, showing that by stopping the current through coil No. 2 a current has been produced or induced, as we say, in coil No. 1, although coil No. 1 is not connected to coil No. 2 in any way. In a moment or two the needle of the galvanometer will come to rest at its original position, showing that the current has ceased. If now the battery be connected to coil No. 2 again, the needle will give another jump, but this time in the opposite direction, showing that the induced current is in the opposite direction. If the current instead of actually being stopped entirely were diminished and then increased, we should see the needle go first one way and then the other, as before, showing that any change in the strength of current in coil No. 2 tends to induce a current in No. 1. Looked at from the standpoint of lines of force, when the current in coil No. 2 is increased more lines of magnetic force are enclosed by No. 1, and a current is produced. When the current is diminished less lines pass through No. 1, and a current is induced in the opposite direction. The nearer the two coils are to each other the greater the effect, and if a soft iron core be introduced into the axis of the coils, the induced current becomes enormously greater than before. This combination of two coils with a common iron core is, of course, nothing more or less in principle than the modern transformer.

Resistance.—In Experiment No. 1 if the length of the connecting wire be increased considerably, we shall be unable to detect any symptoms of an electric current. If a galvanometer were put in circuit and the position of the needle noted and then
gth of the connecting wires increased, the deflection of the
meter would decrease, showing that the current was less
fore. As we have in nowise changed the generator,

pparently the greater length of wire offers a greater resistance o the flow of current, whence comes the idea that every electrical circuit possesses resistance.

Electro-motive Force.—If now we should connect two batteries in tandem and connect their free terminals to the galvanometer, we should find the deflection of the needle much greater than before, which means that the flow of current is greater. One battery of a different type might produce a similar result. As the resistance of the circuit is apparently not changed, but the flow of current is much greater, reasoning by analogy from fluids we should expect that there was such a thing as electrical pressure, and that the use of two batteries in tandem had increased it. The electrical pressure which tends to force a current against the resistance of a circuit is variously spoken of as *electric pressure, difference of potential, electro-motive force* (written *e. m. f.*), and *voltage.*

Units.—In order to deal intelligently with any substance or force it has always been found necessary to have some means of measuring it. Thus with gas we want to know the quantity flowing per minute and its pressure; with water the same things; with gravity we want to know how much more it acts on one body than on another. We therefore have to fix upon some convenient standard of the substance or property we want to measure, and agree to call it a unit. For example, the unit of length or distance is a certain carefully made standard rod divided into three parts, each of which we call a foot, and we measure all distances by seeing how many times a copy of this rod is contained in the distance to be measured. The unit of weight is a certain carefully constructed weight, which we call a pound, and all other weights are compared with this or with careful copies of it, and if a certain body is equal in weight to ten of the standard we say its weight is ten pounds.

In electricity the common properties which it is necessary to measure are current, electro-motive force (pressure), and resistance. *Owing to the peculiar* properties of electricity it is necessary to establish or agree on new units by which to measure these properties. The names of these units have been taken from those of great discoverers in electrical science.

The unit of current is called the ampère, after a noted French physicist, and it is that current which will in one second deposit from a standard solution of silver nitrate .001118 gram (.017 grain) of silver on the cathode plate. This unit is a rate of flow, and is in its nature similar to a rate of 1 gallon of water per second.

Of course no one in measuring a current goes through the long process of measurement by means of depositing a metal any more than in order to measure a length he makes a journey to the British Museum to get the standard yard-stick. Convenient instruments working on the principle of a galvanometer are made so that when a current of one ampère flows through their coils their needle points to 1; with a current of 2 ampères, points to 2, and so on.

The unit of electro-motive force or pressure is named the volt, after an Italian scientist, Volta. It is the electrical pressure furnished by a certain kind of battery whose poles are zinc and mercury. [As a matter of fact the form of cell commonly used as a standard has an e. m. f. of 1.45 volts instead of 1 volt, but the definition of the unit is clearer if we assume that the standard cell gives exactly one volt.]

The unit of resistance, called the ohm, is the resistance of a column of mercury 41.85 inches long and weighing 223 grains at 32° F. The standard ohms for common use are made of wire instead of mercury, either German silver or an alloy of copper and nickel called platinoid being used.

The unit of power is named the Watt, after James Watt, and is equal to $\frac{1}{746}$ of one horse-power. A convenient multiple of
ed the Kilowatt, written K. W., and is equal to 1000
r horse-power are very nearly equal to 3 kilowatts,
= $\frac{3}{4}$ K. W. very nearly.

of Units.—Just as it is convenient to have multiples

a foot, such as a mile, rod, or inch, so in electrical work multi-
s of the above units are found useful. The following prefixes
commonly used:

1 megohm = one million ohms;
1 microhm = " millionth part of 1 ohm;
1 kilowatt = " thousand watts.

he prefixes *meg*, *micro*, and *kilo* can be used with other units
n as above illustrated, but such use is somewhat rare.

aws of Resistance.—The resistance of a wire or conductor
ends on its length and the area of cross-section. The greater
length the greater the resistance. The greater the cross-
tion the *less* the resistance. Although this last is sometimes
ublesome to understand, it is quite analogous to the resistance
ered to the flow of water in a pipe; the greater the section of
pipe the easier water flows through; that is, the *less* is the
istance offered.

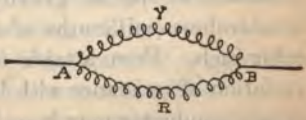
Example.—A certain wire 10 feet long has a resistance of 2 ohms.
hat will be the resistance of 200 feet of it?

Ans.—$20 \times 2 = 40$ ohms.

Example.—100 feet of wire $\frac{1}{16}''$ diam. have a resistance of 1 ohm.
hat will be the resistance of 100 feet of the same kind of wire
t having a diameter of $\frac{1}{20}''$?

Ans. Since the diameter is *one-half* as great, the area is *one-*
arter as great, therefore the resistance of the second wire is four
nes as great as that of the first.

Conductivity is the reverse of resistance, and the conductivity
a wire having a resistance of say 10 ohms is one-tenth, or one
vided by whatever the resist-
ce may be.



Resistances in Multiple.—Two
more wires are in multiple or
rallel when they are connected
shown *in the figure.* To find the joint resistance from A to B

when the resistance of one path is Y ohms and by the other path R ohms.

The joint resistance from A to $B = \frac{R\,Y}{R+Y}$.

Example.—Two resistances of 10 ohms and 20 ohms are joined in multiple. What is their joint resistance?

Ans. $\frac{10\times 20}{20+10}=\frac{200}{30}=6\frac{2}{3}$ ohms.

With three resistances, having values of X ohms, Y ohms, an R ohms each, connected in multiple, their joint resistance is

$$\frac{R\,X\,Y}{R\,X+R\,Y+X\,Y}$$

Example.—Suppose three lamps having resistances of 200, 10 and 50 ohms respectively are connected in multiple. What their joint resistance?

Ans. $\frac{200\times100\times50}{200\times100+200\times50+100\times50}=\frac{1{,}000{,}000}{35{,}000}=28.57$ oh

When, as in the case of incandescent lamps, the resistance each branch is the same, the joint resistance is equal to the res ance of one *divided* by the number of lamps.

Example.—A certain lamp has a resistance of 200 ohms. W would be the joint resistance of 200 of such lamps connected parallel?

Ans. $\frac{200}{200}$, or 1 ohm.

Resistances in Series.—When two resistances are place tandem or series, their joint or total resistance is equal to the of their individual resistances.

Specific resistance is a term having the same relatio resistance as specific gravity has to weight. It is usually g in microhms (millionths of an ohm) per cubic centimetre o

ch. From a table of specific resistances and the law of resistance with length and cross-section, the resist nductor may be calculated.

lowing table is taken from Ayrton.

TABLE OF RELATIVE RESISTANCES.

(*Substances arranged in order of Increasing Resistance for same length and sectional area.*)

Name of Metal.	Resistance in Microhms at 0° Centigrade. 32° Fahr.		Relative Resistance.
	Cubic Centimetre.	Cubic inch.	
Silver, annealed	1·504	0·5921	1
Copper, annealed	1·598	0·6292	1·063
Silver, hard drawn	1·634	0·6433	1·086
Copper, hard drawn	1·634	0·6433	1·086
Gold, annealed	2·058	0·8102	1·369
Gold, hard drawn	2·094	0·8247	1·393
Aluminium, annealed	2·912	1·147	1·935
Zinc, pressed	5·626	2·215	3·741
Platinum, annealed	9·057	3·565	6·022
Iron, annealed	9·716	3·825	6·460
Gold-silver alloy (2 oz. gold, 1 oz. silver), hard, or annealed	10·87	4·281·	7·228
Nickel, annealed	12·47	4·907	8·285
Tin, pressed	13·21	5·202	8·784
Lead, pressed	19·63	7·728	13·05
German silver, hard, or annealed	20·93	8·240	13·92
Platinum-silver alloy (1 oz. platinum, 2 oz. silver), hard, or annealed	24·39	9·603	16·21
Antimony, pressed	35·50	13·98	23·60
Mercury	94·32	37·15	62·73
Bismuth, pressed	131·2	51·65	87·23
Carbon	. . .	. . .	14·

Non-conductors.—The metals generally have a fairly low ecific resistance and are therefore classed as good conductors. n-metals have a high specific resistance, and are called non-nductors or insulators, and are used for supporting or covering res to prevent leakage of electrical currents from them.

The following table gives the approximate relative resistance *several of them referred to* copper as a standard.

Copper	1.
Paper	300,000,000,000,000,000.
Porcelain	4,000,000,000,000,000,000.
Mica	14,000,000,000,000,000,000.
Flint glass	130,000,000,000,000,000,000.
Gutta percha	280,000,000,000,000,000,000.
Wood tar	1,000,000,000,000,000,000,000.
Shellac	5,600,000,000,000,000,000,000.
Ebonite	17,100,000,000,000,000,000,000.
Paraffin wax	20,000,000,000,000,000,000,000.

The above values for the resistance of insulators are only approximate, as their measured resistance will be different according to the electrical pressure with which they are tested, higher measured values being obtained when a small testing pressure is used. Mineral oils are also very good insulators if they are prevented from absorbing moisture by being kept from contact with air.

Change in Resistance with Change in Temperature.—The metals when heated *increase* in resistance, the percentage of increase for each degree rise in temperature being equal for the same metal, although this percentage varies somewhat in the different metals. The following table gives the increase in resistance of 1 ohm for one degree rise in temperature, in the case of some common metals.

Aluminum	.0022	Mercury	.0004
Copper	.0025	Platinum	.0014
German silver	.0001	Silver	.0021
Iron	.0025	Tin	.0020
Lead	.0022	Zinc	.0020

Example.—A certain copper wire has at 60° F. a resistance of 200 ohms. What will the resistance be at 100° F.?

$200 + .0025 \times 40 = 200 + .1 = 200.1$ ohms.

onductors *diminish* in resistance as they are heated. This s much greater than with metals and much less regular. se of carbon the change in resistance in 1 ohm is about m per degree.

Practical Use of Conductors and Insulators.—For carrying ctrical energy from the point where it is generated to the nt where it is to be used we want to use such material and such size that the resistance of the circuit does not exceed sonable limits, although we must be guided by consideration the first cost. Copper has the lowest specific resistance of the nmon metals and is generally employed, although if aluminum s much lower in price than now (30 cts. per pound), it will be erious competitor to copper. Iron is used only on short teleph and telephone lines. It is evident that the circuit should as direct as possible, as the greater its length the greater its istance, and therefore the greater is the amount of energy lost the line.

Insulators are used to prevent current from being led off the iductors. For all work except outdoor work, and, indeed, for arge part of that, the conducting wire is covered with one or re layers of some compound of rubber which is a good insulator. e thicker this rubber covering the better its insulating propers, for we have made the path of leakage of current longer by ickening the rubber coating. A further protection is given by spending the wires at intervals on porcelain or glass or other sulators, so that the wire only comes in contact with its coating, rcelain, or the air, which is also an exceedingly good insulator. sum up briefly, make the path through which you want the irrent to flow as short and easy as possible. Make all possible akage paths as long and narrow as possible.

Current Effects.—Heating.—The passage of current through ny conductor heats it by an amount depending on the resistance the conductor and the strength of the current. If we pass rough a conductor having 10 ohms resistance a current of 10 npères and the same current through another conductor having ohms resistance, the heat units developed in the latter will be uble the number produced in the former coil. This result, own by repeated experiment, is of very great importance, and *expressed by saying that the heating effect* is directly proportional

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the battery; (3) by moving a magnet relatively to a coil the dynamo. Of these the last is the most common, bec has proved to be the most economical. The chemical stands next in importance, being used where only small a of energy are needed.

When two points or objects are at different electric p a current will flow from one to the other if a conductor to connect them. This current will persist till enough el has flown from the high pressure point to the lower to the pressure. Conversely, if we connect two points by passing through a sensitive galvanometer, if its needl deflected it may be assumed that the points are at t electrical pressure.

An actual **mechanical force** is exerted on the substan rating two points at different electrical pressures, and increases as the difference of pressure increases. W difference of pressure gets large enough the substance is cracked and an electrical spark passes which tends to the difference of pressure.

Electrical Pressures in Practice.—While the exact v the same classes of work differ somewhat, the best valu determined for each special case, the following general id be of value:

For ordinary electric bell work, from........................	2 to
" " annunciator " "	5 to
" telephone work, transmitter circuit, from............	2 to
" electric lighting, alternate current systems in houses	52 to
" " " direct " "	110 to
" " " " " on vessels	
" " motors, " "	110 to
" " railways..	500 to
" " lighting, alternate current system, street mains......................................	1100 to
" " power transmission to distances of several miles..	3000 to 20

Ohm's Law, which is the relation existing betwee essure and resistance of a circuit, is the most important law electrical science, and an intelligent application of it will lve most problems which the ordinary engineer will meet. his law is as follows: In an electric circuit the total current mpères] is equal to the total electric pressure [in volts] di- ded by the total resistance [in ohms]. In shorter form it is pressed by the formula $C=\frac{E}{R}$, where $C=$ current in ampères, $=$ pressure in volts, and $R=$ resistance in ohms. Several ex- mples will illustrate its use.

Example 1.—In a certain electrical circuit there is an electro- otive force or electrical pressure of 4 volts. The total resist- ıce of the circuit is 2 ohms. How much will be the current?

Ans.—$C=\frac{E}{R}=\frac{4}{2}=2$ ampères.

Example 2.—What electro-motive force or electrical pressure ust be used to force a current of 10 ampères through a circuit hose resistance is 10 ohms?

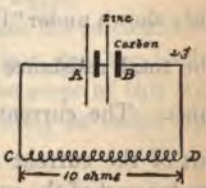
Ans.—$C=\frac{E}{R}$ or $E=CR=10\times 10=100$ volts.

Example 3.—If under a pressure or electro-motive force of 100 olts we get a current flow of 20 ampères, what is the resistance of ıe circuit?

Ans.—$C=\frac{E}{R}$ or $R=\frac{E}{C}=\frac{100}{20}=5$ ohms.

When there is more than one electro-motive force acting in a cir- ıit, we must use for the value of E in the above formula the result- nt of all the separate electro-motive forces cting. When there are several resistances a circuit their sum must be used.

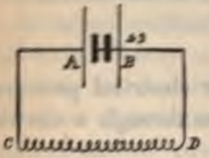
Example 4.—Suppose we have two batter- es, one giving 2 volts and the other 1 volt, heir plates being zinc and carbon, but lifferent solutions being used in each. Con- ect the zinc of one to the carbon of the other, and then connect



to *A* a piece of wire having a resistance of say 10 ohms, as shown in the sketch. When connected in this way—that is, in series and helping each other—the electro-motive forces are added, and the total electro-motive force is 2 + 1, or 3 volts. The batteries themselves have some resistance, and also the lead wires *A C* and *B D*. Suppose that the resistance of one battery is 4 ohms and the other 2 ohms, the resistance of *A C* and *B D* each 1 ohm. Then the total resistance of the circuit is 10 + 1 + 2 + 4 + 1 = 18 ohms.

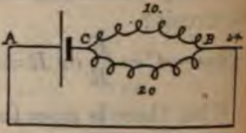
The current will be $\frac{\text{resultant } E}{\text{Total } R} = \frac{3}{18} = \frac{1}{6}$ ampères.

Example 5.—Suppose that one of the batteries was reversed so that the two zincs are connected together as in the sketch. The batteries now oppose each other and the resultant or effective electro-motive force is 2 - 1, or 1 volt.



The resistance of the circuit is as before 18 ohms, and the current will be $\frac{1}{18}$ ampère.

Calculation of Current in Divided Circuits.—Suppose that the battery has an electro-motive force of 2 volts, that its resistance is $\frac{1}{3}$ ohm, that the resistance of the lead wire *A B* is 3 ohms, and that between *C* and *B* we have two paths of resistance 10 and 20 ohms each. What will be the total current flowing through the battery and through *A B*? First find the total resistance of the circuit. The joint resistance between the points B and *E* is, as previously shown under "Resistance," equal to $\frac{10 \times 20}{10 + 20} = \frac{200}{30} = 6\frac{2}{3}$ ohms. The total resistance of the circuit is therefore $6\frac{2}{3} + \frac{1}{3} + 3$, or 10 ohms. The current is equal to $\frac{E}{R} = \frac{2}{10} = .2$ ampères. What the current flows through each branch? Obviously the art of the current will flow through the branch having the resistance. $\frac{10}{30}$ or $\frac{1}{3}$ ampère will flow through the 20 ohms



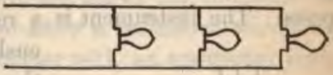
branch, and $\frac{20}{30}$ or $\frac{2}{3}$ ampère will flow through the other branch.

Practical Approximation.—If the resistance of batteries or generator and the leads is small compared to that of the main resistance in circuit, we may neglect them, using for R in the formula the resistance of the external circuit. This is generally the case in electric lighting circuits, where the resistance of the generator will rarely exceed one-hundredth of an ohm, and where the resistance of the line wires will usually be less than one-twentieth of the joint resistance of the lamps.

Example.—On a 110 volt circuit what is the current [total] when one sixteen-candle-power lamp of 220 ohms resistance is turned on? $E = 110$, R is practically 220 ohms. The current $= \frac{110}{220} = \frac{1}{2}$ ampère.

What is the current [total] when two lamps are turned on? The joint resistance of two similar lamps is $\frac{220 \times 220}{220 + 220} = \frac{220 \times 220}{2 + 220} = 110$ ohms, or *half* that of one lamp. The total current $= \frac{110}{110} = 1$ ampère. The current through each lamp is the same, and is $\frac{1}{2}$ ampère as before.

With three lamps turned on the joint resistance is one-third of 220, or $73\frac{1}{3}$, and the total current is $\frac{110}{73\frac{1}{3}} = 1\frac{1}{2}$ ampères, and the current through each lamp is still $\frac{1}{2}$ ampère. Turning on one lamp then adds $\frac{1}{2}$ ampère to the total current. The lamps are connected in multiple as shown in the figure.



The use of alternating currents complicates the calculation of current, pressure, and resistance by Ohm's law, and the method of making such calculations is outside of the scope of this book, inasmuch as the ordinary engineer would rarely be called upon to do so.

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Therefore to measure accurately their current
eter intended to measure small currents. To
e it with the switch-board instrument designed
veral hundred ampères would be like trying to
flour accurately on a pair of hayscales. If we
nt of proper range connect its terminals to two
cuit as *C* and *D* by wires, as shown by dotted
the circuit between *C* and *D*. The total current
ound through the ammeter, and the reading of
f the instrument is correct, give the current in

terminal is marked + and the other —. If
not connected properly, the needle will move or
left of the scale. In this event reverse the wire
the points *C* and *D* to the instrument. Such
lls the polarity of the circuit—that is, which is
e and which the lower pressure side. When the
connected to the higher pressure side of the
deflects in the proper direction.

Known Resistance.—If no ammeter of proper
, we may perhaps have a resistance whose value
ch will carry the current to be measured with-
. In this case with the aid of the voltmeter we
ent. Suppose we have a resistance which we
d a portable voltmeter with an additional scale
o 15 volts, and we want to make the current-
described. Put the resistance in between *C* and
e voltmeter terminals to the ends of the resist-
he reading of the voltmeter was 2.3 volts. The
he resistance is by Ohm's law equal to the elec-
electro-motive force between its terminals di-
tance, or $\frac{2.3}{1}$, which is 2.3 ampères. This is the
e Weston switch-board instruments, a resistance
eing placed in the main circuit of the dynamo
en off from its terminals and run to a voltmeter.

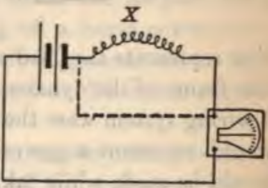
The [illegible]
measure [illegible]
On [illegible]
provid [illegible]
altern [illegible]
scope [illegible]
and [illegible]
an [illegible]
[illegible]
[illegible]
[illegible]

[illegible] punch [illegible]

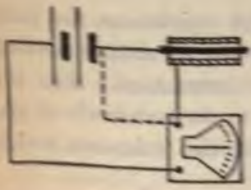
[illegible] mmeter [illegible]
[illegible] can be made [illegible]

eter in series with the resistance and connecting the volt-r to its terminals. Send a current through it from any con-ant source and read both instruments. By Ohm's law $\frac{E}{R}$, or $R=\frac{E}{C}$. Therefore the resistance equals the reading e voltmeter divided by that of the ammeter. The range of mmeter must be suited to the current which the resistance carry without undue heating. This method is particularly able for measuring small resistances, such as armature re-nces, samples of wire, bars, etc.

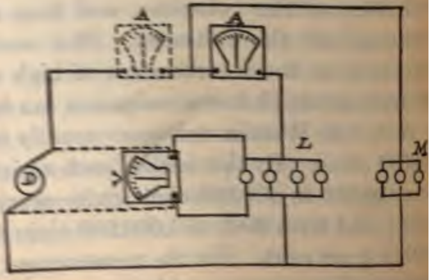
ltmeter Method.—For measuring high resistances, the port-voltmeter and some current-generator are all that is needed. method requires two readings of the instrument. For the reading the instrument is connected to the terminals of the ent-generator. For the second reading the unknown resist-is put in series with the volt-r and then the two connected to generator. In the figure X is the own resistance, and for the first ing the connection shown by the ed line is made. For the second ing the connection is as shown by olid lines. To calculate the resistance from the readings divide irst reading by the second, then multiply the quotient by the tance of the voltmeter, and from the product subtract the tance of the voltmeter. This method is applicable more cially to the measurement of high resistances of 1 meghom ver, although lower resistances can be so measured.



0–150 Weston voltmeter usually has a resistance of about 00 ohms. By this method such an instrument would measure 10,000 to 400,000 ohms quite accurately—say, within 1 per ; and from 4000 to 1,000,000 ohms fairly accurately—say to in 4 per cent. For the measurement of the insulation resist-of wiring systems, cables, armatures (from coil to frame), and *coils (from conductor to* frame) this method is extensiv employed, special voltmeters having a resistance of 40,000 ohms or over being desirable to give greater accuracy in measurements above 1 megohm. As a rule, in such measurements no great accuracy is desired, it being merely necessary to ascertain if the insulation resistance is greater than a certain amount—for armatures and field coils generally 1 meghom. In making such tests the electro-motive force used should be about the same as the insulation will be subjected to in use. Frequently a high insulation is shown by a test made with small electro-motive force where the application of the high working electro-motive force results in a breakdown. The connections to be made for testing an insulation resistance are shown in the figure. The heavy black line represents the copper core, the white space represents the insulating medium, and the cross-patched portion represents the lead sheath of a cable that is being tested or the frame of the dynamo if armature or field is being tested. If a wiring system were the subject of test, the cross-hatched portion would represent a gas or waterpipe. The dotted line connection would be made while taking the second reading.



Measurement of Power.—The power used in any circuit expressed in watts, the electrical unit of power, is equal to the product of the ampères flowing through the circuit and the voltage between the terminals of the circuit. The power in [illegible] it or in any [illegible] circuit can, be measured with a voltmeter and amlepremeter.



sketch consider first only the solid lines. *A* is an ammeter, *V* a voltmeter. *D* represents a dynamo which is supplying groups of lamps at *L* and *M*. Suppose, first, it is desired to w how much electric power is used by the group of lamps *L*. ammeter and voltmeter are connected as shown by the solid s, and the ammeter thus measures the current flowing through lamps, while the voltmeter measures the pressure between ir terminals. The product of the readings of the two instru- nts will give the power in watts. Dividing this product by will give the horse-power.

f the total power given out by the dynamo is desired, connect instruments as shown by the dotted lines; the ammeter then sures the total current flowing through the main circuit and voltmeter measures the electro-motive force between the dy- no terminals.

leters are instruments for recording either the ampère-hours watt-hours, the watt-hour being $\frac{1}{746}$ of a horse-power-hour. lirect-current work there are two kinds in general use in this ntry, the Edison ampère-hour-meter and the Thomson record- watt-meter.

he Edison meter is an electro-chemical meter; the current to neasured, or rather a known fraction of it, one-thousandth, is into a depositing-cell consisting of two zinc plates suspended solution of zinc sulphate. The current takes zinc from one he zinc plates and deposits it on the other plate. The latter e is weighed at the beginning of each month, and from the in weight and the known electro-chemical equivalent of zinc number of ampère-hours is calculated.

he Thomson recording watt-meter is a small motor whose l coils are connected into the main circuit, so that the total rent runs through them. Its armature is connected across the ns. The greater the main current, which is determined by number of lamps turned on, the greater the force tending to the armature, and hence the faster will it turn. Its shaft is nected to a revolution-counter similar to that used in a gas-meter, and its dials graduated by comparison with a standard so as to read properly in watt-hours.

The advantage of the Thomson meter over the Edison is that the simple reading of dials gives the power-consumption, whereas the Edison meter is not direct reading, but requires careful weighing on a delicate balance and after that an arithmetical calculation. The Edison meter, on the other hand, requires much less power to operate it, which is of importance for central-station work. For isolated plants, of course, the Thomson is much to be preferred.

Recording Voltmeters and Ammeters.—Instruments similar in appearance to recording thermometers are available, in which the needle makes a continuous record on a revolving paper dial similar to that of a recording pressure-gauge. Electrically they are galvanometers with a fixed coil and a movable magnet which carries the recording needle.

CHAPTER XXXI.

ELECTRIC GENERATORS.

Batteries or chemical generators are used where the work to be done is so small that it can be done more cheaply by them than with dynamos, and also in some cases where the introduction of an engine necessary to drive the dynamo would be objectionable, if not altogether out of the question. Their greatest use is in operating bells, annunciators, burglar-alarms, time-clocks, telegraphs, telephones, etc.; but many are used by physicians for cautery and for surgical lamps, and by dentists and me- [illegible] for driving small motors, operating fans, grinders, dental [illegible] tc.

[illegible] **ary or storage batteries** are those which, after having [illegible] current for such a time that their active materials are [illegible] hausted, having been changed into chemical substances that do not act on each other, can, by having an electric current passed through them in the opposite direction from some other generator, be brought back into their original condition by having their chemical actions reversed.

Primary batteries are those cells which are not reversible, and, therefore, whose active materials must be renewed from time to time. Many batteries which are in this respect used like primary batteries can be reversed; as, for example, the Daniell cell. The zinc and solution of this cell are, as ordinarily used, renewed when necessary; but the cell is reversible and can be used as a storage cell.

The two classes into which primary batteries are usually divided are closed-circuit batteries and open-circuit batteries.

An open-circuit cell or battery is one which from its nature is only fitted for use on circuits which are for most of the time open, being closed only at the moment when work is to be done, and from the nature of the work remaining closed only a few moments at a time. Such circuits are those for bells, annunciators, alarms, gas-lighting, and telephones. For such circuits the types having zinc for one plate, carbon for the other, and the two immersed in a single fluid, serve admirably, and the combination generally used is zinc and carbon in a solution of sal-ammoniac. This gives an electro-motive force of 1.5 volts nearly, and a fairly low resistance, the ordinary sizes and styles having from $\frac{1}{10}$ to $\frac{5}{10}$ ohm. If the circuit of the cell is kept closed for any length of time, the electro-motive force drops and the resistance rises, owing to the collection of hydrogen-particles on the carbon plate. If the circuit is opened, these disappear in a short time and the cell recovers its original strength. In the class of work mentioned above this is just what happens. If there were some means of getting rid of these hydrogen-particles as fast as they were produced, the cell would be very much improved and would become available for a greater variety of work.

A very *porous carbon* takes up in its pores particles of oxygen *which are held in solution* in the water. These oxygen-particles

unite with more or less of the hurtful hydrogen-particles a
water, so that the bad effect, which is called polarization,
diminished. A French inventor, Leclanché, devised a m
ter means of doing this by putting in cakes of manganes
ide, a strong oxidizing agent. This gives up a part of its
which attacks the hydrogen-particles, forming water. T
of cell is now known as the Leclanché prism-pattern.
cellent cells are made by making the carbon in the form o
hollow cylinder and putting inside the porous cylinder p
manganese binoxide. When it is desired to reduce the
resistance of a cell to the utmost the zinc, instead of hav
usual pencil-form, is made into a hollow cylinder outside
very close to the carbon cylinder. The means of diminish
tery resistance are to increase the surface of the plates an
minish the distance between them, so that two hollow c
cal plates meet the conditions ve
factorily. The carbon cylinder
with pencil zincs is entirely sati
for bell work, etc., in small hous
where signals are made with gr
quency and sometimes for two c
minutes at a time, as in hotel a
ators, elevators, telephones, and
work, the Leclanché pattern sh
used, and in the most severe se
will be advisable to use the patte
ing cylindrical zincs.

Closed-circuit cells must be
g on closed circuits continuously without an a
g of electro-motive force or raising of re
iefly used for such work are the Daniell cell
nde. In the Daniell the harmful hydrogen
r the electro-motive force and raise the resis
of by a second solution, which is a strong o
which burns away the hydrogen. In the Lala

gen set free is attacked by copper oxide, which re- ming water and metallic

Cell.—The original form is illustrated in the cut, a copper plate dipping ition of copper sulphate oxidizing agent), *Z* is a dipping into sulphuric *P* is a porous cup which he sulphuric acid. The penetrate into the pores and will come into con- he copper sulphate, but is prevented by the cup from th it to any great extent. The action is as follows: ves in the acid when the circuit is closed from zinc to ting free hydrogen at the outer surface of the porous copper sulphate attacks this hydrogen, forming water ting copper on the copper plate.

avity pattern is shown in the cut. The two liquids te different specific gravities will not mix to any great extent if the jars are kept quiet. This is especially the case when the circuit is closed and a current is flowing. On open circuit mixture takes place, and the rising copper sulphate coming in contact with the zinc plate, zinc is uselessly dissolved. On this account the Daniell cell is not suited for open-circuit work. The electro-motive force of the Daniell is about 1 volt, and the resistance of ordinary size cell about 4 ohms.

ty Cell.

The Edison-Lalande cell consists of a nc and a plate of black oxide of copper (held in a cop- *suspended in* a solution of caustic potash. On closed circuit the zinc dissolves, forming potassium gen is set free. This is at once attacked b copper oxide, and the result is the formation lic copper. By putting a film of oil on the the local action which would otherwise take p the cell becomes available for open-circuit wo motive force is only $\frac{8}{10}$ volt and its resistance cell no lower than that of the Leclanché p preferable for most open-circuit work, as it re

For motors and cautery work cells are requ current for a longer time than the zinc-carbon could do, and for such service a different class whose characteristics lie somewhere between circuit and the closed-circuit cells. The mos the bichromate cell.

The bichromate cell has zinc and carbon of chromic acid, made by mixing potassiu sulphuric acid. It gives an electro-motive fo and it has a low internal resistance. One gre this cell is that even when the zinc plate is rapidly c this trouble one form has holding the zinc plate u when not in use, while in ous cup is used containing dilute sulphuric acid. T while preserving the zin sistance of the cell.

te Cell.

Care of Cells.—It is in materials of a cell shoul zincs and chemicals contai greatly increase wasteful lo the zinc is eaten up while duced.

mation is a process of alloying the

mercury, which protects the zinc from much of this wasteful action. Zincs are usually more or less amalgamated when purchased, but the process of amalgamation is very easy. The zinc is dipped into dilute sulphuric acid to clean it, and then with a cloth mercury is rubbed on the surface till it presents a uniformly bright appearance.

Renewal of zinc plates should take place when they are nearly eaten away. The remnants can be sold or remelted if there is at hand a suitable mould.

A carbon plate needs no change till its pores are filled, so that hydrogen can no longer be taken up. It will, of course, still continue to work, but not so satisfactorily. It may be improved by boiling it some hours in water, but after one or two such boilings, if the operation of the cell is not satisfactory, a new carbon should be put in.

Where the Leclanché disk or hollow cylinder type is used the carbon is satisfactory till the manganese has given up all the oxygen that it will. After this a new carbon should be put in. It is not possible by the eye to tell whether the oxygen is exhausted except by the appearance of a greater number of hydrogen bubbles than usual on the carbon. A voltmeter attached to the cell when the circuit is closed will show, by the too rapid drop of electro-motive force, that the carbon or solution needs attention.

In the Edison-Lalande cell the two plates and solutions need change all at once, and the proper time to attend to this can be told by the condition of the zinc plate. When nearly gone it is time to put in new materials.

Solutions.—In the sal-ammoniac cells of ordinary size put a quarter of a pound of sal-ammoniac and add *warm* water. The addition of cold water is liable to crack the jar, as sal-ammoniac in dissolving produces a considerable degree of cold. The solution is clear and colorless. If it becomes milky, it shows that more sal-ammoniac is needed. In the ordinary use of a cell water gradually evaporates and the cell should be occasionally *refilled.*

In the Daniell cell, gravity pattern, enough copper-sulphate crystals are put around the copper plate to cover it. Water is put in so as to cover the zinc about one-half inch. A little sulphuric acid is added. After a few hours on closed circuit zinc sulphate will be formed, and a fairly sharp line of demarcation will be seen separating the blue solution of copper sulphate from the clear solution of zinc sulphate. As the cell continues working this line will go lower and lower; when it goes past the halfway distance dip out or siphon out some of the zinc sulphate and replace it by clear water poured in through a funnel reaching down into the solution. If the zinc sulphate gets too strong, it will crystallize on the walls of the jar; while if the copper sulphate is too strong and its level rises up to the zinc, local action will take place and the zinc be wasted.

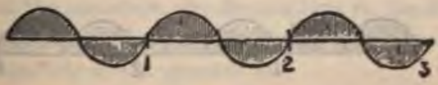
Bichromate Solution.—To 2 pounds of strong sulphuric acid add, stirring constantly, 1 pound of bichromate of potash, powdered, and then after a few minutes add slowly 12 pounds of water. The mixture will become quite warm. After the cell has been used considerably, if the color of the solution becomes bluish, add more potash. If the voltage falls off, but the orange color remains, more sulphuric acid is needed.

Dry cells, so called, are cells in which the solution has been reduced to a pasty condition by adding some substance to the fluid. The only advantages of such cells are their portability. Their resistance is much higher and they polarize much more readily than the ordinary forms.

Various types of cells will be found described in full in Prof. H. S. Carhart's *Primary Batteries* and the work on *Batteries* by Mr. Park Benjamin.

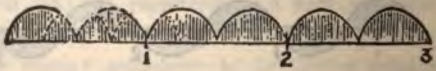
The dynamo may be regarded as a sort of electrical pump [illegible] pumping electricity from a low pressure to a high [illegible] The energy necessary to do this is generally derived [illegible] engine, but, of course, may be obtained from any [illegible]er. For electric lighting or power in isolated plants [illegible] or generators are designed so that when run at constant speed they automatically maintain a practically constant difference of electrical pressure whatever load may be thrown on them, up to the limit of their capacity. As electric power is equal to the product of current by pressure—that is, ampères by volts; and as the volts are practically constant, the power will be proportional to the ampères flowing—that is, to the number of lights thrown on. If the lights burning are few, the ampères will be few and the demand for power on the engine correspondingly small. With more lights more ampères are required, hence more power from the engine, and the cut-off will be lengthened by the governor.

The ideal simple dynamo consists of a single coil of wire rotating between the poles of a magnet, as in the figure. Starting with the coil in the vertical position, and turning it right-handed, as shown by the arrow, we find, by applying the Fleming rule described above, that the current will flow in the coil in the direction shown by the arrow-heads until it has gone halfway around. During the next half revolution the rule will show that the induced currents flow in the opposite direction. There is then a reversal of current twice each revolution. If we measure the strength of the current at different parts of the revolution, and graphically show the variation by a curve, in which horizontal distances from the starting-point represent the angle turned through and vertical distances represent current-strength at that angular position, we shall get a curve such as is shown in the



figure, which represents three complete revolutions. The current *starts at zero, and increases* till one-quarter turn [illegible] passed through, and then diminishes, till at the half-turn it is zero again. From there the *direction* of the current reverses, as shown by the curve, going below the horizontal line, and it increases to the three-quarter point, and then diminishes to zero again. Such a current is called an alternating current, and such a dynamo is an ideally simple alternating current dynamo. The above curve represents also the variation of electrical pressure of such a dynamo. If it were desired to make a dynamo to give a higher pressure, we could do it in one of three ways: by increasing the speed of rotation, by increasing the number of turns in the coil, or by increasing the strength of the magnet. While such a fluctuating or alternating current could be used for lighting and for small-power work we have no satisfactory large motors capable of being run by it, nor can storage batteries be charged with it. It is therefore necessary to introduce some device which will rectify the current—that is, make it flow always in the same direction in the circuit outside of the dynamo, although it alternates in the coil. Such an arrangement is called the commutator.

The commutator is a purely mechanical device, and consists, as shown in the figure, of a split ring, to one side of which one end of the coil is permanently fastened, and to the other side the other end of the coil. The ends of the external circuit are connected to brushes which rest on these, one brush touching one commutator segment and the second brush the other segment. Just as the coil gets into the vertical position where current reverses, each brush changes from the segment with which it was in contact to the her, so that the effect of the reversal of current is neutralized so



far as the external circuit is concerned, the curve of such currents now being as shown in the sketch. In practice the commutator segments are insulated from each other and from the shaft by sheet mica.

The armature, as the moving part is called, is in actual machines made up by winding the conductor on an iron core. The object of the *iron* core is to keep as many as possible of the magnetic lines produced by the magnet in the space where the conductor is moving. Without the core a large part of them would stray out of this space and would not be cut by the coil, and the electro-motive force produced would be very much smaller than when an iron core is used. This core is made in two forms, which give rise to two different classes of armatures, each possessing certain advantages, called the *Gramme ring* and the *drum-wound* armatures.

Ring Armatures.—The figure illustrates a ring armature with four coils instead of one, as in the ideal dynamo, and also shows what changes are necessary in the commutator. It will be seen that there are as many parts or *segments*, as they are called, in the commutator as there are coils or *sections* in the armature. The curve of the currents shows the advantage of the greater number of sections in the armature, the fluctuations in the strength of current being very much less than with one coil. In practice from 60 to 120 segments are in general use.

Drum-wound armatures have an iron core of cylindrical shape, the winding for a four-coil armature being clear from an inspection of the figure. Although it possesses some important advan-

The field of a dynamo is the magnet whose office is to furnish magnetic lines of force for the armature coils to cut. The first magnets used were permanent magnets; but it was soon found that magnets made by carrying current through wire coiled around an iron core were for a given size and weight much stronger, so that now about the only case in which permanent magnets are used is the small magneto-generators used in connection with telephone instruments. According to the number of poles in the field dynamos are classed as bipolar or multipolar.

A bipolar machine is one having but two poles in its field magnet, the arrangement being similar to that of the ideal simple dynamo.

A multipolar machine is one having more than two poles. It will always have an even number, such as four, six, eight, etc., depending on the size of the machine, half of the poles being north and the other half south poles. The cut shows a typical four-pole machine, and the arrow-heads give the direction of the lines of force, which, it will be noticed, are closed loops, returning to their starting-point.

The advantages of a multipolar generator over the bipolar are that for a given size and speed of rotation a higher output can be obtained, so that all modern generators of any size are made multipolar.

The winding of the multipolar machine armature is shown in the cut, which represents a four-pole machine with ring armature. The two positive brushes may be connected to each other and the two negative brushes to each other by wires, so that it is not absolutely necessary to have as many brushes as there are poles; but this has not been found desirable in practice, and nearly all machines have the same number of brushes as poles.

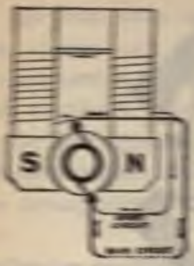
The classification of dynamos is further made according to *the winding* around the field and the manner in which it is con-by two strong heads with bolts running from one head through holes in the disks to the other head, the bolts being insulated from the disks. The disks are connected to the shafts through spiders keyed to shaft as shown. This construction leaves the inside of the armature hollow, so that air can enter and pass out

for the purpose of dissipating the large amount of heat produced in the armature coils and core.

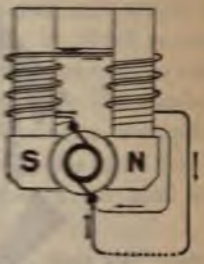
The armature conductors are of copper wire insulated with two layers of cotton, and are further insulated from the core by fibre or other insulating materials, of which mica is the best. In the large-size machines copper bars of rectangular section are used, connected at the ends by specially shaped pieces of copper. The size of the conductors is made such that, with the ventilation obtained by the air circulating through them, they do not reach a temperature more than 80° to 85° F. above that of the surrounding air after a run of six or eight hours at full load.

By looking at the typical four-coiled armature it will be seen that there are two paths for the current from one brush through the armature coils to the other brush, and as these are of equal resistance, one-half of the total current flows through each branch. If, therefore, as sometimes happens, one coil is broken, there is still a circuit closed from one brush to the other, and we cannot with a *magnetic testing-bell* find out that there is a break. In such a *case the output of the* machine would be very much less, and *here would be* serious sparking at the commutator.

lation as does the indicator-card to the engine. It is obtained taking measurement at constant speed of the voltages of the m chine and the corresponding ampères, at different loads, from

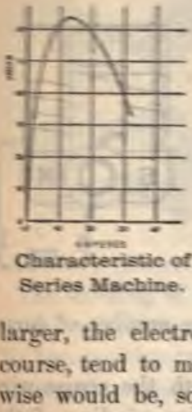


Shunt Dynamo.



Compound Machine.

load to full load, and plotting these values as follows: Distan measured vertically from a horizontal axis represent volts horizontal distances represent ampères. T curve drawn through the plotted poi shows the behavior of the machine.

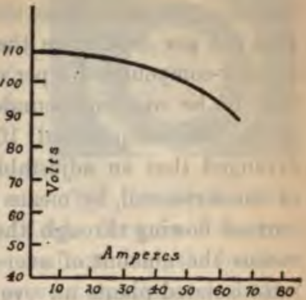


Characteristic of Series Machine.

Series Characteristic.—That part of curve to the right of the maximum poin the range over which series machines usually employed. It shows that as the c rent increases the electro-motive force fa That is, on a circuit supplied by such a chine, if we should diminish the resistan which would tend to make the curr larger, the electro-motive force will drop. This drop will, course, tend to make the increase of current less than it ot wise would be, so that such a machine automatically tends maintain the current in its circuit at a constant strength. series-machine is, therefore, used in constant current distributi as for arc lamps on long-distance circuits.

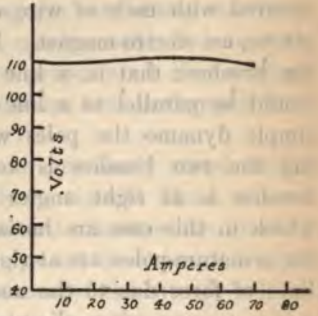
***Shunt* Characteristic.**—With the ammeter in the main or al *circuit* the curve is a gradually drooping one.

ressure is, however, fairly constant for all strengths of current, nd the shunt machine would be sed where a constant pressure ystem distribution is employed, s for incandescent lamps and notors.



Characteristic of Shunt Dynamo.

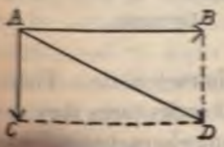
Compound Characteristic.— By carrying the main current around the fields as well as the shunt coils we get the joint effect of two windings. The effect of the shunt coils alone is to give a nearly constant pressure, as shown in the characteristic above, but it droops somewhat. The effect of current around the series coils is to add lines of force, and the greater the current strength the greater number of lines is added, and consequently the higher the pressure furnished by the machine. The series coils will, then, acting by themselves produce a rising characteristic, as in the left-hand part of the curve of the series characteristic. (The right-hand part is taken when the current has become so large as to saturate the magnet cores, so that adding current no longer adds lines of force), while the shunt coil gives a falling characteristic. Therefore by properly proportioning the number of series turns they can be made to neutralize the drop of the shunt characteristic, and the machine then gives a practically constant pressure at all loads.)



Characteristic of Compound Dynamo.

An over-compounded machine is one in which the series coil is given more turns than will just balance the drop of the simple shunt machine. The characteristic will therefore rise, the volts increasing as we increase the ampères. When the voltage at full load is 5 per cent. more than at no load the machine is said to be over-compounded 5 per cent. If the rise is 10 per cent., it is said to be over-compounded 10 per cent. Most machines are made over-compounded 10 per cent. to 12 per cent.; but so arranged that an adjustable shunt is placed across the terminals of the series coil, by means of which the proportion of the main current flowing through the series coil can be varied. By this means the amount of over-compounding is easily adjusted. For most isolated plants an over-compounding of 3 per cent. to 5 per cent. is used, 2 per cent. of which is useful in counteracting the drop of speed in the engine at full load and the remainder to make up for drop of pressure in the wiring.

Armature Reaction.—The armature, consisting of an iron core covered with coils of wire carrying an electric current, is, of course, an electro-magnet. The poles are at the points opposite the brushes; that is, a line drawn from one pole to the other would be parallel to a line joining the brushes. In the ideal simple dynamo the poles would be vertical, as the line joining the two brushes is vertical. But the line joining the brushes is at right angles to the lines of force of the field, which in this case are horizontal. Therefore it is evident that the armature-poles are at right angles to the field-poles, and the lines of force due to the magnetism are at right angles to the lines of force due to the field alone. The resultant direction of the magnetic field will lie somewhere between the directions of the two fields due to magnet and armature, and may be found by applying the parallelogram of forces as in Chapter I. Let *A B* represent in direction and intensity

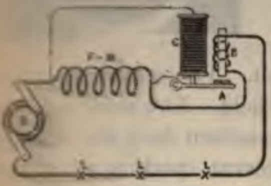


mber of lines of force due to the field magnets, and *A C* nt likewise the lines due to the armature. Then *A D* will

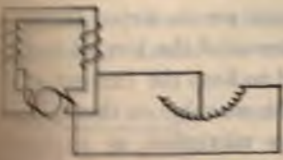
sent the direction of the resultant field. The cut shows this rtion of the field in an actual arm-, the experiment being made with filings. When no current flows igh the armature coils the lines of are horizontal, but when current through it the resultant field is ed forward in the direction of rota-of the armature, as shown in the cut. The greater the arm- current the greater the shifting of field. Now since the line ie brushes is at right angles to the resultant field, the brushes be shifted forward, in order to prevent sparking when the on the machine increases. The amount by which they are ed is called the *lead.*

he lead in small machines of older types is considerable, unting to 10 to 20 degrees. To diminish it we must make magnetic field due to the field magnets very strong relatively iat of the armature. In modern machines this is done, with result that after the brushes are properly set they need no ement to prevent sparking even when load is changed from to full load.

gulation of Series Dynamos.—As previously stated, series iines are used almost exclusively on circuits whose current gth it is desired to maintain constant whatever the number mps thrown on. Since the lamps are in series, the more s turned on the higher the resistance of the circuit and the er the electro-motive force needed to keep the current at the ed value. Although by using the machine on that part of haracteristic to the right of the maximum, as explained r *series characteristic,* the machine tends to regulate the press-utomatically, yet it is necessary to use special devices to nplish satisfactory regulation. There are several ways in the electro-motive force furnished by a machine may be d. One is to shift the rocker arm carrying the brushes; but *auses severe sparking,* and if used in some arc machines requires a special construction of the commutator. Another way is to have an adjustable resistance in multiple with the field coils and arrange this resistance so that when lamps are thrown off the resistance of this shunt path is lessened, thus taking away current from the field coils and cutting down the electro-motive force of the machine. The figure shows the principle of the Brush regulator. *D* is the dynamo armature, *F-M* the field coils, and *L, L, L,* the lamps. *C* is a resistance made of carbon plates connected in multiple with the field coils, as shown. If lamps are thrown off, thus diminishing the resistance of the circuit, the coil *C* raises its armature *A*, putting a pressure on the carbon disks. This diminishes the resistance of the shunt circuit through *C*, and takes away more of the current from the field coils, thus diminishing the number of magnetic lines of force produced, and hence also the electro-motive force of the machine. If lights are thrown on, the reverse action takes place.



The regulation of shunt or compound machines is done by varying the current around the field coils; but as such machines give very nearly perfect regulation automatically so long as speed is maintained constant, only a hand-regulator, called a rheostat, is provided. This rheostat consists of a number of coils of iron wire embedded in an insulating enamel or mounted on porcelain, the whole contained in an iron framework or box. An arm sweeps over the terminal points connected to the [illegible] of these coils, as shown in the sketch. Moving the handle [illegible] would cut down the electro-motive force of the [illegible] to the right would raise it. This regulation is [illegible] except when the speed changes or when a machine [illegible] rted up.



oubles and Care of Dynamos.—In a book by Messrs. ter and Wheeler this subject will be found very fully treated. Thompson's *Dynamo-Electric Machinery,* which is of the very est value in studying dynamos in detail, also has much of as well. When a dynamo is in good order the only things ring attention more than in any piece of machinery are the utator and brushes. The commutator should be cleaned r three times daily by holding on it while it is turning a cototh. Afterward put a *very* little vaseline on the cloth. Ocally hold fine sand-paper against the commutator to smooth rface. *Never* use emery or oil on it. If it gets untrue—s, out of a perfect cylindrical shape after some months' use ough bad sparking—it must be turned down smooth by the f a lathe-tool rest and tool.

e brushes, which are now generally made of carbon or fibreite, must be carefully fitted to touch closely the commusurface and the rocker-arm carrying them adjusted till there sparking at any load. Sometimes considerable labor must ent in securing freedom from sparking. After once adjusted rly they will run for weeks without any further adjustment. should be carefully watched, however, and if they show any of sparking they should be adjusted again till this disap-

end to the commutator and brushes, keep everything clean ry, and allow no oil except in the bearings, and a dynamo n general give no more trouble than any piece of moving inery.

CHAPTER XXXII.

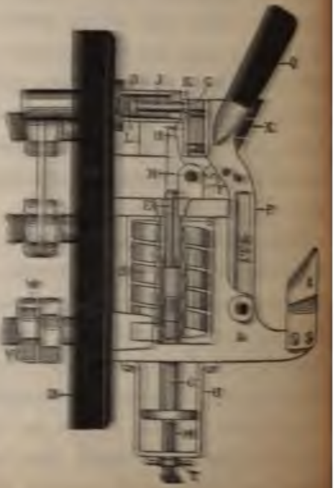
DISTRIBUTION OF ELECTRICAL ENERGY.

e production and distribution of electrical energy are very like a small water-system, where water is pumped from a o *a high reservoir*, taken from the reservoir through pipes [illegible] D, so that whatever current the machine furnishes is measured by the ammeter *A*. Both leads pass through fuses *FF*, whose purpose is to protect the machine from being injured by an accidental overload. They are made of an alloy of lead and tin, and of such size that they will melt when carrying a current slightly larger (about 25 per cent.) than that for which the machine was designed. When they have melted, of course the machine is cut off from connection with the switch-board and circuits. These fuses do not, of course, protect the machine from troubles within itself, but only from being overheated by too low a resistance of the circuit due to any cause whatever. Owing to the uncertain action of large fuses, those designed to blow, say, at 500 ampères and melting at perhaps 400° or 600°, they are generally giving way to magnetic circuit-breaking devices, called circuit-breakers, which will be described further on. *R* is the rheostat for varying the voltage of the machine, and *V* is the voltmeter which measures, when connected as shown, the voltage or difference of pressure between the bus bars. The two switches at the right are to make and break connection between the lighting circuits and the bus bars.

The two lamps connected in series between the bus bars are for showing if any part of the circuit becomes connected to earth or to any conductor connected with earth, such as gas-, water-, and steam-pipes, the steel frame of the building, etc. It is called the ground-detector.

The ground detector consists of two 110-volt lamps connected in series with each other and across or between the bus bars. The junction between the two lamps is connected to earth—*i. e.*, to a convenient water-pipe. So long as the insulation of the circuit is all right the two lights burn alike equally dim, since they are designed for 110 volts at their terminals and they have only 55 volts under the circum- But suppose any point on the circuit, as P, is purposely or accidentally connected to earth. Then the left-hand light will burn bright while the right-hand one will burn exceedingly dim, or perhaps not at all. The reason is that the grounding of the point *P* has put it in electrical connection with the point of junction of the two lamps, through a very low resistance. The current through the right-hand lamp is, therefore, diminished, its terminals being short-circuited. The left-hand lamp will have practically 110 volts between its terminals, since the joint resistance of the right-hand lamp and the other path from *A* to *P* is exceedingly small, and hence the pressure used up being also exceedingly small. If the point *P* were on the other side of the circuit, the right-hand lamp would burn brightly and the left-hand one very dimly. To find the location of the ground-switches they are opened one by one till that one is found which, on being opened, relieves the ground. This circuit is then examined in detail with a magneto bell. The brightness with which one of the lights burns gives an approximate idea of how bad the ground is; but only very roughly. When real accuracy is desired a ground-detector is used consisting of a voltmeter whose zero-point is in the middle. It is connected so that one of its terminals is put to earth; the other by pressing one key is connected to the positive bus bar. The deflection of the neddle then gives the leakage current flowing through the insulation of the negative side of the circuit. Releasing this key and pressing another key connects the voltmeter terminal to the other bus bar and gives the leakage current on the other side of the circuit.

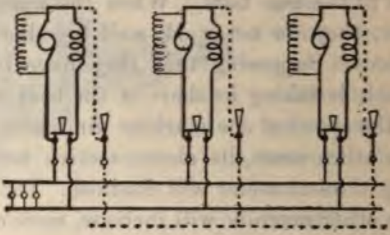
Circuit-breakers are switches so arranged that they are opened automatically when the current flowing through is too great for the circuit which they are designed to protect. When their handle on being opened breaks the positive and negative sides of the circuit it is called a double-pole circuit-breaker; when only one side is interrupted it is called a single-pole circuit-breaker. The movement of the handle is due to the action of a spring tending to push the handle outward, thus breaking the circuit. When every- ing is all right on the circuit, the handle being pushed in so as to close the circuit, it is held in, in spite of the spring, by a little trigger. If the current gets too great, a coil of wire in the shape of a helix, through which the current passes, draws up a movable iron plunger, which lifts the trigger and sets the handle free to be opened by the spring. The two cuts show the action of a common circuit-breaker of the single-pole type. In the first cut, which shows the handle open, the current comes in at the back of the instrument at *P*, and passes around the coil to the terminal *A*. Then if the handle is closed the current flows across to *B* and out to the circuit. The second figure shows the instrument in greater detail. *H* is the trigger which holds the handle closed, and *O* is the spring which will open it if the trigger is unlocked. *C* is the iron plunger which is raised up to hit the trigger whenever the current through the coil *B* is too great. By turning the screw *M* in so as to raise *C*, the breaker will open at a smaller current. By turning *M* out, it will take a larger current to set [illegible]



[illegible]tors in Multiple.—[illegible]tremely convenient [illegible] plant has two or [illegible]erators to be able

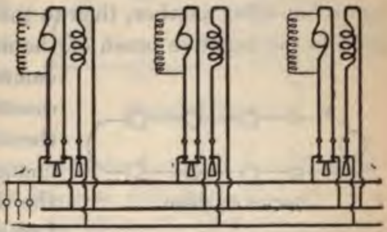
them in multiple on the same set of bus bars, for by this
gement when the load is light one machine will take care of it,
s it increases additional machines can be started up and con-
d in to the bus bars to take care of the increasing demand.
shunt machines may be run in multiple without any trouble,
ng only necessary to get the second machine at the same volt-
s the first by means of the rheostat in the field circuit, and
the machine switch can be thrown *in*, thus connecting the
d machine to the bus bars. When the machines are com-
d, however, they do not work well together without some
tional devices. Supposing that they have been thrown in
iple and each is taking its share of the load as shown by the
eters. If the speed of one machine diminishes owing to belt-
age or any other cause, its electro-motive force will be less
the reading of its ammeter will diminish. The reading of the
eter of the other machine will increase, more current flowing
gh it. Therefore its series coils will produce more lines of
, thus raising its electro-motive force and making it take still
of the load. This will continue till the higher pressure
ine is taking all the load and the current through the other
ine drops to zero and reverses in direction, after which it
e driven as a motor by the other machine. Some device
be used so that if one machine increases in speed relatively
e other one, the increased current flowing will be sent
d the series field-coils of the lower speed machine. The
npanying figure shows the arrangement, called the *equalizing*
ction, commonly used. The equalizer connection, as here
n by the dotted lines, was first suggested by Gramme for
machines and by Mordey for compound. If made suf-
tly heavy, it will not only effectually prevent the reversal of
ity of any of the machines so connected, but will, in a great
ure, equalize the work done by the generators under varying
tions of speed. Any number of dynamos may be connected
this manner, and, even if they are of different capacities,
machine will give current in proportion to its rated output,

provided the combined resistances of the leads to the bus bars, the armatures, and the series fields, are inversely proportional to the ampère capacities of the machines. Without the equalizer connections, or if these are not sufficiently heavy, a change of speed or of load is liable to produce a reversal of polarity in the deficient machine, in which case it will run as a motor, supplying none of its share of the current; but, on the contrary, making an additional load for the other machines and perhaps causing a costly interruption in the operation of the plant.



The method of proceeding when one machine is supplying current and it is desired to connect another up with it is as follows, it being understood, of course, that the switches belonging to machine No. 2 are open: First, start up the engine of No. 2 and turn its rheostat till its pressure is the same as that of the bus bars or perhaps one-half volt higher. Then close the single-pole switch in the equalizer circuit, shown dotted, and finally close the machine's double-pole switch which connects it to the bus bars. Its ammeter reading will then increase, and the rheostat handles of the two machines are moved till the ammeters read alike (if the machines are the same size) and the voltage of the bus bars is correct. After that the machines will need little attention, as if one drops in speed a little current will be sent around its series coil from the other machine through the equalizer circuit, thus *keeping* up its voltage. Instead of a two-pole switch in the dynamo ds *and* a single-pole switch in the equalizer lead, a three-pole switch is frequently employed. In this case the middle blade is used for the equalizer wire, and is so adjusted that it closes the equalizer circuit just before the other two blades close their circuits.

This method is generally satisfactory, although it does not equalize the load so perfectly as the following method, devised by Mr. Edwin R. Keller. This method differs from the previous one in that it will be seen that this is accomplished by connecting the beginnings of all of the series coils to an extra bus bar, to which is connected also one brush of each machine, instead of connecting the series windings direct to the brushes and the junctions of these to the equalizing bus bar, as in Gramme's method.



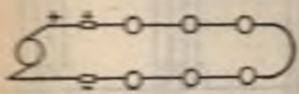
By arranging the connections in this manner it is evident that the currents in the series coils of the machines will, at all times, be proportional to the capacities of the machines, provided the resistances are proportioned in such a way that the drop of potential from the brushes of all the machines to the bus bars will be the same at full load.

The diagram shows how this method would be arranged at the switch-board. The mode of operation would be as follows: Whenever it is desired to throw in an additional machine the single-pole switch is first closed. This completes the series field circuit, and we immediately have a current in the series coils of the new machine, which will be proportional to its capacity. The rheostat in the shunt circuit is then adjusted until the new machine generates the desired electro-motive force. After this is done the main switch may be closed without producing any further disturbance in the electro-motive force of the system.

It has these disadvantages, however: it necessitates an additional conductor from the dynamo to the switch-board, and, moreover, the full current passes through the conductors, which here replace the equalizer. Hence, the first cost is somewhat increased, and, further, a certain amount of energy is lost in heating the conductors.

Systems of Distribution.—There are two common arrangements of circuits, called respectively the *series* system and the *multiple* or *parallel* system.

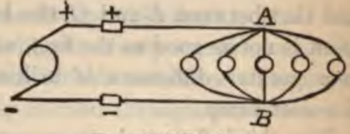
Series System.—In this system, which is the simpler, the conductor starts from the positive brush of the generator, goes to the positive bus bar of the switch-board, then out through all the lamps one after another, then to the negative bus bar, and finally back to the negative brush of the machine. Such a circuit to be commercially satisfactory must be a *constant current* circuit. That is, throwing on or off lamps must not change the value of the current, for the lamps burn at their proper brilliancy only when a certain current flows through them. When lamps are thrown on, the resistance of the circuits is increased, and to maintain the same current the electric pressure must be correspondingly raised. This is accomplished by a special regulator on the dynamo, as previously explained. The pressure between the terminals of the dynamo is therefore proportional to the number of lamps burning. As the ordinary 2000 candle-power street arc requires a pressure of about 50 volts between its terminals to force the proper current (9.6 ampères) through it, a circuit of 100 lights would have a pressure at the machine terminals of about 5000 volts, an extremely dangerous pressure. The lowest voltage incandescent lamps in commercial use require about 50 volts also, so that it is evident that a series distribution is necessarily a high-pressure distribution, and therefore dangerous. It has the further disadvantage t an interruption of the circuit at any one point is an inter- tion of the whole circuit, and will put out all the lamps.



Series System.

For these two reasons it is used only in outdoor distribution, where the wire, being on poles, is out of the reach of any one, and where any breaks in the circuit are quickly found and repaired. Its chief advantage is that, being a high-pressure system, it transmits energy with a small loss over comparatively small conductors.

The Parallel System.—In this system the current from the dynamo is divided and flows through the lamps, and afterward the separate currents are joined together and flow to the dynamos. If the resistances of the lamps are the same and that of the wires connecting them to *A B* also the same, the currents through all the lamps will be alike. By Ohm's law the current through any lamp is equal to the pressure or voltage between *A* and *B* divided by the resistance of the lamp. Now suppose one lamp is turned off; will the brightness of the others be affected? Not if the voltage between *A* and *B* is kept constant, for the resistance of each lamp is a constant, having no relation whatever to the fact that other lamps are turned on or off. Therefore the current through each of the remaining lamps is just the same as it was before the one lamp was turned off. And as the brilliancy depends strictly upon the current, it is likewise unchanged.

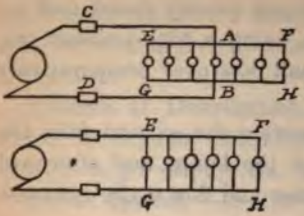


Parallel System.

The parallel system is therefore a constant potential or *constant-pressure* system, and also when distributing direct to lamps a low-pressure system. In practice the pressure between *A* and *B* is not kept quite constant; but so long as the variation is not more than 2 or 3 per cent. it is not noticed by the eye.

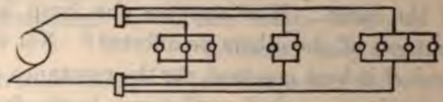
The arrangement can, therefore, be somewhat modified so as to save wire, as in these two figures. The wires *E A* and *D B* are called *feeders*, the wires *E F* and *G H* are called *mains*, and the wires leading from the mains to the lamps are called *branches*.

In the first figure the middle lamp will burn a little brighter than the others, the two end ones being the dimmest, owing to the loss of pressure in the mains between *A* and *E* and *B* and *G* on one side and *A* and *F* and *B* and *H* on the other side. This loss can be reduced to a point as low as desired by increasing the size of the mains.

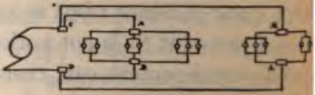


In the second figure the lamp between *F* and *H* is the dimmest and that between *E* and *G* the brightest. This second arrangement is not as good as the first, as for a given size of wire there is a greater difference of brilliancy between the brightest and dimmest lamp.

The third figure shows a somewhat less simple distribution, where more than one feeder-circuit leaves the switch-board. In such systems the three feeders will probably be of different siz wires, according to their length and the number of lights the carry. They will be calculated so that the pressure lost on eac is the same.

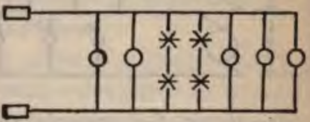


The fourth figure shows an arrangement very common in modern buildings where it is desired that all safety devices, such a fuses and circuit-breakers, shall be placed in closets. *A* and *B* here represent small bus bars on a small switch-board, or panel-board, as it is generally called, from which run the circuits for a single floor or perhaps a singl ' *rge room.* *K* and *L* represent bus bars on another panel-board *nother* floor. Separate feeders run to each, and on each a

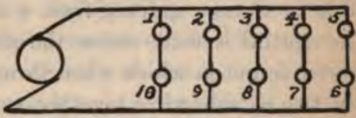


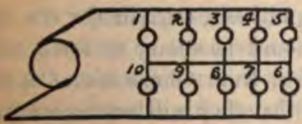
placed the fuses for each separate circuit running from the bus bars. There would thus be on the panel-board *A B* six fuses, two for each of the three circuits leading from the bus bars.

Modified Systems of Distribution.—It is very common in parallel systems to put two lamps in series with each other, and then connect them to the mains, especially when arc lamps are used. The reason is that arc lamps of the *open arc* type require only about 50 volts at their terminals, while most incandescent distribution is at 110 volts. We should, therefore, be obliged, if only one arc were to be used, to put in series with it a considerable resistance, so as to use up the surplus 60 volts in forcing current through the resistance.

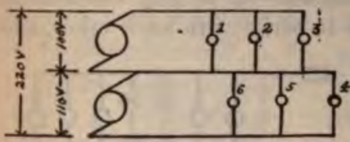


Three-wire System.—An extremely important modification is the Edison three-wire system, which is a device for obtaining the advantages of distributing at 220 volts instead of 110, which, as we shall see, introduces a great saving in wire, without its accompanying disadvantages of greater pressure at the lamps. If we put two 110 volt lamps in series with each other and then connect them across the mains running from a 220 volt dynamo, we shall have a 220 volt distribution system, using 110 volt lamps, which will work perfectly satisfactorily until the filament of some lamp breaks or till some one turns it off. Then the mate to that lamp, the one which was in series with it, will be extinguished. To overcome this a wire may be added as shown; but now if lamp 6, say, be turned off, the current for lamps 1, 2, 3, 4, and 5 must now pass through four lamps, so that 7, 8, 9, and 10 will *burn with excessive brightness* and will be quickly spoiled.





avoid this objection the following arrangement of Edison is used: Two 110-volt machines are connected in series and the middle or neutral wire is connected to their junction. When the same number of lamps are burning on each side of the neutral wire there is no current flowing through the neutral and the same current flows through each machine. When No. 4 is turned out, for example, the lower machine supplies only the current necessary for lamps 5 and 6, while the upper continues to supply the same as before, the current for one lamp returning to the upper machine over the neutral. If all lamps on one side were turned out, the machine on that side would furnish no current, and the other machine would continue to work as before. It is not necessary to make the neutral so large as the outside wires, although this is usually done. Where it is desired to be able to change quickly from a three-wire to a two-wire system, the neutral is made twice the size of either outside wire and a switch is put in which when thrown to a certain position connects the two outside wires together, so that they act as one side of the circuit under the new arrangement, while the neutral acts as the other side.



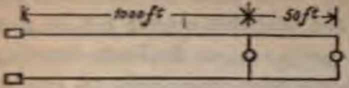
Size of Conductors.—We know from Experiment No. 1 that when an electric current traverses a wire it heats it more or less, depending on the strength of current and the material and the size of the wire. This heating represents, of course, some loss or waste of the electrical energy of the current, and the amount of this loss in *watts* is equal to the square of the current multiplied by the resistance of the conductor, or, in brief, C^2R, or $C\times C\times R$. The loss of pressure—that is, the amount necessary to force the current C against the resistance R—is, from Ohm's law, $C\times R$. Conductors must be large enough so that they will not be heated beyond a safe amount (underwriters allow a rise in temperature of about 18° above the surrounding air, it being considered that a greater degree of heating would injure the insulating covering of the wire), and also that the loss in pressure is no greater than the nature of the service will permit. The sizes are calculated, first, to meet the pressure-requirement, and then by looking in the table of safe carrying capacities we find whether the size calculated is large enough to meet the underwriters' requirements. It generally will be, except for short distances.

The allowable loss of pressure on wires is a matter which requires careful thought and considerable calculation to secure the best results. This is especially the case when the circuits supply incandescent lamps, the requirements for which are much more severe than for motors or arc lamps. Some general principles will be laid down, which if followed will lead to satisfactory results. The pressure at any lamp should not vary more than 2 to 4 per cent. under any variations in the number of lamps burning; 2 per cent. would represent a good result, and 4 per cent. only a fairly satisfactory one.

If there is but one feeder from the bus bars, we can obtain the result of 2 per cent. more easily in two ways. The first one and the simpler one is to use such size of wires that the loss of pressure, or *drop*, as it is called, between bus bars and lamps is only 2 per cent. of the voltage of the machine, which we will suppose to be 110 volts. Of the 2.2 volts allowable, we would use 1 volt on the feeder, ½ volt on the main, and ½ volt on the branches in many cases; but if the mains or branches were very short it would be better to use up only ¼ volt on each and 1½ volts on the feeder. We would then need to keep the machine at constant speed, giving constant pressure at the branches, and the desired result would be obtained.

An equally good result can be obtained much more cheaply by allowing on the feeder a drop of, say, 4 per cent., or 4.4 volts, and 1 volt on the mains and 1 volt on the branches; and instead of keeping the voltage of the machine constant, raise it in pro-
rtion to the reading of the ammeter. When only a small cur-
flows over the feeder, of course the loss of pressure is n

farther lamp being 3 per cent. of the initial voltage, and there being a further requirement that no two lights on the same circuit shall differ in pressure by more than 1 volt. The initial pressure between the bus bars is 110 volts.



To meet the second requirement the allowable loss between the first and the second lamp is 1 volt in a length of circuit of 100 feet and a current of 1 ampère. By Ohm's law $R = \frac{E}{C} = \frac{1}{1} = 1$ ohm. That is, the wire must be of such a size that 100 feet will have a resistance of 1 ohm; 1000 feet of this wire will have a resistance of 10 ohms. Looking in the wire tables we find that the nearest size is a No. 20 B. & S. gauge. This wire is so small that it is mechanically unsafe to use, underwriters not allowing, on this account, the use of a wire less than No. 14, 100 feet of which wire has a resistance of .25 ohm nearly. The drop or loss of pressure in forcing 1 ampère through this resistance would be $.25 \times 1 = .25$ volt. According to the first requirement, the total allowable drop being 3 per cent. of 110, or 3.3 volts, this would leave as the allowable drop from the bus bars to the *first* lamp 3.3 less .25 volt, or 3.05 volts—call it 3 volts in round numbers. The length of circuit is 2000 feet and the current 2 ampères. The resistance must be $\frac{3}{2} = 1.5$. If 2000 feet is to have a resistance of 1.5 ohms, 1000 feet will have a resistance $= \frac{1.5 \times 1000}{2000} = .75$ ohm. The nearest size wire to this is No. 9, but as this is a little too small, and is moreover an odd size, we would use the next larger size, No. 8. Two thousand feet of No. 8 have a resistance of 1.25 ohms, and the drop would be $2 \times 1.25 = 2.5$ volts to the first lamp and .25 volt from the first to the second, making the total drop from the bus bars to the last lamp 2.75 volts.

Advantages of Using High Pressure.—A given amount of *energy can be transmitted with less loss in heating the line wires if the pressure is increased.* An example will make this clear.

Suppose it is desired to transmit 1100 watts power from one point to another 1000 feet distant. We may transmit it at any one of various pressures, for example, 110, 220, 550, and 1100 volts. At 110 volts the current would be $\frac{1100}{110} = 10$ ampères. Suppose the wire used is a No. 7, having a resistance of closely .5 ohm per 1000 feet. The total resistance of the line would be twice this, or 1 ohm, since the total distance is 2000 feet. The loss in pressure is $E = CR = 10 \times 1$, or 10 volts. The total energy lost is $C \times C \times R = 10 \times 10 \times 1$, or 100 watts. Making similar calculations for transmission at the other voltages we can construct the following table:

Power transmitted in watts. $C \times E$	Volts at which transmitted. E	Corresponding number of ampères. C	Power lost in watts. C^2R	Volts drop in line. CR	Per cent. power lost. $C^2R \div 1100$	Per cent. volts lost. $CR \div E$
1100	110	10	100	10	11.	9.9
1100	220	5	25	5	2.75	2.27
1100	550	2	4	2	.0227	.363
1100	1100	1	1	1	.0009	.091

At 100 volts the lost energy is 1 watt, while at 110 volts it is 100 watts. That is, by using a pressure 10 times as great the loss is only one-hundredth of what it would be at the lower pressure. We could therefore use a wire whose cross-section was but one-hundredth of what would be needed if we transmit at the lower pressure. The example shows clearly why it is that in long-distance transmissions, where the cost of the line is a large item, the pressures used are so high, reaching to 10,000 and even 20,000 volts.

Materials Used for Electrical Conductors.—Copper is used almost exclusively on account of its low resistance and fairly low price. It is soft-drawn for inside work, but hard-drawn for outside conductors on account of the increased tensile strength given by the hard-drawing process. Iron, which was formerly used largely on telegraph circuits, is used to a limited extent on short lines on account of its cheapness. It is never used for electric lighting or power circuits. Aluminum has many properties which make it useful, and if the cost of production should fall muc below its present figure, about 30 cents per pound, it will be an important rival of copper.

Insulation of Wires.—Telephone and telegraph wires strung outdoors on porcelain or glass insulators are not covered with any insulating material, and electric light and power wires in uninhabited or sparsely settled districts may be left bare likewise; but in towns and cities they are always coated with an insulating material. All wires for inside work are also covered. For outside work the wires have two braids (the best quality three braids) of cotton woven tightly around them and soaked in a fairly waterproof bituminous substance which serves to prevent the cotton braidings becoming wet. Such wires go under the name of double- or triple-braided weather-proof. A modified form of this wire, known as fire- and weather-proof, has been largely used for inside work. The inner cotton braidings are impregnated with white lead, which is a good insulator when dry and which makes the inner cotton braid very difficult to burn. The thin outer braiding, soaked in weather-proof compound, serves to keep the inner coatings dry. Both these wires are giving place to wires covered with rubber compounds, which, although much more expensive, are much better insulators. An outside braid is put around the rubber coats to protect them from abrasion. The quality of the rubber insulation on wires depends largely upon the percentage of pure rubber in its composition, which varies from 30 per cent. upward. The inner coat is made of either vulcanized white or red rubber in the best wires, as black rubber contains sulphur, which attacks the copper.

Cables.—Where the conductors are to be laid in water or in very damp places, as in underground work, or even the ducts leading from dynamos to switch-board, the insulated wires are encased in lead $\frac{1}{16}$ inch or more in thickness. Such conductors are known as cables. For such work use is made of other insulators besides those d[redacted]d above, such as fibre, jute, and paper, the thickness of eing increased in proportion to the size of wire and sed.

Wire Gauges.—There are several different gauges in use, the ndard in this country being the Brown & Sharpe (B. & S.). e following table gives the principal gauges in use and their nparative dimensions:

WIRE GAUGES IN MILS.

Numbers.	Roebling.	Brown & Sharpe.	Birmingham or Stubs.	New British standard.
000 000	460.	....	....	464.
00 000	430.	....	....	432.
0 000	393.	460.	454.	400.
000	362.	409.6	425.	372.
00	331.	364.8	380.	348.
0	307.	324.9	340.	324.
1	283.	289.3	300.	300.
2	263.	257.6	284.	276.
3	244.	229.4	259.	252.
4	225.	204.3	238.	232.
5	207.	181.9	220.	212.
6	192.	162.	203.	192.
7	177.	144.3	180.	176.
8	162.	128.5	165.	160.
9	148.	114.4	148.	144.
10	135.	101.9	134.	128.
11	120.	90.74	120.	116.
12	105.	80.81	109.	104.
13	92.	71.96	95.	92.
14	80.	64.08	83.	80.
15	72.	57.07	72.	72.
16	63.	50.82	65.	64.
17	54.	45.26	58.	56.
18	47.	40.3	49.	48.
19	41.	35.89	42.	40.
20	35.	31.96	35.	36.
21	32.	28.46	32.	32.
22	28.	25.35	28.	28.
23	25.	22.57	25.	24.
24	23.	20.1	22.	22.
25	20.	17.9	20.	20.
26	18.	15.94	18.	18.
27	17.	14.2	16.	16.4
28	16.	12.64	14.	14.8
29	15.	11.26	13.	13.6
30	14.	10.03	12.	12.4
31	13.	8.93	10.	11.6
32	13.	7.95	9.	10.8
33	11.	7.08	8.	10.
34	10.	6.3	7.	9.2

mil = one-*thousandth of* one inch.

he *area in circular mils* equals the square of the diameter in mils.

PROPERTIES OF COPPER WIRE.

ENGLISH SYSTEM—BROWN & SHARPE GAUGE.

Numbers.	Diameters in mils.	Areas in circular mils. C. M. = d^2.	Weights.		Resistances per 1 000 feet in International ohms.	
			1 000 feet.	Mile.	At 60° F.	At 75° F.
0 000	460.	211 600.	641.	3 382.	.048 11	.049 66
000	410.	168 100.	509.	2 687.	.060 56	.062 51
00	365.	133 225.	403.	2 129.	.076 42	.078 87
0	325.	105 625.	320.	1 688.	.096 39	.099 48
1	289.	83 521.	253.	1 335.	.121 9	.125 8
2	258.	66 564.	202.	1 064.	.152 9	.157 9
3	229.	52 441.	159.	838.	.194 1	.200 4
4	204.	41 616.	126.	665.	.244 6	.252 5
5	182.	33 124.	100.	529.	.307 4	.317 2
6	162.	26 244.	79.	419.	.387 9	.400 4
7	144.	20 736.	63.	331.	.491	.506 7
8	128.	16 384.	50.	262.	.621 4	.641 3
9	114.	12 996.	39.	208.	.783 4	.808 5
10	102.	10 404.	32.	166.	.978 5	1.01
11	91.	8 281.	25.	132.	1.229	1.269
12	81.	6 561.	20.	105.	1.552	1.601
13	72.	5 184.	15.7	83.	1.964	2.027
14	64.	4 096.	12.4	65.	2.485	2.565
15	57.	3 249.	9.8	52.	3.133	3.234
16	51.	2 601.	7.9	42.	3.914	4.04
17	45.	2 025.	6.1	32.	5.028	5.189
18	40.	1 600.	4.8	25.6	6.363	6.567
19	36.	1 296.	3.9	20.7	7.855	8.108
20	32.	1 024.	3.1	16.4	9.942	10.26
21	28.5	812.3	2.5	13.	12.53	12.94
22	25.3	640.1	1.9	10.2	15.9	16.41
23	22.6	510.8	1.5	8.2	19.93	20.57
24	20.1	404.	1.2	6.5	25.2	26.01
25	17.9	320.4	.97	5.1	31.77	32.79
26	15.9	252.8	.77	4.	40.27	41.56
27	14.2	201.6	.61	3.2	50.49	52.11
28	12.6	158.8	.48	2.5	64.13	66.18
29	11.3	127.7	.39	2.	79.73	82.29
30	10.	100.	.3	1.6	101.8	105.1
31	8.9	79.2	.24	1.27	128.5	132.7
32	8.	64.	.19	1.02	159.1	164.2
33	7.1	50.4	.15	.81	202.	208.4
34	6.3	39.7	.12	.63	256.5	264.7
35	5.6	31.4	.095	.5	324.6	335.1
36	5.	25.	.076	.4	407.2	420.3

There are two points in this table which will be found easy to remembe and very convenient in practice—namely, that the resistance of 1000 feet o *No. 10 is* almost exactly 1 ohm at 75° F., and that a change of three sizes eithe *halves or* doubles the resistance, according as we go up or down the table.

STRANDS OF COPPER WIRE.

B. & S. gauge.	Circular mils.	Diameters.		Weights.		Resistance at 75° F. per 1 000 feet.
		Decimal parts of inch.	Nearest 32d.	1 000 feet.	Mile.	
....	1 000 000	1.152	1 3/16	3 050	16 104	.010 51
....	950 000	1.125	1 1/8	2 898	15 299	.011 06
....	900 000	1.092	1 3/32	2 745	14 494	.011 67
....	850 000	1.062	1 1/16	2 593	13 688	.012 36
....	800 000	1.035	1 1/32	2 440	12 883	.013 13
....	750 000	.999	1	2 288	12 078	.014 01
....	700 000	.963	31/32	2 135	11 273	.015 01
....	650 000	.927	15/16	1 983	10 468	.016 17
....	600 000	.891	29/32	1 830	9 662	.017 51
....	550 000	.855	7/8	1 678	8 857	.019 1
....	500 000	.819	13/16	1 525	8 052	.021 01
....	450 000	.770	25/32	1 373	7 247	.023 35
....	400 000	.728	3/4	1 220	6 442	.026 27
....	350 000	.679	11/16	1 068	5 636	.030 02
....	300 000	.630	5/8	915	4 831	.035 02
	250 000	.590	19/32	762	4 026	.042 03
0 000	211 600	.530	17/32	645	3 405	.049 66
000	168 100	.470	15/32	513	2 709	.062 51
00	133 225	.420	7/16	406	2 144	.078 87
0	105 625	.375	3/8	322	1 700	.099 48
1	83 521	.330	11/32	255	1 346	.125 8
2	66 564	.291	5/16	203	1 072	.157 9
3	52 441	.261	9/32	160	845	.200 4
4	41 616	.231	1/4	127	671	.252 5

TENSILE STRENGTH OF COPPER WIRE.

B. & S. gauge.	Breaking weight. Pounds.		B. & S. gauge.	Breaking weight. Pounds.	
	Hard drawn.	Annealed.		Hard drawn.	Annealed.
0 000	3 310	5 650	9	617	349
000	6 580	4 480	10	489	277
00	5 226	3 553	11	388	219
0	4 558	2 818	12	307	174
1	3 746	2 234	13	244	138
2	3 127	1 772	14	193	109
3	2 480	1 405	15	153	87
4	1 967	1 114	16	133	69
5	1 559	883	17	97	55
6	1 237	700	18	77	43
7	980	555	19	61	34
8	778	440	20	48	27

[illegible]

[illegible]

[illegible]

[illegible] Iron Wire

[illegible]	[illegible]	[illegible]		[illegible]		Resistance per mile [illegible]		
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Steel
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33.3	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	110.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	108.5	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

WEATHERPROOF WIRE.

Numbers, B. & S. G.	Double braid.			Triple braid.			Approximate weights. Pounds.	
	Outside diameters in 32ds inch.	Weights. Pounds.		Outside diameters in 32ds inch.	Weights. Pounds.			
		1 000 feet.	Mile.		1 000 feet.	Mile.	Reel.	Coil.
0 000	20	716	3 781	24	775	4 092	2 000	250
000	18	575	3 036	22	630	3 326	2 000	250
00	17	465	2 455	18	490	2 587	500	250
0	16	375	1 980	17	400	2 112	500	250
1	15	285	1 505	16	306	1 616	500	250
2	14	245	1 294	15	268	1 415	500	250
3	13	190	1 003	14	210	1 109	500	250
4	11	152	803	12	164	866	250	125
5	10	120	634	11	145	766	260	130
6	9	98	518	10	112	591	275	140
8	8	66	349	9	78	412	200	100
10	7	45	238	8	55	290	200	100
12	6	30	158	7	35	185	.....	25
14	5	20	106	6	26	137	.....	25
16	4	14	74	5	20	106	.....	25
18	3	10	53	4	16	85	.....	25

STRANDED WEATHERPROOF FEED WIRE.

Circular mils.	Outside diameters. Inches.	Weights. Pounds.		Approximate length on reels. Feet
		1 000 feet.	Mile.	
1 000 000	$1\frac{1}{2}$	3 550	18 744	800
900 000	$1\frac{13}{32}$	3 215	16 975	800
800 000	$1\frac{11}{32}$	2 880	15 206	850
750 000	$1\frac{5}{16}$	2 713	14 325	850
700 000	$1\frac{9}{32}$	2 545	13 438	900
650 000	$1\frac{1}{4}$	2 378	12 556	900
600 000	$1\frac{7}{32}$	2 210	11 668	1 000
550 000	$1\frac{3}{16}$	2 043	10 787	1 200
500 000	$1\frac{1}{8}$	1 875	9 900	1 320
450 000	$1\frac{3}{32}$	1 703	8 992	1 400
400 000	$1\frac{1}{16}$	1 530	8 078	1 450
350 000	1	1 358	7 170	1 500
300 000	$\frac{15}{16}$	1 185	6 257	1 600
250 000	$\frac{29}{32}$	1 012	5 343	1 600

e table is calculated for concentric strands. Rope-laid ds are larger.

re and weatherproof wire has about the same weight and *de diameter as triple* braid weatherproof.

Crescent Rubber Wire.

LARGER CONDUCTORS.

Numbers. B. & S. G.	Circular mils.	Outside diameters. Inches.	Weights per 1 000 feet. Pounds.	Sizes of wires in strand. B. & S. G.	
				Regular.	Flexible.
——	[illegible]	[illegible]	[illegible]	8	22
——	[illegible]	[illegible]	[illegible]	8	22
——	[illegible]	[illegible]	[illegible]	8	22
——	[illegible]	[illegible]	[illegible]	10	22
——	[illegible]	[illegible]	[illegible]	10	22
——	[illegible]	[illegible]	[illegible]	10	24
——	[illegible]	[illegible]	[illegible]	10	24
——	[illegible]	[illegible]	[illegible]	10	24
——	[illegible]	[illegible]	[illegible]	10	24
——	[illegible]	[illegible]	[illegible]	10	24
	[illegible]	[illegible]	[illegible]	10	24
0000	——	[illegible]	[illegible]	10	25
000	——	[illegible]	[illegible]	10	25
00	——	[illegible]	[illegible]	11	25

Crescent Rubber Wire.

SMALLER SIZES.

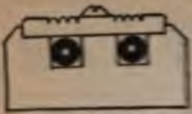
Numbers, B. & S. G.	Outside diameters in 32ds of an inch.		Weights per 1 000 feet. Pounds.	Sizes of wires in strand. B. & S. G.	
	Solid.	Stranded.		Regular.	Flexible.
0	18	20	489	12	16
1	16	18	393	12	16
2	14	15	309	12	18
3	13	14	244	13	18
4	12	13	198	14	20
5	11	12	168	15	20
6	10	11	146	16	20
8	9	10	106	18	22
10	8	8	77	20	25
12	7	7	55	20	25
14	6	6	35	21	25
16	5	5	25	23	25
18	4	4	20	25	25

LEAD-ENCASED CABLES.

bers, S. G.	Circular mils.	Outside diameters. Inches.	Weights, 1 000 feet. Pounds.	Ampères causing 14° F. rise.
..	1 000 000	$1\frac{13}{16}$	6 685	624
..	900 000	$1\frac{23}{32}$	6 228	580
..	800 000	$1\frac{21}{32}$	5 773	514
..	750 000	$1\frac{5}{8}$	5 543	489
..	700 000	$1\frac{19}{32}$	5 315	454
..	650 000	$1\frac{9}{16}$	5 088	439
..	600 000	$1\frac{17}{32}$	4 857	411
..	550 000	$1\frac{1}{2}$	4 630	385
..	500 000	$1\frac{7}{16}$	4 278	362
..	450 000	$1\frac{3}{8}$	3 923	337
..	400 000	$1\frac{11}{32}$	3 619	327
..	350 000	$1\frac{5}{16}$	3 416	298
..	300 000	$1\frac{1}{4}$	3 060	270
..	250 000	$1\frac{3}{16}$	2 732	242
0	211 600	$1\frac{3}{32}$	2 533	221
0	168 100	$1\frac{1}{16}$	2 300	190
0	133 225	1	2 021	157
0	105 625	$\frac{15}{16}$	1 772	135
1	83 521	$\frac{29}{32}$	1 633	115
2	66 564	$\frac{7}{8}$	1 482	100
3	52 441	$\frac{25}{32}$	1 360	86
4	41 616	$\frac{3}{4}$	1 251	73
6	26 244	$\frac{11}{16}$	1 046	51

hods of Carrying Conductors.—These may be divided into asses: *open work,* where the conductors are in plain sight; *oncealed work,* where they are hidden from view. Open is used only in mills, factories, and similar buildings, where rance is a secondary consideration. The wires are fastened celain insulators by means of tie wires. Wherever it is ary to pass through a floor or partition the wires pass h porcelain or glass tubes placed in the partition or floor. work has the advantage of cheapness, and moreover any are quickly detected and repaired. Concealed work may *ther subdivided into* moulding-work, porcelain-work, and

conduit-work. In moulding-work the wires are placed in grooved
strips of wood of section similar to that
shown in the sketch, and are then concealed
by a capping of wood which is screwed on.
As moist wood is not a good insulator, such
work must not be used in damp places, and



underwriters do not permit its use in lofts or in any place which
is not on the surface. Concealed porcelain-work is precisely lik
open work, except that, being out of sight, it is not so neatly don
Conduits made of various materials have come into use withi
the last few years. The fundamental idea of a conduit is to pr
vide a raceway which may be installed during the constructi
of the building and into which wires may be afterward dra
In case of any injury to the wires after they are in place it is
pected that they can be easily withdrawn and replaced by
wires. A suitable conduit should, therefore, be strong enoug
protect wires within it from the accidents that are liable to
to it, such as by hammering, jarring, etc., and it should also
a smooth inside surface, so as not to scratch the insulation d
the drawing-in process. Moreover, it should not be attack
moisture, cements, or plasters. The early conduits, such as
ducts, brass-armored fibre-ducts, and circular-loom condui
not fulfil these requirements, and have almost entirely
way to an iron or steel conduit. At present these consist
iron or steel pipe lined with fibre, wood, or rubber com
partly to secure a smooth inside surface and partly to as
insulating the wire. It is probable, however, that this insu
lining will be done away with either by improving the m
by making the pipe so as to secure a smooth inner surface,
[illegible] enamel. If these pipes are made thick enough,
[illegible] entirely satisfactory. In a conduit system the p
[illegible] sides of a circuit are carried both in one tube, b
[illegible] ments an excessive drop in pressure occur
[illegible] the iron unless this is done. It is, mor
[illegible] upper, be troubles in the

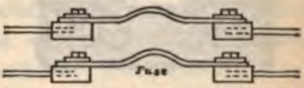
14
16
18

es, such as overheating due to short circuits or leakages, are fined within the pipe and do not give rise to fires in surrounding woodwork. Bends are made by elbows and couplings or by efully bending the pipe. Such a system is practically obligay in modern fireproof-constructed buildings, and is used altoher in spite of its high cost.

ppliances Used on the Line.—A considerable number of dees have come into use on electric circuits for making the disbution of electrical energy as convenient and as safe as possible. nong these are fuses, cut-outs and circuit-breakers, switches, kets or receptacles, insulating joints, dimmers, etc.

The fuse is used to prevent wires being traversed by a current ove the safe carrying capacity. It consists usually of a small ce of an alloy of lead and zinc soldered to two copper termils slotted so as to admit the stud. They are inserted at every int in a circuit where the wire diminishes in size and are placed the circuit of the smaller wire. The figure shows how this is done, e larger wire being led into two blocks having each a threaded

Fuse.



No. 10. No. 8.

d carrying a nut and washer. The smaller wires run into simir blocks and the fuses are put on with their copper terminals mped securely under the nuts. The safe carrying capacity of . 10 wire for concealed work, as given by the underwriters' ble, is 25 ampères. The fuses used ought to be such that they uld melt and thus interrupt the passage of current over the No. wire in the above cut if any accidental leakage should allow re than 25 ampères to flow through it; but as practically the es made of a certain size and intended to blow at this currentength, may blow at a smaller current-strength or a larger one, eeway of 25 to 30 per cent. is allowed, and a fuse marked to blow at 25 ampères is one which it is expected will actually melt at 30 to 35 ampères.

The uncertainty of the action of fuses, especially in large sizes, has led to the use of circuit-breakers, which were described under the heading "Switch-boards." In the opinion of the authors, the use of fuses above 50 ampères is extremely undesirable unless much greater care is taken in testing and using them than is the case with the ordinary commercial product.

Cut-outs.—The combination of fuse-blocks, studs, and screws or nuts, with convenient terminals for holding the wires when mounted on a piece of slate, marble, or porcelain, is called a *cut-out.* When the smaller wires continue in the same general direction as the larger, the pattern used is called a main line cut-out, and when the directions are at right angles the pattern is known as a branch cut-out. Cuts of both styles are shown. They should be furnished with a cover of slate, porcelain, or mica, so that if the fuse blows when some trouble occurs there will be no danger of injury or defacement by the particles of melted fuse-metal.


Main Line Cut-out.


Branch Cut-out.

Switches in their action correspond to valves in that they are used to throw on and shut off current. They differ from valves in that they either shut it off entirely or throw it on entirely, there being no intermediate positions by which the strength of current can be regulated. If this is desired, a *dimmer* must be used.

Switches are *single pole* if one side of the circuit is opened and closed by them; *double pole*, if both sides are controlled; and *treble pole*, if, as in some cases, the same handle is made to control switch-blades, which open and close three wires. A *double-*

throw switch is one by means of which the blades can be thrown into connection with either of two circuits. It is frequently used when a building is to be lighted for most of the time by its own plant, but in case of emergencies is to be lighted by some other plant. In such cases the hinged blade is connected to the circuit of the buildings, the upper terminals to the plant of the building, and the lower terminals to the outside plant, and *vice versa.*

Single-throw Switch.

Double-throw Switch.

Knife-blade switches are those above illustrated, in which the contact-making piece has a shape somewhat like a knife-blade and is also hinged at one end.

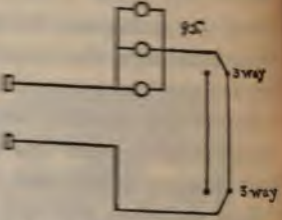
Snap switches are switches specially shaped to secure greater compactness, and are also provided with a spring which makes the motion of the contact piece positive. Once started, it goes either to the position of *make* or to that of *break,* it not being possible for it to stop at a position of partial or imperfect contact. Snap switches are provided with covers which prevent persons from accidentally touching the conductors and thus receiving an electric shock. For this reason they are used in rooms and nearly all locations except on switch-boards and panel-boards. They are made in sizes up to 100 ampères ; but for any current above 25 ampères it is generally advisable to use knife-blade switches, as the latter are much less liable to trouble from imperfect contacts, broken parts, etc. T

Snap Switch.

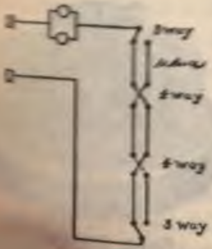
switches which shall be inconspicuous a specially designed snap switch is made so that its covering plate can be set flush with the wall. It is operated by turning a handle in some patterns, or by pushing one button to open and another to close the circuit in another pattern. The cut shows the style adopted by the company which first made the flush type of switches.

Flush Switch.

3-way switches are employed where it is desired to turn lamps on or off from either of two points. The method of connection is shown in the diagram, a 3-way switch being placed at each point. The figure shows the lamps burning. Throwing either switch will extinguish them, after which a movement of either will again light them.



4-way or Commutation Switches.—By means of these and two 3-way switches it is possible to control lamps from any one of any number of points. In the diagram the lamps are shown burning. If any switch is turned into the dotted position, the lamps will be extinguished. If now any switch is turned, they will burn again.



Chandelier Switches.—Another special switch is so arranged that by turning it one-quarter round one light on the chandelier will burn, another quarter lights additional lamps, a third-quarter turn causes mps to burn, while the fourth-quarter turn extinguishes m.

t Surfaces.—The relative quality of switches depends y upon the quality of workmanship. The parts must, e designed large enough to carry the current without heating. It is usual to allow, where the current ugh solid copper, a current-density of 1000 ampères inch of cross-section, and for brass, whose specific re- nuch greater than that of copper, a less density depend- percentage of copper in the brass. Where the current ugh the contact surface of two pieces, as from blade to ost careful workmanship is needed. The blades should in and should touch along the whole surface of the clip. is the case a current of about 100 ampères per square tact surface can be safely allowed, but for the ordinary ip found on most switch-boards 75 ampères per square be safer. Where the contact is made between two s smoothly faced and parallel and held together by a er size, a density of 200 ampères per square inch of con- can be allowed.

are mechanical arrangements for holding a lamp-bulb still allowing it to be easily withdrawn. Electrically contact between the two wires em and the terminals of the nt. Key-sockets have in ad- ny single-pole snap switch rupts this contact. They are ferent styles to fit the various the principal of which are , Thomson-Houston (T.-H.), ghouse.

les.—A receptacle originally socket made so as to screw to ceiling. Latterly the term in- ry useful device called the at- lug, which is employed where l to use current temporarily *a flexible connection* between the circuit and the lamp,

Westinghouse Key-socket.

motor, or other device in which current is to be used. The Chapman receptacle consists of a porcelain box with two terminals into which

Chapman Receptacle and Plug.

Plug.

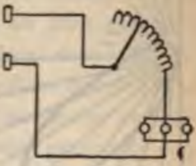
the circuit wires are led. These terminals are each in connection with a flat piece of copper. The *plug* to which the flexible conductors are attached has also two terminals, likewise connected through fuses to flat contact pieces. When the plug is pushed in the receptacle contact is made and the flexible cords and apparatus attached are connected to the circuit. When out of use the plug is pulled out and a hinged lid drops down and covers the contacts.

The flexible cord, while extremely convenient, is one of the least safe parts of an electrical system. A cut-out containing fuses is therefore always placed at its junction with the main circuit. With the receptacle this cut-out is in the plug. In other cases it is a small porcelain affair of various shapes, and is known as a K. W. or a *ceiling rosette.*

Joint.

Insulating joints are used wherever fixtures are combination gas and electric. They are made in two parts insulated from each other. The upper part is connected electrically to the gas-pipe system, since it is screwed on to the end of the gas-pipe. The lower side is likewise connected electrically to the fixture, since the latter is screwed into the joint; but owing to the insulating piece the fixture is insulated from the gas- Therefore an accidental contact between a conductor l the fixture does not connect the conductor to the earth through gas-pipe system.

Dimmers.—A dimmer is an adjustable resistance or rheostat ich is placed in series with the group of lamps whose brilliancy is desired to vary. Turning the dimmer ndle one way throws more resistance in ries with the lamps, and therefore cuts wn the current flowing through them, ich, of course, makes them burn more nly. Turning the handle the other way s the opposite effect. They are princi- lly used in theatres and halls. Since they cut down current by erposing their own resistance, they are heated up to a consid- ble extent and should be mounted like any rheostat on slate marble, or some incombustible substance.



CHAPTER XXXIII.

THE ELECTRIC LIGHT.

Arc Lamps.—When a current from a source of some 50 volts essure is passed through the junction of two pieces of carbon, d these pieces are then separated about $\frac{1}{16}$ inch, an intensely lliant white light is produced, which is called the electric arc. the intense heat produced the carbon on the positive side is porized. Part is burned in the air, while a small amount is rried over to the negative carbon. There it is burned away ether with the carbon already there, the rate of consumption the positive being, roughly speaking, twice as great as that of negative.

Distribution of the Light.—The intensity of the arc varies atly when looked at from different directions. Measurements *de show that if plotted,* letting distances from the arc repreent candle-power at that angle, the curve showing variation in brilliancy will be for direct current lamps approximately as shown, the upper carbon being as usual the positive carbon.

Rating of Lamps.—Lamps are rated in candle-power according to their brilliancy in the angle of greatest brilliancy. Thus the ordinary street lamp rated at 2000 candle-power gives that brilliancy only at an angle from the horizontal of about 45 degrees. At any other angle its brilliancy is less, and the average will not be much over 800 candle-power. Such a lamp requires a current of 9.6 ampères and about 45 or 50 volts, and a lamp using such current and pressure that their product is 450 watts may be considered commercially a 2000 candle-power lamp.

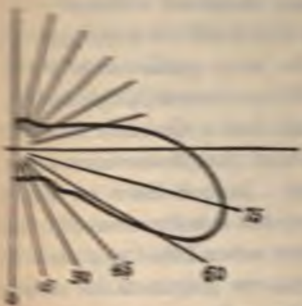
Classification.—Lamps may be classified in several different ways: 1. According to the kind of distribution-system for which they are intended, as constant potential arc lamps and series arc lamps; as the latter are in general used now only by central stations, their description will be omitted. 2. According as they are to be supplied by direct or alternating current, into direct current arcs and alternating arcs; only the former will be considered. 3. According to the degree of enclosure of the arc, into open arcs and closed arcs.

Requirements of All Arc Lamps.—All lamps to be commercially satisfactory must do two things: They must strike the arc—that is, after current has commenced to flow they must automatically draw the carbons apart so as to *strike* the arc. They must also regulate—that is, as the carbons burn away they must be automatically fed together, and the feeding of one must not appreciably affect the brilliancy of others.

stant Potential Arcs.—The mechanism of such lamps is of plest description unless several are intended to run in series. The current coming from the line to the positive lamp-terminal passes through a coarse wire coil and then through a chain or brush contact to the upper carbon, through the upper and lower carbons, and back through a wire resistance, which can be varied, to the other terminal of the lamp, and thence to line. The passage of current through the coil lifts an iron armature or core, as the case may be, to a certain distance depending on the strength of the current. This armature lifts a clutch-device which raises the upper carbon. The arc is thus struck and the lamp continues to burn, the two carbons being gradually consumed and the arc becoming longer. As the arc lengthens its resistance becomes greater and the current less. This allows the armature to drop down a little, and the clutch tripping against a stop lets the upper carbon slide through a little, thus shortening the arc. The moment the arc has been shortened sufficiently to increase the current enough to lift the clutch off the tripping-stop the feeding of the carbon ceases and the lamp continues to burn till the arc again becomes too long. When several lamps are to be operated in series they will not all feed at the same time, so that the action of one would interfere with the others unless some different arrangements were introduced. In such cases an additional magnet with fine wire coil is connected as a shunt around the arc, and its armature arranged so that when lifted to a certain point it makes the clutch feed. As the arc lengthens its resistance increases, and also the pressure between its terminals. Hence more current is sent around the fine wire coils, raising their armature and starting the feeding mechanism.

Open Arcs.—When the carbons burn in open air or in a globe of considerable size (usually 12 inches in diameter) to which air has free access, they are said to be open arcs. Under such circumstances the consumption of carbon is quite rapid, an upper carbon, 12 inches long by ½ inch diameter, lasting about seven hours, while the lower or negative carbon lasts about twice as long. To secure a longer life, the device was tried of enclosing the *arc in an air-tight* globe or in a globe filled with a gas like nitrogen or carbonic acid, in which the carbon would not burn. Such lamps are called closed arcs.

The closed arc, working in a vacuum, was not a success, and it has been found necessary to give a slight access of air so as to burn the particles of carbon that are detached. The rate of combustion is, however, so slow that the lamps require trimming only once in 100 or in 150 hours, as against once in 7 hours for the open arcs. The length of the arc which will burn quietly is much greater in the closed arc, so that the voltage is higher, rising to 80 or 90 volts, with a corresponding reduction of current to about 5 ampères for the nominal 2000 candle-power lamp. This is quite an advantage, as it is not necessary to put two lamps in series across 110-volt mains to avoid an excessive waste of energy in a resistance coil. Owing to the use of two globes, one of which is usually opalescent, there is a more even distribution of light than for open arcs, as will be seen by comparing the accompanying figure with the one preceding.



Incandescent lamps consist of a carbon filament attached to platinum wires, which is mounted in a glass globe from which the air has been exhausted and which is sealed up so as to exclude air. The platinum wires serve to connect the filament to the terminals of the lamp base. The vacuum is made as perfect as possible, so that there may remain no air inside the globe in which the highly heated filament would burn away.

The filament is made by taking a slender piece of some material consisting largely of carbon, such as bamboo, silk, paper, or cellulose, and heating it intensely in a furnace so as to drive out all the other material, leaving a very nearly pure carbon thread. to smooth out the roughness and make its section uniform oints, a current is passed through it large enough to heat it ıearly a white heat in an atmosphere of some hydrocarbon, like l gas. This causes carbon to be deposited most largely at the test points, which are those of the smallest cross-section. The nent is then attached to the platinum leading-in wires and ed in the globe. A mechanical air-pump exhausts the air n the globe, and finally, by passing a strong current through filament, the latter, heated to incandescence, burns away the nant of oxygen remaining. The bulb is then sealed up and


Edison.

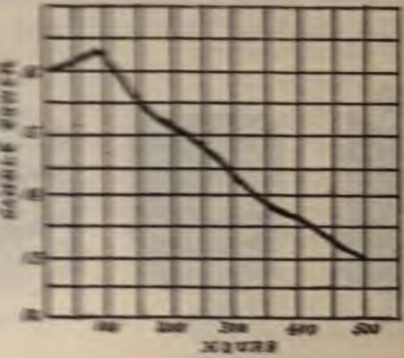

T-H.


Westinghouse.

platinum wires connected to the lamp-base terminals, These of different styles, the three most common being shown in accompanying cuts. Finally, the lamps are tested to see at t voltage they will give the candle-power for which they are nded.

he candle-powers ordinarily made are 8, 10, 12, 16, 20, 24, 50, 100, and 150, though it is unusual to find the last two s, arc lamps being substituted for them. As the lamp con- ıes in use its candle-power gradually diminishes, owing to the osition of carbon from the filament on to the walls of the be, the layer of carbon absorbing the light rays, so that after w hundred hours' burning the lamp must be replaced by a one. The curve on the next page, obtained from tests on mercial lamps, shows this action plainly.

he voltages for which lamps are usually made are as follows: n 50, 51, 52, and so on up to 60; 70, 71, 72, and up to 80; *101, and up to 125;* and from 220 to 250. In the voltages above 125 volts lamps of 16 candle-power and over are made, with the smaller candle-powers the filament would be too fine be mechanically of sufficient strength. The use of 220-volt lam as previously pointed out, makes the wiring system much cheap and they are being extensively employed, although it is not p



sible at present to make a 220-volt lamp of 16 candle-powe good as a 110-volt lamp of that candle-power.

Life and Efficiency of Lamps.—A 16 candle-power lamp 110 volts requires a current of from .38 to .6 ampère to he hot enough to give 16 candle-power, according to the nature cross-section of its filament. The one with the finer filament quiring but .38 ampère, would, however, not last nearly as as the one requiring .6 ampère. .38 ampère at 110 volts is e to 41.8 watts. Dividing by 16, we have 2.6 watts power requ per candle-power produced. This figure is called the effici of the lamp. The smaller the power required to produce candle-power the more efficient the lamp. Unfortunately, gr efficiency is accompanied by a corresponding shortness of lif be seen by the following table of approximate values w expected with good lamps:

Efficiency. Watts per candle.	Life-hours.	Watts per 16 c. p. lamp.	Ampères for 16 c. p. 110-volt lamp.
2.6	400	41.8	.38
3.1	600	49.6	.45
3.6	800	57.6	.52
4.0	1000	64.0	.60

The choice of efficiency which it is advisable to use in a given case depends upon the cost of power. If coal is cheap, it pays to use a low efficiency and long life. If coal is dear, the high efficiency lamp should be used, provided the speed regulation of the engine is good enough to prevent fluctuations in the voltage of the dynamo, it being understood that any rise in voltage above that for which the lamp is intended shortens its life very seriously. Of course, where all the exhaust steam of the generator engine is used in steam heating it is desirable to use the low efficiency and long life lamps.

Distribution of Light.—In calculating on the distribution of lights, we must take into consideration the character of the space to be lighted, its dimensions, the color of the walls, and the brilliancy required. As a measure of the brilliancy it is often convenient to make use of a unit of intensity of illumination, called the candle-foot (written c. ft.), which is the intensity of illumination produced by one standard candle at a distance of one foot. As is well known, the intensity of illumination from a given source varies inversely with the square of the distance; that is to say, one candle at 4 ft. would give an intensity of illumination of $\frac{1}{16}$ c. ft.; and at a distance of 2 ft. would give $\frac{1}{4}$ c. ft. A 16 candle-power lamp at 1 foot would give 16 c. ft., at 2 ft. would give 4 c. ft., and at 4 ft. would give 1 c. ft.

The number of candle feet at any point is found as follows: If due to one lamp, divide the candle-power of the lamp by the square of the distance in feet from the lamp to the point in question. If there are several lamps at equal distances, divide the *total candle-power* by the square of the distance. If they a several lamps, compute the candle feet due to each and add them together.

Effect of Height of Lamp.—Suppose that we have at the height of 7 feet above the floor four 16 candle-power lamps; the illumination immediately beneath the lamps on the floor would be $\frac{4\times16}{7\times7}$ $=\frac{64}{49}=1.3$. With lamps 8 feet high the illumination would be $\frac{64}{64}$ $=1$ c. ft.; at 9 feet it would be $\frac{64}{81}=.79$ c. ft.; at 10 feet it would be $\frac{64}{100}$ c. ft., or practically one-half what it would be at 7 feet. In this calculation we have evidently neglected the effect of reflection, but the figures give a fair idea of the effect of placing the lights at different heights. Generally the lamps are placed at a height of 7 feet or 7 feet 6 inches above the floor.

Effect of Color and Surface of Walls.—The following table gives the percentage of the total light cast upon different surfaces which is reflected by these surfaces. The lighter colors reflect a large amount of light and the dark ones almost none.

White blotting-paper	82	Plane deal (dirty)	20
White cartridge-paper	80	Yellow cardboard	30
Yellow wall-paper	40	Parchment (1 thickness)	22
Blue paper	25	" (2 ")	35
Dark brown paper	13	Yellow painted wall (clean)	40
Deep chocolate paper	4	" " (dirty)	20
Plane deal (clean)	40–50	Black cloth	1-2

Effect of Arrangement.—We will first consider this matter, neglecting the effect of walls and ceiling. We will suppose that it is desired to secure a certain minimum illumination; that is to say, a certain number of c. ft. at that point of the room which is least illuminated. Suppose, for example, that we take (see figure on page 743) a room 30 feet square, and that the lights are placed at four points in the room, each of the being 5 feet perpendicularly distant from two walls; the ts would then, if joined together, form a square whose feet and whose diagonal is about 28 feet. The least d point would be at the intersection of the diagonals.

g a point on this intersection at the same height from the as the lamps are hung, if we two 16 candle-power lamps at corner the illumination at the would be

$$\frac{\times 4 \times 16}{14 \times 14} = \frac{32}{49} = .65 \text{ c. ft.}$$

lumination at the corners equals

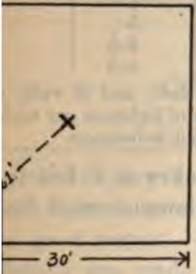
$$\frac{32}{7 \times 7} = \frac{32}{49} \text{ c. ft.,}$$

ering only the two nearest lamps.

t lamps at centre. If, as in the figure, we mass the eight at the centre, the minimum illumination, which now will be at the corners of the room, will be

$$\frac{8 \times 16}{21 \times 21} = \frac{128}{441} = 295 \text{ c. ft.,}$$

which is very much less minimum illumination than we obtained before, and which shows very clearly that for the given expenditure of energy we will get a much greater minimum illumination as well as a more uniform illumination by distributing instead of massing them at one point.



unt of Light Required.—This depends on the purpose for the room is used and the color of the walls. We should t that to get the greatest amount of illumination from the kpenditure of energy requires that we should subdivide our on the other hand, this increases the cost of installation, must take both of these matters into account. In arranging distribution of lights, we may, for private houses, whose s do not vary much from 10 feet in height, make use of a ition based on the number of square feet to be allowed to candle-power light. The following tables will give an idea *ighting which may* be obtained from various distributions.

PRIVATE HOUSES OF SMALL SIZE.

	Square feet.	No. 16 c. p. lights.	Min. ill'n if dark walls.	General effect.
Chambers..........	150	1	.25 c. ft.	Fair.
"	200	2	.33 "	Fairly good.
Kitchens..........	150	1	.25 "	Fairly good.
Corridors..........		1		
Dining-room......	200	3	.50 "	Good.
Parlor.............	200	3	.50 "	Good.

or 1 16 candle-power light every 66 square feet with white walls.

FOR LARGER DWELLINGS.

	Square feet.	No. 16 c. p. lights.
Chambers..........	150	2
"	200	3
Kitchen...........		3
Pantry.............		1
Dining room	250	5
Library	250	4–5
Parlor..............	250	4–5

or 1 16 candle-power light every 50 square feet; and if walls are not white make allowance by increasing the number of lights as per table showing relative amounts of light reflected by different substances.

In these tables the height of lamps is taken at 7 feet 6 inches to 8 feet. For a greater height proper allowance must be made, as shown previously.

Hotels and Apartment-houses.—

The sleeping-rooms and parlors similar to private houses.

Corridors, 1st floor, bright, 1–3 lights chandelier every 25 feet, main corridor.
" " good, 1–2 " " subcorridor.
" other floors, " 1–2 " " main corridor.
" " fair, 1 " " subcorridor.

Elevators, small, 1 light; large, 2 lights.

Café, 12 feet ceiling, brilliant, 1 16 candle-power light to every 25 square feet, subdivided according to tables.

Dining-room, 15 feet high, 1 16 candle-power light to every 25 square feet, subdivided.

Office, reading-room, and bar similarly lighted.

Toilet-rooms, one to every two closets, set on partitions.

-rooms 1 16 candle-power light to 50 square feet.

r-shop, like office, location front and behind chairs.

res and Large Halls.—The height is so great that we ake it into account, and it is better to work from cu. ft., nderstanding that lights are well distributed. .03 c. p. - gives good illumination; .04 c. p. per cu. ft. gives bright ion. We should aim not to have light staring in the therefore no chandeliers in centre; while lamps on gal- ould have opal globes whose absorption is about 50

.—

ent light, 1 16 candle-power to 25–50 square feet.

1 2000 candle-power every 15 feet or 225 square feet.

1 2000 candle-power every 30 feet if the store is narrow.

ts.—

feet high.

1 2000 candle-power to every 40 feet or 1600 square feet.

CHAPTER XXXIV.

ELECTRIC MOTORS.

ICALLY any direct-current dynamo, if current be supplied ll operate as a motor, and a well-designed dynamo will good motor. Certain alterations in winding and in tails are made in motors to improve certain qualities y be specially desired. The motor will not necessarily he same direction as it did as a dynamo when current rough it in the same direction. For example, a series when operated as a motor will run in the opposite direc- n that which it had as a dynamo, and to make it turn in direction it is necessary to reverse the direction of cur- ugh the fields or armatures. A shunt machine used as a ill turn in the same direction that it had as a dynamo. ng the direction of current supplied to either, as by inter- g the connecting wires from positive to negative sides of will not change the direction of rotation of either series *motor. To* reverse them it is necessary to reverse the direction of current running through the field or the armature. The compound dynamo, if the effect of the series coils is weak relatively to those of the shunt coils, will behave like a shunt motor. If the series coils preponderate in strength, it will act like a series motor.

Uses of Different Types.—The series motor is used where it is necessary to start with full load and where automatic regulation for constant speed is not necessary, a hand regulation being used, as, for example, in hoists, cranes, street railways, etc.

A shunt motor is used where automatic regulation for constant speed is desired. A good shunt motor will not change its speed more than 5 per cent. when the load is varied from zero to a maximum. While there is only one speed at which this automatic regulation is closest, yet by putting resistances in series with the armature a shunt motor can be made to run at slower speed and still give fair regulation.

Compound motors are used where closer speed regulation than that given by shunt motors is desired, and in special cases, such as on planers where it is desired to check the sudden large flow of current during reversal.

Regulation of Speed.—With a series motor, whose use is practically confined to constant potential circuits, there are two common methods of changing the speed:

1. To change the pressure supplied to it, by putting in series with the motor a rheostat in which more or less pressure is used up according to the position of the rheostat-handle. Lowering the pressure will, of course, lower the speed.

2. To change the strength of the field of the motor. This is done by winding the field coils in sections and bringing out the ends to a sort of commutating device called a controller. In one position of the controller handle the sections will all be in series, cutting down the current and making the ampère turns of the field, and hence its strength, low. In the next position, for example, three sections will be in series and three others in series, two sets of three in multiple, which will diminish the

resistance, let more current through, and increase the ampère turns. Another position will put more in multiple and less in series, and so on till the final step puts all the sections in multiple, giving the lowest possible resistance, highest number of ampères, greatest number of ampère turns, and strongest field. With the series motor on constant potential circuits the speed is increased in proportion as we increase the field strength. A combination of the two methods is frequently used, the resistance being used during the first positions in order to cut down the excessive flow of current on starting.

With shunt motors it is necessary on starting to put a considerable resistance in series with the armature, on account of its very low resistance, which will vary from $\frac{1}{100}$ to $\frac{1}{1000}$ of an ohm or less, according to its size. Such a low resistance thrown across 110 volts would cause an enormous current, which would injure the commutator and brushes by sparking and the armature coils by heating. As the machine speeds up the resistance may be cut down, because the armature, which is turning in a magnetic field, produces an electro-motive force opposite to that of the circuit, which tends to cut the current down. This electro-motive force is called the *back* electro-motive force of the motor, and is always less than the electro-motive force of the circuit by the amount required to drive current through the armature. It is, of course, proportional to the speed of the motor, and its relation to the electro-motive force of the circuit is as follows: Let E be the pressure of the circuit at the motor terminals, R the resistance of the armature, C the current flowing; then the back electro-motive force, $e = E - C\ R$. Starting resistances, or starting boxes as they are called, are usually not designed to be left in circuit more than the few seconds needed to get the motor up to speed; but if made of wire large enough to carry the currents without overheating, they can be used for regulating the speed of the motor. Such specially designed boxes are called *speed-regulating*, or simply *regulating*, *rheostats*.

Another method of varying the speed of a shunt motor is to put a rheostat in the field circuit and vary the current flowing around the field. Weakening the field will speed up the machine, while strengthening it will have the opposite effect. Note that this is just opposite to what happens with the series motor on constant potential circuits.

Compound motors are generally regulated like shunt motors; but in some special cases the series coils are wound in sections and thrown in series, and finally in multiple, as is the case with series motors.

Protective devices are specially necessary with shunt and compound motors on account of their very low armature resistances, as explained above; and all motors need to be protected from the danger of being overloaded. An overload, by slowing down the motor, diminishes the back electro-motive force and therefore allows an excessive current to flow, which, if long continued, would burn out the armature. The protection formerly used was a pair of fuses, one in each of the circuit wires, which were of such a size that they were expected to blow at any current exceeding that corresponding to the maximum load for which the motor was designed. Owing to the uncertain action of fuses, a circuit-breaker is now almost universally used, mounted on the starting-box. Another thing which must be guarded against is this: Suppose that the circuit to which the motor is connected is overloaded, perhaps by some accident, and the circuit-breaker of that circuit on the switch-board should open. This would cut off current from the motor and it would stop. Now if nothing were done except at the switch-board to throw in the circuit-breaker again, we should throw the full voltage on the motor armature, none of the rheostat being in series with it, as it had been previously cut out of the circuit when the motor was first brought up to speed. The result, of course, would be a tremendous flow of current and injury to commutator, brushes, and perhaps the ure, depending upon how quickly some one opened the hich connected the motor to the circuit. To obviate this , the rheostat arm has attached to it a spring which tends to pull it back to the position in which all of its coils are in series with the armature. At the other limit of its motion, where it would stand when all the coils had been cut out of the circuit, is a magnet wound with fine wire and supplied from the circuit wires. When the rheostat arm gets to this position the magnet holds it there by its attraction for a piece of iron mounted on the arm, as long as the current flows through the coil; but if the circuit-breaker goes off or the voltage disappears for any reason, the magnet lets go and the spring pulls the rheostat arm back to the position of safety.

Size and Speed of Motors.—Motors may be obtained of any desired size, voltage, and speed. The commercial sizes are from $\frac{1}{12}$, $\frac{1}{6}$, $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 3, 4, 5, 7½, 10, 15, 20, 25, 50, 75, 100 horse-power and upward. The standard voltages are 110, 220, and 500, these operating on voltages from 110 to 125, 220 to 250, and 500 to 550. As to speed, there is no such thing as standard speed for different sizes, the speeds of the different manufacturers varying widely. It should be understood that with motors, as with dynamos, the speed at which a certain size shall run determines the cost. For example, a machine of such size and winding that it will give 100 horse-power at a speed of 500 revolutions per minute, will give only 50 horse-power if the winding be altered so that it will run at half that speed.

A motor generator, as its name indicates, is a combined motor and generator. The most easily understood form would be a motor which might be designed for any voltage, speed, and power, coupled directly to the shaft of a dynamo designed for the same speed, but for any voltage and the same output as the motor. Such a machine has two distinct commutators, brushes, armatures, and fields. By using a common armature core and field, and putting the two sets of armature windings on the same core, insulated, of course, carefully from each other, the compactness of the machine is very much improved, and this is the arrangement of the modern direct-current motor generator. Its princi-
al uses are as follows:

1. To change from a high pressure and small current to a lower pressure and correspondingly greater current.

2. With its generator armature in series with some circuit to raise the pressure of that particular circuit higher than that of the other circuits supplied from the principal generator. In such case it is called a booster.

3. In connection with storage batteries, it being used in series with the charging mains to increase the pressure in proportion as the batteries become more fully charged.

It is also used to a considerable extent in telephone exchanges for operating the calling circuits, the generator end being arranged to give an alternating current.

CHAPTER XXXV.

THE STORAGE BATTERY.

The principles of the storage battery have already been taken up in an earlier chapter, and it only remains to describe the battery as made and used in practice. Owing to the purchase by one company of all the important storage battery patents in this country the situation of the industry is much simplified, there being practically only one battery upon the market, which is known as the chloride battery. It derives its name from the method of making the plates, pencils of lead chloride being inserted in the leaden frames, to be afterward treated chemically so as to produce the active material of the plates. This treatment consists first in suspending the plate together with a zinc plate in a bath of zinc chloride, with the resulting formation of zinc chloride and pure lead, instead of the lead chloride. The zinc chloride [illegible] away, leaving the pencils in the form of finely divided [illegible] lead. The object of securing this spongy form of lead [illegible] nt as much surface as possible to the action of the liquid [illegible] acid) to be used in the battery. These plates might [illegible] ed as negative plates, although further treatment might improve their action. To form positive plates two are taken and suspended in dilute sulphuric acid and a current sent through them. One of them becomes coated with a reddish-brown substance, which is peroxide of lead. Hydrogen bubbles collecting on the surface of the other attack any oxide that may remain on the other plate and leave a clean surface of lead. After the plates have been charged the charging current is shut off and they are discharged by connecting them together. They are then charged again, the oxidation of the first plate going to a greater depth than before. As this peroxide is the active material of the cell, the amount of it produced determines the capacity of the cell; therefore the plates are alternately charged and discharged, so that the layer of lead which becomes oxidized during the charge may be as deep as possible. There is a limit to this depth, beyond which the chemical actions will not penetrate, and when this is reached the forming process is stopped. The peroxide plate, which is reddish in color, is the plate from which current flows during discharge, and is called the positive plate. The gray-colored plate is the one toward which current flows during discharge, and is consequently called the negative plate. In makin

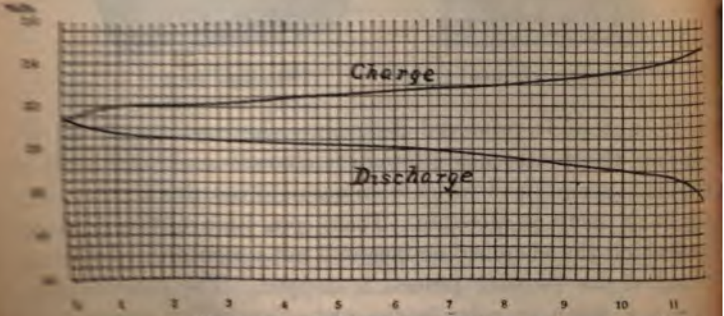
Negative Plate.

Storage Cell.

up a storage cell from the previously formed plates we first take a negative plate, then a positive, then another negative, and so on, there being always one more negative than positive plates. All the negatives are connected together by a lead strip, and similarly all the positives; but each negative is separated from neighboring positives by a space of perhaps an eighth of an inch, filled with dilute sulphuric acid, the general arrangement being shown in the cut.

Charge and Discharge.—After the completely formed positive and negative plates are put in the containing jar or tank with dilute sulphuric acid and are electrically connected together by a wire, current commences to flow and corresponding chemical changes occur. These changes are somewhat complex; but in a general way it may be said that the peroxide of lead on the positive plate is changed to lead sulphate and the pure spongy lead of the negative plate is also changed to lead sulphate. The electro-motive force of the cell will during this process fall from about 2.2 volts when fully charged to 1.8 volts, at which point the discharge should be stopped, in order to prevent the plates being injured.

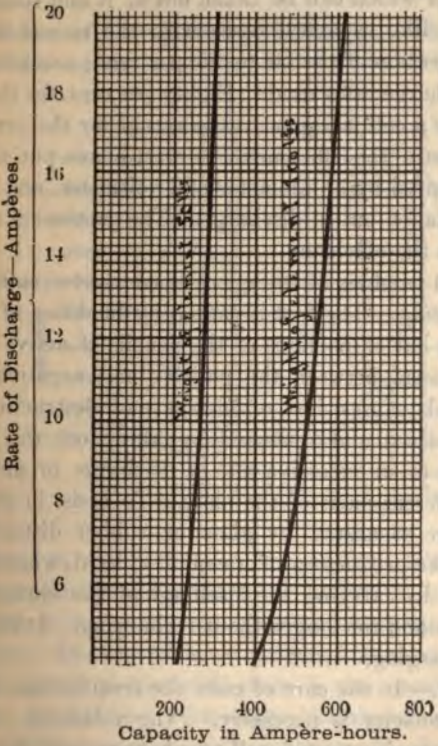
If current from some generator be sent through the cell in the [illegible], sulphate of lead on the positive plate is again [illegible]ide of lead [illegible] sulphate of lead on the nega



Charge and Discharge Curves.

plate is changed to metallic lead, and with each charge and harge of the cell these chemical actions take place. The tro-motive force of the cell rises as the charge increases, and variation can best be seen by plotting a curve, as in the ac-panying diagram, which shows the variation of electro-motive e through a complete charge and discharge.

apacity of Storage Cells.—The unit of capacity is the ère-hour, and a cell of 50 ampère-hours' capacity is one

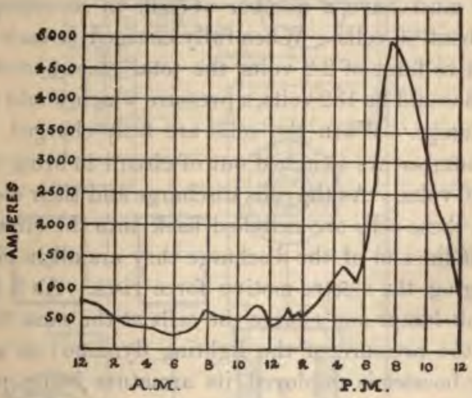


ch when discharged at its normal rate gives out such a number *npères for such a* number of hours that the product of the num-part of this curve, it being charged while the load on the dynamos is light, and thrown in multiple with the generators, so as to take a part of the load, between the hours when the peak occurs. In this way the boilers, engines, and dynamos work at a more uniform load, and therefore more economically than they otherwise would.

Method of Connecting Batteries.—Owing to the fact that the electro-motive force of a cell increases with charge and diminishes with discharge, it is necessary to have special arrangements by which a dynamo while supplying lights may charge a battery of cells, and by which the electro-motive force of a set of cells may be kept constant while they are supplying lamps. The arrangement for discharge will be first described. Supposing a 110-volt system, we must have a number of cells in series equal to $\frac{110}{1.8}$ volts, or about 60 cells. When fully charged, as each cell has an electro-motive force of 2.2 volts, the total electro-motive force of the 60 cells would be 132 volts, a pressure which would seriously injure the lamps. When the cells are fully charged, therefore, a sufficient number are switched out of circuit to bring the pressure down to 110 volts. As the cells discharge and their electro-motive force falls, these cells are switched back into the circuit one at a time, till at the end of the discharge they are all in circuit.

In charging, the electro-motive force rises. As it is desired to run 110-volt lamps and charge the cells at the same time, we cannot raise the pressure of the lighting dynamo; so an auxiliary dynamo or booster is employed, its armature being put in series with the cells and its field varied by its rheostat so as to give enough additional volts for charging at the proper rate. The accompanying diagram of connections shows the arrangement. *B* is the booster and *R* its rheostat. *V* is a voltmeter and *A* an ammeter, so arranged that its needle stands in the centre of the scale when no current is flowing through it, moving to one side for a charging current and to the opposite side for a discharge current. *K* represents the main battery and *H* the switch which throws the *reserve cells* in and out. S is a double-throw switch, which in *one position* [illegible]ects the batteries to the lamps to be supplied density of the solution, which when fully charged should be 1.22. It diminishes, as the cells are discharged, down to about 1.17. The readings of the hydrometer, therefore, give an indication of the condition of each cell in which it is placed. The regular use of these two instruments, a careful attention to the discharge rate, regular inspection of cells, and the making good of water lost by evaporation, so as to keep the tops of the plates always covered, constitute the most vital points connected with the use of storage batteries.

Advantages of Using Storage Batteries.—There are two cases in which the use of the storage battery is of the highest benefit.

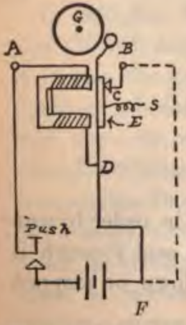


The first is to use it to take care of light loads, allowing the moving machinery and perhaps the boilers to be shut down and doing away with the expense of the necessary attendance for such machinery. The second is to take what is called the peak of the load. In almost no electrical plant is the amount of power used uniform. In lighting work there is a variation something like that shown in the diagram, where during the hours from four to six comes a very large load. The storage battery can be used to *great advantage in supplying* power represented by the uppe

CHAPTER XXXVI.

ELECTRIC SIGNALS.

Nearly all signal systems coming under the charge of the ordinary engineer consist of four elements—the battery, the line, the operating station, and the receiving station. The battery furnishes the electrical energy for operating the signals, and the line serves to transmit this energy. The operating-station, which generally consists of a key, a switch, or a push-button, closes the electrical circuit and permits the operating-current to flow. The receiving-stations are somewhat varied in design. They may consist of a bell or telegraph-sounder, giving the signals by sound, or of a galvanometer or a shutter-drop, which conveys the signals by means of sight. Frequently the two methods of sound and sight are combined. Of the four elements, the battery and line have already been discussed in previous chapters, and the key or push-button is so simple that it requires no description further than to say that it consists of a fixed contact-piece and movable contact-piece, into each of which is connected one of the circuit wires. When the two pieces are brought into contact the electrical circuit is closed and current flows. The receiving mechanisms will be taken up in connection with the special systems of signalling of which they form a part.



Electric bell and circuit.

Electric Bells.—An electric bell consists of an electro-magnet, to the armature of which is connected a hammer arranged to strike a gong when the armature is pulled up to the core of the magnet by the passage of an electric current. When current ceases the magnet loses its strength and a spring pulls the armature away from the core and also the hammer from the gong. Bells are divided into *two classes,* known as *single*-stroke and vibrating bells.

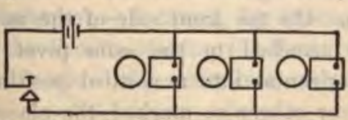
A single-stroke bell is one which makes one stroke only each time that its push-button is pressed. In the accompanying cut, if the line were connected as shown in solid lines, to *A* and *D*, the bell would be single stroke.

A vibrating bell is one whose hammer continues to vibrate as long as its push-button is pressed. The way in which this is accomplished is simple. Suppose that in the cut on p. 758 above the connection between *F* and *D* is taken away and the connection between *F* and *B*, shown with dotted line, is made instead. When the button is pressed down, the circuit being closed, current will flow from *F* to *B*, *B* to the contact-point *C*, through the armature *E* to *D*, from *D* through the magnet coil to *A*, and from *A* back through the closed push and battery to *F*. Owing to the current, the electro-magnet pulls the armature *E* toward itself and the hammer strikes the gong *G;* but as soon as the armature moves toward the magnet the circuit is opened, because *C* no longer touches *E*. The current therefore stops, and as the electro-magnet no longer has any strength, the armature is pulled away from it by the spring *S*. This movement, however, brings *E* and *C* into contact again, causing the whole action to be repeated, and this continues as long as the push-button is held down, provided the battery keeps up its strength. Such is the principle on which work the ordinary bells used for houses, offices, etc.

The buzzer is practically a bell with the gong omitted, and is used where the powerful noise of the bell would be annoying.

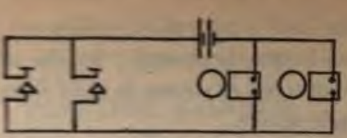
Styles of Bells.—Bells are known as *wooden box* if the working parts are covered with wood, *iron box* if covered with iron, and skeleton frame if they are not covered at all.

Possible Arrangements of Bells.—The accompanying diagrams

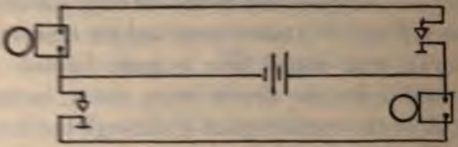


One push operating two or more bells at the same time.

show the method of connecting in some of the more important cases.



Any one of two or more pushes operating one or more bells.



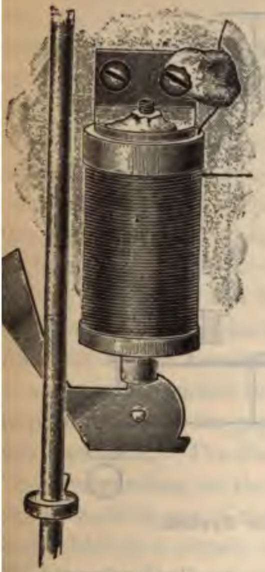
No. 1 push operating a distant bell at station No. 2, together with a push at No. 2 operating a bell at No. 1, known as the return call.

Any number of pushes may each operate its own bell or buzzer. This system is the same as the annunciator system.

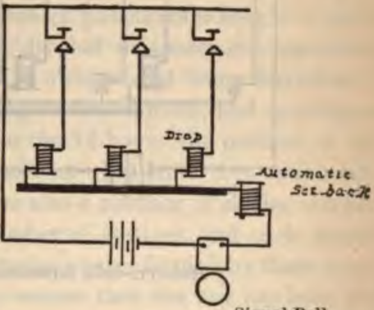
Any number of pushes may each operate its own bell and each have a return call. This is the same as a return-call annunciator system.

The annunciator in principle consists of a number of bells mounted together in a case, each operated by its own push located in some distant place. In practice, however, it would be difficult to tell from the sound of the bells which station was calling, so the hammers and gongs are omitted, and instead we have a simple mechanism operated by the armature, called the drop. One of the simplest forms is shown in the cut on page 761. When the current flows through the coil the armature *A* is drawn up a little way into the coil and the shutter *S*, which is hung eccentrically, being released when *A* is lifted, turns through one-quarter turn. On the front side of the annunciator case a needle, which is attached to the same pivot which carries *S*, moves from a horizontal into a vertical position. Each needle being numbered or otherwise marked, the place from which the signal is sent is, of course, known. A rod carrying little stops serves when p[illegible]p to restore the needles to their horizontal

ition. This rod can be operated by hand or by an electro-gnet connected so as to be pulled up when any push is pressed. In this case all needles previously standing vertical assume the horizontal position, and then the needle corresponding to the button pressed turns into the vertical position. This arrangement is called the *automatic set-back.* The accompanying diagram shows the con-
tions of an annunciator system. To attract the attention the sig-bell is added, so connected that when any push is pressed it gs.



Annunciator Drop.

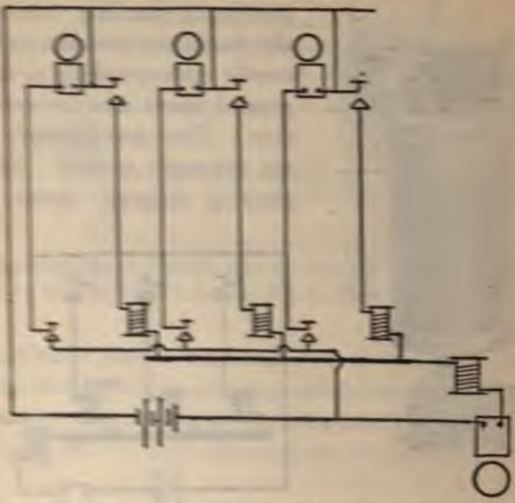


Annunciator System.

The return-bell annunciator system, which is like the simple unciator system, with the addition of a wire between each push the annunciator, is shown in the diagram on page 762.

Fire-alarm Attachment.—A device for closing simultaneously ain or all of the circuits ringing the distant bells as may be ired, is frequently added for annunciators used in hotels and rtment-houses.

Burglar-alarm systems are similar to simple annunciator sys-s, *with the addition* of a bell in an auxiliary circuit which is closed when any of the drops operate. This auxiliary bell will therefore continue to ring till some one comes along and restores



Return-call Annunciator System.

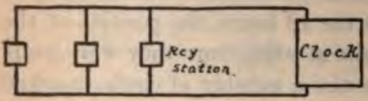
the drops to their usual position with the needles horizontal. The push-buttons are of a somewhat modified pattern and are placed in doors and window-casings, so that if either a door or window is opened the contacts of the button touch each other and close the circuit, causing the corresponding drop on the instrument to operate. Frequently the pushes of all the windows and outside doors of any one room are connected in multiple on one circuit, so that any one of them when closed operates the drop corresponding, it not being necessary to have a drop for each window and door, but only for each room.

Watchmen's systems for insuring that watchmen make their rounds at the time and in the order in which they are expected to do so, may be divided into two different classes, according as ergy for actuating the recording device is derived from a battery or a small dynamo, namely, into the *battery* and *magneto-systems*. The battery system has two different types, the difference consisting in the method of wiring and the design of push-button.

Battery System with Simple Push-button.—This system is wired like a simple annunciator system. Its push-buttons are of such pattern that circuit will be closed in them only by pushing into them a special key carried by the watchman. The annunciator of the ordinary system, with slight modification, becomes the watchman's clock. The signal bell and self-restoring magnet of the annunciator are omitted. The armature of each drop is made to actuate a little needle which punctures a hole in a paper recording-dial. This dial being divided in spaces corresponding to the hours from 12 o'clock to 12 o'clock, and being further subdivided into spaces corresponding to five minutes, and rotating so as to make one complete turn in the 12 hours, the position of the punctured holes on the paper tells at what time they were made by the watchman. The dial has also a number of circles marked on it corresponding to the number of stations, and each needle pricks its holes in one of the circular spaces formed by these rings, so that a hole in a certain ring means that the key has been put in the corresponding station push-button. The weak point of this system is that if the watchman can get at the two wires leading to any station and can connect them together, he can make the clock register as if he had actually gone to that station.

The magneto-system overcomes this objection, and also obviates the care of batteries. In this system the wiring and clock are the same; but instead of the special push-button to be operated by a key, a little dynamo, called a magneto, is placed at each station. The watchman carries a handle which he puts on a stud connected with the shaft of the dynamo armature. Turning the handle sends a current through the coil corresponding at the clock and causes the needle to make a record.

The other type of battery system has a less expensive system *of wiring than either of* the two preceding, and it is very difficult for the watchman to make a proper record on the clock without actually going to each station. At the clock one magnet and needle do all the recording for each watchman. Each push-button station is numbered, and on the dial when that station is operated the number of pricks are made in the paper corresponding to the station number. The station consists of an iron box with a hole in it for the watchman to insert his key. Inside the box is a sort of toothed wheel to which one of the wires is connected. The other wire is connected to a strip, which is adjusted so that the teeth will come in contact with it. As the watchman puts his key in he gives it a turn and the toothed wheel, having a number of teeth corresponding to the number of the station, is made to turn, and by its motion to make and break contact with the strip as many times as there are teeth. This will, of course, cause the needle to make an equal number of holes in the paper dial of the clock. The wiring system is of the simplest description, as will be seen from the diagram, the stations being in multiple across two wires. Its disadvantage, compared to the magneto-system, is that the batteries require some attention and expenditure for renewals. This is, however, slight, as half a dozen cells for each watchman suffice for ordinary conditions.



Batteries Required.—The type used is some form of the zinc-carbon sal-ammoniac battery. For single bells or annunciators with short circuits, as in a dwelling-house, three cells are usually sufficient. For larger buildings five or six will be needed. For automatic fire-alarms a much larger number is needed, the exact number being stated by the manufacturer, as a rule. For burglar-alarm and watch-clock systems six are as a rule sufficient, and sometimes a less number may be used.

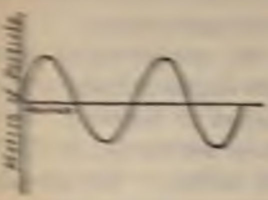
The wire used frequently is what is known to the trade as *annunciator* wire, the insulation of which consists of a double cotton *covering* di[illegible] in paraffin. A better insulation, whose use is advised, is what is known as office wire; while the *common* wire —that is, the one in the sketches which runs to one side of all the pushes—should be made with weather-proof insulation. In the better class of work the *common* wire is made with a rubber insulation and the other wires of rubber or weather-proof.

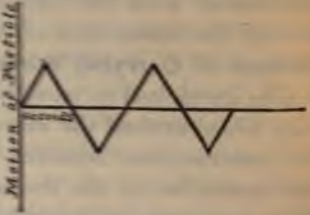
Methods of Carrying Wires.—In the cheaper classes of work the wires are tacked to wood-work with staples or held by a piece of tape folded around the wire and tacked to the wood. In fire-proof constructions, however, the wires are carried in conduit, which should be of the iron-armored variety. The prevailing practice is to carry as many wires as is desired in one tube.

CHAPTER XXXVII.

THE TELEPHONE.

The phenomenon of sound is caused by vibrations of the particles of air; its pitch is dependent upon the *number* of vibrations per second, its loudness on the *wideness* of those vibrations, and its quality, that property by which we distinguish tones of the same pitch and loudness, upon the *form* of the vibrations. This last point is somewhat difficult to understand. Suppose that a mass of air is set in vibration by a tuning-fork, and that we study the motion of a single particle of air by plotting on a flat surface. Let distances to the right of the vertical represent time, and vertical distances represent the distance which the particle has moved through at any time. The motion of the particle would be represented by the wavy line in the figure. Distances above the horizontal correspond to motion in one direction from its position of rest, and distances below the horizontal represent similarly motion in the opposite direction. If we set the air into vibration by means of a bowed violin-string, the shape of the wavy line would be very much *altered, as in the second figure.* To perfectly reproduce sounds is necessary to reproduce the pitch or number of waves per second and the quality or form of these waves, and sufficient wideness of

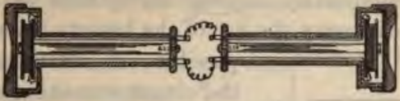




vibration (distance above and below the horizontal line) to affect the listening ear.

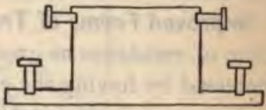
The telephonic transmission of speech between two points may be best considered in two parts: 1. The transmitter, which produces in the wires connecting the two points a varying current whose curve of variation, if plotted, has the same number of vibrations per second, and whose form is the same as that of the sound waves which strike upon the diaphragm of the transmitter mouthpiece. 2. The receiver, into which comes this varying current, which is made to set a diaphragm into vibrations exactly similar to those of the transmitter diaphragm. The receiver diaphragm, of course, sets the air surrounding it into vibrations similar to those caused by the voice speaking, and the ear of the listener is affected in the same way, though not so strongly as if the speaker were talking directly to him. In the early telephones the transmitters and receivers were identical, but in recent years another type of transmitter has been developed to secure greater loudness. The receiver is, however, still used in nearly its original form, and is known as the *magneto-receiver*.

The magneto-receiver consists of a bar magnet with a short ical pole-piece of soft iron on one end. Mounted on this as an axis is a little wooden spool wound with fine wire. f the spool is a thin circular disk of soft iron. The diagram shows two of these connected by wire ready for talking. Suppose the left-hand one is used as the transmitter and the other

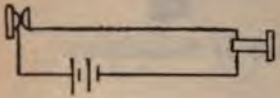


Magneto-receivers used Alternately as Transmitters.

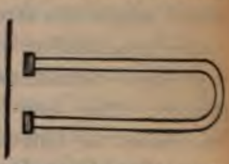
as the receiver, the action is as follows: The voice of the speaker sets the diaphragm of the transmitter into vibration. The motion of the iron near the magnet-pole alters the position and density of the magnetic lines of force enclosed by the coil and sets up a varying electro-motive force in the coil. This produces a current in the line with a similar variation or wave-form to the original sound-wave. This varying current flowing around the coil of the *receiver* causes the strength of its pull on the receiver diaphragm to vary in a similar way, and therefore to set up in the receiver diaphragm vibrations similar to those of the transmitter diaphragm. This sets the surrounding air into similar vibration. This causes the listener's ear to be affected just as if the speaker were talking directly in his ear, although not so loudly. When the speaker has finished he puts the instrument to his ear and listens to the other party. To avoid the necessity of changing, each party may have two telephones, one for talking and the other for listening, connected in series as shown in the diagram.



The Battery Transmitter.—In the magneto-transmitter just described the varying current is produced by setting up an electromotive force whose wave-form of variation is similar to that of the sound-wave producing it. Another way to produce the varying current is to use a constant electro-motive force, but employing *a resistance varied by* the sound-wave and having the same wave-form of variation. It was discovered that the resistance of the point of contact of two pieces of carbon varied exactly with the pressure put upon it, or rather inversely as the pressure put upon it, the conductivity varying exactly with the pressure. By virtue of this discovery the use of the battery transmitter became possible. A current is sent through the circuit consisting of the receiver, line, and carbon contact, as shown in the diagram. One of the carbon pieces is fixed and the other moves with the diaphragm. When the latter is spoken against, its vibrations cause the varying pressures on the contact between the two carbon pieces. This causes the varying resistance, which produces the varying current necessary to transmit speech.

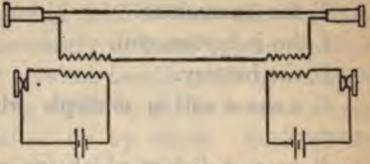

Carbon Transmitter.

Improved Forms of Receiver.—In the later forms the receiver magnet is made of a horseshoe shape, each pole having a spool of wire, it having been found experimentally that with this form a given motion of the diaphragm produces the greatest possible change in the number of lines of force enclosed by the coils.


Horseshoe Magnet Receiver.

Improved Forms of Transmitters.—In order to make the variation of resistance as great as possible the number of contacts is increased by having the circuit pass through a number of small carbon particles against which the diaphragm presses. The designs of such transmitters are exceedingly numerous, the principal difficulties to be overcome being questions of patents and the liability of the carbon particles to pack, which prevents their freedom of movement.

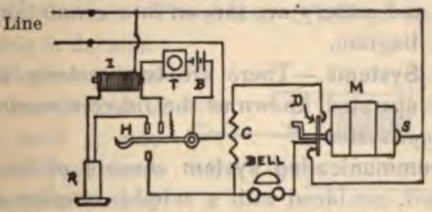
The Induction Coil.—On long lines the resistance of the lines, which is fixed in value, is so much greater than that of the variable carbon c[illegible]at the effect of the latter is practically zero. To ov[illegible]ficulty the induction-coil is used. It consists of a bundle of fine iron wires about three inches long, and wound around these as an axis is a coarse wire coil of about No. 16 wire and a fine wire coil of No. 24 or smaller, according to the length of line. The coil is connected as shown in the diagram, and the effect is so much improved that speech is possible, commercially, over distances as great as 1500 miles. There is no trouble in speaking over greater distances than this were it not for the expense of constructing suitable lines.



Connections using Induction Coils.

Methods of Calling Up.—For short lines a return-call bell system is employed, but for distances over two or three hundred feet either specially wound bells or a *magneto-call* must be used.

The magneto-call consists of a small hand dynamo, which gives alternating currents. These traverse the coils of an electro-magnet whose armature is a permanent magnet, and alternately tip it one way or the other. The armature carries a hammer, which strikes alternately two gongs placed one on each side of it. The method of connecting a telephone instrument with a magneto-call is shown in the diagram, where the letters indicate the following parts:



Connections of a Magneto-call Instrument.

M, the magneto-generator.

R, the receiver, to be hung up on a hook, except when talking.

H, the automatic hook.

T, the transmitter.

I, the induction-coil.

B, the battery.

C, a shunt coil in multiple with bell when magneto is being turned.

D, contact disk to which one end of magneto-armature is connected.

E, end of armature shaft to which other end of armature coil is connected.

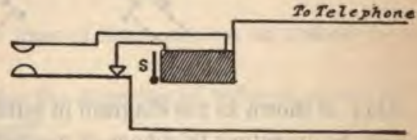
The diagram shows the condition of things when no one is talking. With no one talking the call-bell only is in circuit with the line wires. When the operator at this instrument wants to call up No. 2 he turns the handle of the magneto. This pushes over the armature a little to the right and closes the contact at *D*, breaking contact at the hook-shaped contact opposite *D* on the disk, and throws his generator on to the line, so that it rings his bell and that of No. 2. When both receivers are taken off the hook the bells and magnetos are cut out of circuit and the induction-coil, receiver, and battery are thrown into connection, as will be seen from the diagram.

Telephone Systems.—There are two systems under which telephones are operated, known as the *intercommunicating* system and the *exchange* system.

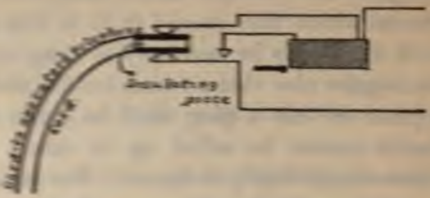
The intercommunicating system consists of instruments as above described, combined with a suitable number of wires running to all instruments, and at each instrument such a form of pr[illegible]tical-contact changing switch as to enable each telephone [illegible] call up any particular station without interfering with [illegible] who may be talking. There are numerous examples of [illegible]s, only a few of which are satisfactory. All of them [illegible]nany wires running to all telephones as there are telephones in the system, plus two wires in addition, while some of the systems require three wires. They may be operated with a battery or magneto-call, though usually using the former. The vital requirement which they should fulfil is that after finishing conversation it shall only be necessary to hang up the receiver. Some systems require also that a switch-handle shall be returned to the same place or that a plug shall be put in a certain hole, else that station cannot be called up by others. Such an arrangement, however, is fatally defective. For numbers above fifteen or twenty it is rarely desirable to use the intercommunicating system, although much larger systems are in operation.

Exchange System.—In such systems two (or sometimes three) wires run from each telephone to a central point, at which an operator sits, whose duty it is to connect the lines of any two telephones by means of a convenient switch-board and to disconnect them when they have finished talking. The connections are made through a pair of flexible cords, called talking cords, which are attached to plug-shaped pieces. The signals of the person calling may be made on an ordinary annunciator if a battery call is used; but as in general a magneto-call is employed, a special form of drop is used.

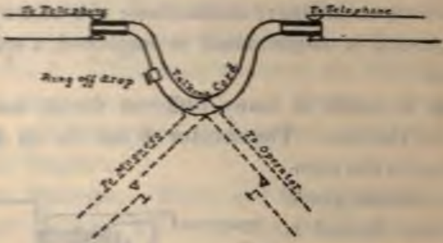
The drop is made in many different forms, one of which is illustrated in the cut. The shutter *S* has on its face a number corresponding to the number of the telephone whose wires lead into it and is hinged in such a way that when a current passes through the coil of the drop a catch attached to the armature of the coil is moved out of the way and the shutter falls, calling the attention of the operator to that particular subscriber. The operator puts one of a pair of talking cords in connection with the calling telephone, as shown in the second cut. The *plug when* pushed into the drop separates the *two contact-pieces and one* wire of the cord is connected to one side



of the line and the other wire of the cord to the other side of the line. It will also be noticed that the coil is cut out of circuit by the



spreading action of the plug. The operator asks what number is wanted, and on receiving a reply puts the plug on the other end of the cord into the drop of the number wanted and presses a key or throws a switch, which for a moment disconnects the cord from the caller's line. Then she connects a magneto-call to the talking cord and rings up the party desired. Then releasing the key or switch she throws the two subscribers into connection with each



other, as shown in the diagram in solid line. The dotted lines show how the operator's telephone or magneto may be thrown in by pushing the proper keys. When the two parties have finished talking each hangs up his receiver and gives a partial turn to the handle of his magneto. This will make the shutter of the ring-off drop l tell the operator that that particular talking-cord is no use. She then takes out the plugs and restores the ring hutter and the shutters of the other two drops to their vertical positions, ready to receive new signals. There are, of course, several talking-cords, so that any number of pairs of subscribers may talk together without interfering with each other.

In large exchanges numerous additions and modifications to such an arrangement are made in order to make the operation of the board quicker and less liable to error. For example, the falling of a shutter is made to close an auxiliary circuit and ring a bell or light a lamp to call the operator's attention, and a power generator is used so that simply pressing a key tends to send a ringing current on to the line to which the talking-cord is connected, etc.

QUESTIONS.

How may an electric current be produced?

What is a battery?

What metal is usually employed for one pole of a battery?

What kind of a solution is generally employed?

What are some of the effects which an electric current will produce.

What is an *anode?* A *cathode?*

How can the direction in which an electric current flows be determined?

What is a galvanometer, and how is it made?

What are lines of magnetic force? How may they be observed?

What is produced when lines of force are cut or crossed by a conductor?

What is Fleming's rule for the direction of induced currents?

What is an electro-magnet?

What is the fundamental experiment on which the electric motor is based?

Explain how the idea of electrical resistance has arisen?

What does e. m. f. mean?

What are the three principal electrical units, and what are their *names?*

What is a kilowatt?

What are the laws governing resistance?

What is conductivity?

Define specific resistance.

What effect does a change in temperature have on resistance?

For what purpose is an insulator used?

What is the relation of heating effect to current strength?

Define electro-chemical equivalent.

How much silver will be deposited in one second by a current of one ampère?

Describe the general process of electro-plating.

How may an electro-motive force be produced?

Give an example of some values used in practice.

What is Ohm's law?

Describe the method of measuring a current.

How would you measure voltage? How a low resistance?

How would you measure a high resistance?

Describe the measurement of power.

What is the principle on which the Edison meter operates?

What is a storage battery?

What is an open-circuit battery? Describe one.

Describe the Daniell cell. The Edison-Lalande. For what kinds of work is each of these cells suited?

When would you use a bichromate cell?

How would you amalgamate a zinc plate?

By analogy how may a dynamo be regarded?

Describe an ideal simple dynamo with commutator.

What is the difference between a ring and a drum armature?

Why are armatures slotted? Why laminated?

What is a multipolar dynamo, and why is it made?

What is a series dynamo? A shunt dynamo? A compound?

What is a characteristic? Draw the characteristics of the three types mentioned.

What is meant by over-compounding, and why is it done?

How is the regulation of a shunt machine accomplished?

What is a switchboard, and for what is it used?

Describe the ground detector.

Explain the purpose and action of a circuit-breaker.

Explain how to run two dynamos in multiple.

Describe the series system of distribution. State disadvantages.

Describe the parallel system and state its advantages.

What are *feeders? Mains? Branches?*

Describe the Edison three-wire system. What advantage has it?

Explain how to calculate the size of wire for a given distance, current, and drop.

Why are high electric pressures used?

Explain the methods used in insulating conductors.

Describe the various methods used in carrying electrical conductors.

What is a fuse, and what is its purpose? What is a cut-out?

Describe the various kinds of switches.

What is a socket? A receptacle? Describe the Chapman.

Why are insulating joints used?

What is a dimmer?

What is a 2000-c. p. arc lamp?

What must all satisfactory lamps do?

What is an enclosed arc, and what are its advantages?

Describe the incandescent lamp and its manufacture.

What candle-powers and voltages are commonly made?

What is meant by the efficiency of a lamp?

How does it vary with the life?

When is it desirable to use a high efficiency lamp?

What is the unit of illumination, the candle-foot?

How does intensity of illumination vary with the distance?

What is the effect of color on the amount of light reflected?

Show the advantage of scattered lights over the same number massed at one point.

What difference exists between a dynamo and a motor?

For what purpose is a series motor used?

When is a shunt motor desirable?

How is speed regulation obtained with a series motor? How with a shunt motor?

Explain why a starting-box is needed for motors on constant potential circuits.

Explain what protective devices are needed.

What is a motor-generator? What are its principal uses?

Describe the *chloride* accumulator or storage battery.

How can you tell which plates are positive and which negative?

Describe the phenomena of charge and discharge and show the variation of pressure at the cell terminals.

What is an ampère hour?

How does the rate of discharge affect the efficiency and capacity of a storage cell?

What are the principal troubles of storage cells? State the advantages of using them.

Describe an electric bell, both single-stroke and vibrating.

What is a buzzer?

Describe an annunciator system. How does the return-call system differ?

Explain the operation of a fire-alarm attachment.

What modifications are made for a burglar-alarm system?

Explain a watchman's time-detector system?

What are the advantages of the magneto system?

What batteries would you use for an annunciator system? What kinds of wire are used, and how carried?

How is sound produced? What are its three qualities?

What is necessary in order to reproduce a certain sound?

Explain the magneto receiver.

Explain the telephone transmission of speech by means of it.

Describe the battery transmitter.

What improvements have been made in receivers? What in transmitters?

What is an induction coil, and for what purpose is it used?

Explain the magneto-call system.

W[illegible] an intercommunicating telephone system?

PART X.

RULES AND TABLES USED IN CALCULATION.

CHAPTER XXXVIII.

Arithmetic is the art of computation with numbers or known antities. It comprises various operations, such as addition, subaction, multiplication, division, powers, roots, ratio, proportion, c.*

Signification of Signs Used in Calculations.

$=$	signifies	Equality,	as	3 added to $2 = 5$.
$+$	"	Addition,	"	$4 + 2 = 6$.
$-$	"	Subtraction,	"	$7 - 4 = 3$.
$\times$	"	Multiplication,	"	$6 \times 2 = 12$.
$\div$	"	Division,	"	$16 \div 4 = 4$.
: : : :	"	Proportion,	"	2 is to 3 so is 4 to 6.
$\surd$	"	Square Root,	"	$\sqrt{16} = 4$.
$\sqrt[3]{}$	"	Cube Root,	"	$\sqrt[3]{64} = 4$.
3^2	"	3 is to be squared,	"	$3^2 = 9$.
3^3	"	3 is to be cubed,	"	$3^3 = 27$.

$(2 + 5)\,4 = 28$ signifies that if two and five are added together and their sum multiplied by four the product equals twenty-eight.

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* It is assumed that the user of this book is familiar with the simpler erations, such as addition, subtraction, multiplication, etc., and hence ose are not taken up. The rules given in this chapter are intended only refresh the memory. Those who desire a thorough treatment of the subct are *referred to Greenleaf's* Arithmetic.

+ plus, means that the number after it is to be *added* to the number before it: thus, 5 + 4 are 9.

− minus, means that the number after it is to be *subtracted* from the number before it: thus, 5 − 4 is 1.

× multiplied by, means that the number before it is to be *multiplied* by the number after it: thus, 9 × 3 are 27.

÷ divided by, means that the number before it is to be *divided* by the number after it: thus, 9 ÷ 3 are 3.

= equal to, means that the quantity after it is of the same value as the quantity before it: thus, 5 + 6 = 11.

There are two systems of notation used in arithmetic, the *Arabic* and the Roman. The former is the familiar one, based on the figures

1, 2, 3, 4, 5, 6, 7, 8, 9, 0,

any two or more of which joined together make a number. The Roman is no longer used in calculations but is frequently employed in numbering. One of the principal defects of this system is that it has no symbol for the cipher.

ROMAN NOTATION.

The following ten characters represent in Roman notation the numbers from one to ten, viz.:

I. II. III. IV. V. VI. VII. VIII. IX. X.

Larger numbers are made up by combining these signs thus: eleven, XI; twelve, XII; thirteen, XIII; twenty-one, XXI, etc. The table of Arabic and Roman equivalents will make this clear.

Arabic.	Roman.	Arabic.	Roman.	Arabic.	Roman.
13	XIII	20	XX	70	LXX
14	XIV	21	XXI	80	LXXX
15	XV	30	XXX	90	XC
16	XVI	40	XL	91	XCI
17	XVII	50	L	100	C
	XVIII	60	LX	101	CI
	XIX	61	LXI	102	CII

Ratio.

Ratio is the relation as to magnitude which one number bears o another, thus

$$6:3$$

s read 6 is to 3, and means the numerical relation which 6 bears o 3. The ratio of two quantities is measured by the quotient obained in dividing the one by the other. For this reason it may lso be written in the form of a fraction thus:

$$6:3=\frac{6}{3}=2;$$

hat is, the ratio of 6 to 3 is equal to 6 divided by 3, which equals 2.

Proportion.

Proportion is an expression of equality between two ratios, thus

$$6:3=4:2$$

is a proportion, which may also be written

$$6:3::4:2$$

or

$$\frac{6}{3}=\frac{4}{2}$$

It will be observed that every proportion must consist of four terms, of which the two outer ones are called the *extremes* and the two inner ones the *means*. Thus in the above proportion 6 and 2 are the extremes, while 3 and 4 are the means. In every true proportion the product of the means must be equal to the product of the extremes; hence if three terms of a proportion are known, the fourth may be found by the

RULE OF THREE.

If two means and one extreme are given, divide the product of he means by the extreme; the quotient will be the other exreme, and *vice versâ*, thus:

$$8:4::\ ?\ :12.$$

To find the other mean, we multiply 8 by 12 and divide by 4.

$$\frac{8 \times 12}{4} = 24.$$

which is the other mean.

Example.—If it requires a 25 horse-power engine to run th tools of a certain kind, how many horse-power will be required t run 24 tools of the same kind?

$$3 : 24 :: 25 : ?$$

$$\frac{24 \times 25}{3} = 200 \text{ horse-power.}$$

Instead of using an interrogation point to represent the unknown term, it is customary to use the letter *x*.

FRACTIONS.

To reduce from common or vulgar fractions to decimal fractions, annex ciphers to the numerator and divide by the denominator. Thus $\frac{1}{16} = 1 \div 16 = .0625$.

TABLE OF VULGAR AND DECIMAL FRACTIONS OF AN INCH.

Vulgar Fractions of an Inch.	Decimal Fractions of an Inch.	Vulgar Fractions of an Inch.	Decimal Fractions of an Inch.	Vulgar Fractions of an Inch.	Decimal Fractions of an Inch.
$\frac{1}{32}$	·03125	$\frac{3}{8}$	·375	$\frac{11}{16}$	·6875
$\frac{1}{16}$	·0625	$\frac{3}{8}$ $\frac{1}{32}$	·40625	$\frac{11}{16}$ $\frac{1}{32}$	·71875
$\frac{1}{16}$ $\frac{1}{32}$	·09375	$\frac{7}{16}$	·4375	$\frac{3}{4}$	·75
$\frac{1}{8}$	·125	$\frac{7}{16}$ $\frac{1}{32}$	·46375	$\frac{3}{4}$ $\frac{1}{32}$	·78125
$\frac{1}{8}$ $\frac{1}{32}$	·15625	$\frac{1}{2}$	·5	$\frac{13}{16}$	·8125
$\frac{3}{16}$	·1875	$\frac{1}{2}$ $\frac{1}{32}$	·53125	$\frac{13}{16}$ $\frac{1}{32}$	84375
$\frac{3}{16}$ $\frac{1}{32}$	·21875	$\frac{9}{16}$	·5625	$\frac{7}{8}$	·875
$\frac{1}{4}$	·25	$\frac{9}{16}$ $\frac{1}{32}$	·59375	$\frac{7}{8}$ $\frac{1}{32}$	·90625
$\frac{1}{4}$ $\frac{1}{32}$	·28125	$\frac{5}{8}$	·625	$\frac{15}{16}$	·9375
$\frac{5}{16}$	·3125	$\frac{5}{8}$ $\frac{1}{32}$	·65625	$\frac{15}{16}$ $\frac{1}{32}$	·96875
$\frac{5}{16}$ $\frac{1}{32}$	·34375				

In the first column $\frac{1}{16}\,\frac{1}{32}$ means $\frac{1}{16} + \frac{1}{32}$; $\frac{1}{8}\,\frac{1}{32}$ means $\frac{1}{8} + \frac{1}{32}$.

Powers.

The power of a number indicates how many times the number s to be multiplied by itself. Thus, 2 to the fourth power means multiplied by itself four times.

$$2 \times 2 \times 2 \times 2 = 16.$$

It is usually written with a small numeral at the top, thus:

3^2, means three to the second power or 3 squared.
3^3, " " third " or 3 cubed.
3^4, " " fourth " etc.

Example.—What is the fifth power of 3?

$$3 \times 3 \times 3 \times 3 \times 3 = 243.$$

Roots.

A root is the reverse of a power; thus the third or cube root of 7 means the number which, multipled by itself three times, vould give a product of 27. Roots are usually written with the umber of which a root is to be extracted under the radical sign $\surd$, with a small numeral indicating which root, thus

$$\sqrt[3]{1728}$$

neans the cube or third root of 1728. If no numeral is placed in he radical, the second or square root is meant.

The square root may be extracted by the following:

Rule.—Separate the given number into as many periods as possible, beginning at the right by placing a mark between the second nd third digits, the fourth and fifth, the sixth and seventh, etc. If he number contains a decimal, begin at the decimal point instead f at the right, and separate as before, going toward the left for he whole number and toward the right for the decimal.

Find the greatest square contained in the left-hand period, write he root of it at the right of the number, and subtract the square rom the left-hand period.

Bring down the next period to the right of the remainder for a ew dividend and double the root already found for a trial divisor. *Find how often this* divisor is contained in the dividend

[illegible]

[illegible] the remainder [illegible] down the [illegible]

[illegible] the periods have been brought [illegible]

[illegible]

[illegible] of cube root of a number may be extracted by the [illegible]

[illegible] periods the same as in square [illegible] contains three instead of two digits. [illegible] greatest [illegible] in the first period and write its root as [illegible] root. From that period subtract [illegible] the remainder bring down the next period for [illegible]

[illegible] of the root figure by three hundred for a [illegible] contained in the dividend, and the result is the next figure of the root.

[illegible] the trial divisor thirty times the product obtained by multiplying the root, excepting the units figure, by the units figure and add the square of the last figure for a true divisor.

Multiply the true divisor by the last figure of the root, subtract the product from the dividend and to the remainder bring down the next period for a new dividend.

Multiply the square of the root figures already found by three hundred for a new trial divisor and proceed as before until all the periods are brought down.

NOTE.—What has been said in the note after the rule for extracting square root applies also to cube root, except that two ciphers must be placed at the right of a true divisor, instead of one, when it is not contained in the corresponding dividend.

Example.—

$$\sqrt[3]{122615.327232}\,?$$

$$\begin{array}{r|l}
 & 122'615.327'232 \;\underline{|\,49.68} \\
 & \underline{64} \\
100 \times 3 \times 4^2 = 4800 & 58615 \\
30 \times 4 \times 9 = 1080 & \\
9^2 = \underline{\quad 81} & 53649 \\
5961 & \\
\hline
300 \times \overline{49}^2 = 720300 & 4966327 \\
30 \times 49 \times 6 = 8820 & \\
6^2 = \underline{\quad 36} & \\
729156 & \underline{4374936} \\
300 \times \overline{496}^2 = 73804800 & 591391232 \\
30 \times 496 \times 8 = 119040 & \\
8^2 = \underline{\quad 64} & \\
73923904 & \underline{591391232}
\end{array}$$

The raising of powers and extraction of roots of numbers may be performed by the aid of *logarithms* much more easily than by common rules given above. An explanation of the use of logarithms will be found further on in this chapter, and the student will be well repaid for the labor required to master them by the aid which he will derive from their employment.

TABLE

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS OF ALL NUMBERS FROM 1 TO 620.

Number.	Square.	Cube.	Square Root.	Cube Root.
1	1	1	1.	1.
2	4	8	1.4142 136	1.2599 21
3	9	27	1.7230 508	1.4422 496
4	16	64	2.	1.5874 011
5	25	125	2.2360 68	1.7099 759
6	36	216	2.4494 897	1.8171 206
7	49	343	2.6457 513	1.9129 312
8	64	512	2.8284 271	2.
9	81	729	3.	2.0800 837
10	1 00	1 000	3.1622 777	2.1544 347
11	1 21	1 331	3.3166 248	2.2239 801
12	1 44	1 728	3.4641 016	2.2894 286
13	1 69	2 197	3.6055 513	2.3513 347
14	1 96	2 744	3.7416 574	2.4101 422
15	2 25	3 375	3.8729 833	2.4662 121
16	2 56	4 096	4.	2.5198 421
17	2 89	4 913	4.1231 056	2.5712 816
18	3 24	5 832	4.2426 407	2.6207 414
19	3 61	6 859	4.3585 989	2.6684 016
20	4 00	8 000	4.4721 36	2.7144 177
21	4 41	9 261	4.5825 757	2.7589 243
22	4 84	10 648	4.6904 158	2.8020 393
23	5 29	12 167	4.7958 315	2.8438 67
24	5 76	13 824	4.8989 795	2.8844 991
25	6 25	15 625	5.	2.9240 177
26	6 76	17 576	5.0990 195	2.9224 96
27	7 29	19 683	5.1961 524	3.
28	7 84	21 952	5.2915 026	3.0365 889
29	8 41	24 389	5.3851 648	3.0723 168
30	9 00	27 000	5.4772 256	3.1072 325
31	9 61	29 791	5.5677 644	3.1413 806
32	10 24	32 768	5.6568 542	3.1748 021
33	10 89	35 937	5.7445 626	3.2075 343
34	11 56	39 304	5.8309 519	3.2396 118
35	12 25	42 875	5.9160 798	3.2710 663
36	12 96	46 656	6.	3.3019 272
37	13 69	50 653	6.0827 625	3.3322 218
38	14 44	54 872	6.1644 14	3.3619 754
39	15 21	59 319	6.2449 98	3.3912 114
40	16 00	64 000	6.3245 553	3.4199 519
41	16 81	68 921	6.4031 242	3.4482 172

TABLE—*(Continued)*

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
42	17 64	74 088	6.4807 407	3.4760 266
43	18 49	79 507	6.5574 385	3.5033 981
44	19 36	85 184	6.6332 496	3.5303 483
45	20 25	91 125	6.7082 039	3.5568 933
46	21 16	97 336	6.7823 3	3.5830 479
47	22 09	103 823	6.8556 546	3.6088 261
48	23 04	110 592	6.9282 032	3.6342 411
49	24 01	117 649	7.	3.6593 057
50	25 00	125 000	7.0710 678	3.6840 314
51	26 01	132 651	7.1414 284	3.7084 298
52	27 04	140 608	7.2111 026	3.7325 111
53	28 09	148 877	7.2801 099	3.7562 858
54	29 16	157 464	7.3484 692	3.7797 631
55	30 25	166 375	7.4161 985	3.8029 525
56	31 36	175 616	7.4833 148	3.8258 624
57	32 49	185 193	7.5498 344	3.8485 011
58	33 64	195 112	7.6157 731	3.8708 766
59	34 81	205 379	7.6811 457	3.8929 965
60	36 00	216 000	7.7459 667	3.9148 676
61	37 21	226 981	7.8102 497	3.9364 972
62	38 44	238 328	7.8740 079	3.9578 915
63	39 69	250 047	7.9372 539	3.9790 571
64	40 96	262 144	8.	4.
65	42 25	274 625	8.0622 577	4.0207 256
66	43 56	287 496	8.1240 384	4.0412 401
67	44 89	300 763	8.1853 528	4.0615 48
68	46 24	314 432	8.2462 113	4.0816 551
69	47 61	328 509	8.3066 239	4.1015 661
70	49 00	343 000	8.3666 003	4.1212 853
71	50 41	357 911	8.4261 498	4.1408 178
72	51 84	373 248	8.4852 814	4.1601 676
73	53 29	389 017	8.5440 037	4.1793 39
74	54 76	405 224	8.6023 253	4.1983 364
75	56 25	421 875	8.6602 54	4.2171 633
76	57 76	438 976	8.7177 979	4.2358 236
77	59 29	456 533	8.7749 644	4.2543 21
78	60 84	474 552	8.8317 609	4.2726 586
79	62 41	493 039	8.8881 944	4.2908 404
80	64 00	512 000	8.9442 719	4.3088 695
81	65 61	531 441	9.	4.3267 487
82	67 24	551 368	9.0553 851	4.3444 815
83	68 89	571 787	9.1104 336	4.3620 707

TABLE—(*Continued*)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
84	70 56	592 704	9.1651 514	4.3795 191
85	72 25	614 125	9.2195 445	4.3968 296
86	73 96	636 056	9.2736 185	4.4140 049
87	75 69	658 503	9.3273 791	4.4310 476
88	77 44	681 472	9.3808 315	4.4479 602
89	79 21	704 969	9.4339 811	4.4647 451
90	81 00	729 000	9.4868 33	4.4814 047
91	82 81	753 571	9.5393 92	4.4979 414
92	84 64	778 688	9.5916 63	4.5143 574
93	86 49	804 357	9.6436 508	4.5306 549
94	88 36	830 584	9.6953 597	4.5468 359
95	90 25	857 375	9.7467 943	4.5629 026
96	92 16	884 736	9.7979 59	4.5788 57
97	94 09	912 673	9.8488 578	4.5947 009
98	96 04	941 192	9.8994 949	4.6104 363
99	98 01	970 299	9.9498 744	4.6260 65
100	1 00 00	1 000 000	10.	4.6415 888
101	1 02 01	1 030 301	10.0498 756	4.6570 095
102	1 04 04	1 061 208	10.0995 049	4.6723 287
103	1 06 09	1 092 727	10.1488 916	4.6875 482
104	1 08 16	1 124 864	10.1980 39	4.7026 694
105	1 10 25	1 157 625	10.2469 508	4.7176 94
106	1 12 36	1 191 016	10.2956 301	4.7326 235
107	1 14 49	1 225 043	10.3440 804	4.7474 594
108	1 16 64	1 259 712	10.3923 048	4.7622 032
109	1 18 81	1 295 029	10.4403 065	4.7768 562
110	1 21 00	1 331 000	10.4880 885	4.7914 199
111	1 23 21	1 367 631	10.5356 538	4.8058 995
112	1 25 44	1 404 928	10.5830 052	4.8202 845
113	1 27 69	1 442 897	10.6301 458	4.8345 881
114	1 29 96	1 481 544	10.6770 783	4.8488 076
115	1 32 25	1 520 875	10.7238 053	4.8629 442
116	1 34 56	1 560 896	10.7703 296	4.8769 99
117	1 36 89	1 601 613	10.8166 538	4.8909 732
118	1 39 24	1 643 032	10.8627 805	4.9048 681
119	1 41 61	1 685 159	10.9087 121	4.9186 847
120	1 44 00	1 728 000	10.9544 512	4.9324 242
121	1 46 41	1 771 561	11.	4.9460 874
122	1 48 34	1 815 848	11.0453 61	4.9596 757
123	1 51 29	1 860 867	11.0905 365	4.9731 898
124	1 53 76	1 906 624	11.1355 287	4.9866 31
125	1 56 25	1 953 125	11.1803 399	5.

TABLE—(*Continued*)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
126	1 58 76	2 000 376	11.2249 722	5.0132 979
127	1 61 29	2 048 383	11.2694 277	5.0265 257
128	1 63 84	2 097 152	11.3137 085	5.0396 842
129	1 66 41	2 146 689	11.3578 167	5.0527 743
130	1 69 00	2 197 000	11.4017 543	5.0657 97
131	1 71 61	2 248 091	11.4455 231	5.0787 531
132	1 74 24	2 299 968	11.4891 253	5.0916 434
133	1 76 89	2 352 637	11.5325 626	5.1044 687
134	1 79 56	2 406 104	11.5758 369	5.1172 299
135	1 82 25	2 460 375	11.6189 5	5.1299 278
136	1 84 96	2 515 456	11.6619 038	5.1425 632
137	1 87 69	2 571 353	11.7046 999	5.1551 367
138	1 90 44	2 628 072	11.7473 401	5.1676 493
139	1 93 21	2 685 619	11.7898 261	5.1801 015
140	1 96 00	2 744 000	11.8321 596	5.1924 941
141	1 98 81	2 803 221	11.8743 421	5.2048 279
142	2 01 64	2 863 288	11.9163 753	5.2171 034
143	2 04 49	2 924 207	11.9582 607	5.2293 215
144	2 07 36	2 985 984	12.	5.2414 828
145	2 10 25	3 048 625	12.0415 946	5.2535 879
146	2 13 16	3 112 136	12.0830 46	5.2656 374
147	2 16 09	3 176 523	12.1243 557	5.2776 321
148	2 19 04	3 241 792	12.1655 251	5.2895 725
149	2 22 01	3 307 949	12.2065 556	5.3014 592
150	2 25 00	3 375 000	12.2474 487	5.3132 928
151	2 28 01	3 442 951	12.2882 057	5.3250 74
152	2 31 04	3 511 008	12.3288 28	5.3368 033
153	2 34 09	3 581 577	12.3693 169	5.3484 812
154	2 37 16	3 652 264	12.4096 736	5.3601 084
155	2 40 25	3 723 875	12.4498 996	5.3716 854
156	2 43 36	3 796 416	12.4899 96	5.3832 126
157	2 46 49	3 869 893	12.5299 641	5.3946 907
158	2 49 64	3 944 312	12.5698 051	5.4061 202
159	2 52 81	4 019 679	12.6095 202	5.4175 015
160	2 56 00	4 096 000	12.6491 106	5.4288 352
161	2 59 21	4 173 281	12.6885 775	5.4401 218
162	2 62 44	4 251 528	12.7279 221	5.4513 618
163	2 65 69	4 330 747	12.7671 453	5.4625 556
164	2 68 96	4 410 944	12.8062 485	5.4737 037
165	2 72 25	4 492 125	12.8452 326	5.4848 066
166	2 75 56	4 574 296	12.8840 987	5.4958 647
167	2 78 89	4 657 463	12.9228 48	5.5068 784

TABLE—*(Continued)*

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
252	6 35 04	16 003 008	15.8745 079	6.3163 596
253	6 40 09	16 194 277	15.9059 737	6.3247 035
254	6 45 16	16 387 064	15.9373 775	6.3330 256
255	6 50 25	16 581 375	15.9687 194	6.3413 257
256	6 55 36	16 777 216	16.	6.3496 042
257	6 60 49	16 974 593	16.0312 195	6.3578 611
258	6 65 64	17 173 512	16.0623 784	6.3660 968
259	6 70 81	17 373 979	16.0934 769	6.3743 111
260	6 76 00	17 576 000	16.1245 155	6.3825 043
261	6 81 21	17 779 581	16.1554 944	6.3906 765
262	6 86 44	17 984 728	16.1864 141	6.3988 279
263	6 91 69	18 191 447	16.2172 747	6.4069 585
264	6 96 96	18 399 744	16.2480 768	6.4150 687
265	7 02 25	18 609 625	16.2788 206	6.4231 583
266	7 07 56	18 821 096	16.3095 064	6.4312 276
267	7 12 89	19 034 163	16.3401 346	6.4392 767
268	7 18 24	19 248 832	16.3707 055	6.4473 057
269	7 23 61	19 465 109	16.4012 195	6.4553 148
270	7 29 00	19 683 000	16.4316 767	6.4633 041
271	7 34 41	19 902 511	16.4620 776	6.4712 736
272	7 39 84	20 123 648	16.4924 225	6.4792 236
273	7 45 29	20 346 417	16.5227 116	6.4871 541
274	7 50 76	20 570 824	16.5529 454	6.4950 653
275	7 56 25	20 796 875	16.5831 24	6.5029 572
276	7 61 76	21 024 576	16.6132 477	6.5108 3
277	7 67 29	21 253 933	16.6433 17	6.5186 839
278	7 72 84	21 484 952	16.6783 32	6.5265 189
279	7 78 41	21 717 639	16.7032 931	6.5343 351
280	7 84 00	21 952 000	16.7332 005	6.5421 326
281	7 89 61	22 188 041	16.7630 546	6.5499 116
282	7 95 24	22 425 768	16.7928 556	6.5576 722
283	8 00 89	22 665 187	16.8226 038	6.5654 144
284	8 06 56	22 906 304	16.8522 995	6.5731 385
285	8 12 25	23 149 125	16.8819 43	6.5808 443
286	8 17 96	23 393 656	16.9115 345	6.5885 323
287	8 23 69	23 639 903	16.9410 743	6.5962 023
288	8 29 44	23 887 872	16.9705 627	6.6038 545
289	8 35 21	24 137 569	17.	6.6114 89
290	8 41 00	24 389 000	17.0293 864	6.6191 06
291	8 46 81	24 642 171	17.0587 221	6.6267 054
292	8 52 64	24 897 088	17.0880 075	6.6342 874
93	8 58 49	25 153 757	17.1172 428	6.6418 522

TABLE—(*Continued*)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
294	8 64 36	25 412 184	17.1464 282	6.6493 998
295	8 70 25	25 672 375	17.1755 64	6.6569 302
296	8 76 16	25 934 336	17.2046 505	6.6644 437
297	8 82 09	26 198 073	17.2336 879	6.6719 403
298	8 88 04	26 463 592	17.2626 765	6.6794 2
299	8 94 01	26 730 899	17.2916 165	6.6868 831
300	9 00 00	27 000 000	17.3205 081	6.6943 295
301	9 06 01	27 270 901	17.3493 516	6.7017 593
302	9 12 04	27 543 608	17.3781 472	6.7091 729
303	9 18 09	27 818 127	17.4068 952	6.7165 7
304	9 24 16	28 094 464	17.4355 958	6.7239 508
305	9 30 25	28 372 625	17.4642 492	6.7313 155
306	9 36 36	28 652 616	17.4928 557	6.7386 641
307	9 42 49	28 934 443	17.5214 155	6.7459 967
308	9 48 64	29 218 112	17.5499 288	6.7533 134
309	9 54 81	29 503 609	17.5783 958	6.7606 143
310	9 61 00	29 791 000	17.6068 169	6.7678 995
311	9 67 21	30 080 231	17.6151 921	6.7751 69
312	9 73 44	30 371 328	17.6635 217	6.7824 229
313	9 79 69	30 664 297	17.6918 06	6.7896 613
314	9 85 96	30 959 144	17.7200 451	6.7968 844
315	9 92 25	31 255 875	17.7482 393	6.8040 921
316	9 98 56	31 554 496	17.7763 888	6.8112 847
317	10 04 89	31 855 013	17.8044 938	6.8184 62
318	10 11 24	32 157 432	17.8325 545	6.8256 242
319	10 17 61	32 461 759	17.8605 711	6.8327 714
320	10 24 00	32 768 000	17.8885 438	6.8399 037
321	10 30 41	33 076 161	17.9164 729	6.8470 213
322	10 36 84	33 386 248	17.9443 584	6.8541 24
323	10 43 29	33 698 267	17.9722 008	6.8612 12
324	10 49 76	34 012 224	18.	6.8682 855
325	10 56 25	34 328 125	18.0277 564	6.8753 433
326	10 62 76	34 645 976	18.0554 701	6.8823 888
327	10 69 29	34 965 783	18.0831 413	6.8894 188
328	10 75 84	35 287 552	18.1107 703	6.8964 345
329	10 82 41	35 611 289	18.1383 571	6.9034 359
330	10 89 00	35 937 000	18.1659 021	6.9104 232
331	10 95 61	36 264 691	18.1934 054	6.9173 964
332	11 02 24	36 594 368	18.2208 672	6.9243 556
333	11 08 89	36 926 037	18.2482 876	6.9313 088
334	11 15 56	37 259 704	18.2756 669	6.9382 321
335	11 22 25	37 595 375	18.3030 052	6.9451 496

TABLE—(Continued)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
420	17 64 00	74 088 000	20.4939 015	7.4888 724
421	17 72 41	74 618 461	20.5182 845	7.4948 113
422	17 80 84	75 151 448	20.5426 386	7.5007 406
423	17 89 29	75 686 967	20.5669 638	7.5066 607
424	17 97 76	76 225 024	20.5912 603	7.5125 715
425	18 06 25	76 765 625	20.6155 281	7.5184 73
426	18 14 76	77 308 776	20.6397 674	7.5243 652
427	18 23 29	77 854 483	20.6639 783	7.5302 482
428	18 31 84	78 402 752	20.6881 609	7.5361 221
429	18 40 41	78 953 589	20.7123 152	7.5419 867
430	18 49 00	79 507 000	20.7364 414	7.5478 423
431	18 57 61	80 062 991	20.7605 395	7.5536 888
432	18 66 24	80 621 568	20.7846 097	7.5595 263
433	18 74 89	81 182 737	20.8086 52	7.5653 548
434	18 83 56	81 746 504	20.8326 667	7.5711 743
435	18 92 25	82 312 875	20.8566 536	7.5769 849
436	19 00 96	82 881 856	20.8806 13	7.5827 865
437	19 09 69	83 453 453	20.9045 45	7.5885 793
438	19 18 44	84 027 672	20.9284 495	7.5943 633
439	19 27 21	84 604 519	20.9523 268	7.6001 385
440	19 36 00	85 184 000	20.9761 77	7.6059 049
441	19 44 81	85 766 121	21.	7.6116 626
442	19 53 64	86 350 888	21.0237 96	7.6174 116
443	19 62 49	86 938 307	21.0475 652	7.6231 519
444	19 71 36	87 528 384	21.0713 075	7.6288 837
445	19 80 25	88 121 125	21.0950 231	7.6346 067
446	19 89 16	88 716 536	21.1187 121	7.6403 213
447	19 98 09	89 314 623	21.1423 745	7.6460 272
448	20 07 04	89 915 392	21.1660 105	7.6517 247
449	20 16 01	90 518 849	21.1896 201	7.6574 138
450	20 25 00	91 125 000	21.2132 034	7.6630 943
451	20 34 01	91 733 851	21.2367 606	7.6687 665
452	20 43 04	92 345 408	21.2602 916	7.6744 303
453	20 52 09	92 959 677	21.2837 967	7.6800 857
454	20 61 16	93 576 664	21.3072 758	7.6857 328
455	20 70 25	94 196 375	21.3307 29	7.6913 717
456	20 79 36	94 818 816	21.3541 565	7.6970 023
457	20 88 49	95 443 993	21.3775 583	7.7026 246
[illegible]	20 97 64	96 071 912	21.4009 346	7.7082 388
[illegible]	21 06 81	96 702 579	21.4242 853	7.7138 448
[illegible]	21 16 00	97 336 000	21.4476 106	7.7194 426
[illegible]	21 25 21	97 972 181	21.4709 106	7.7250 325

TABLE—(*Continued*)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
462	21 34 44	98 611 128	21.4941 853	7.7306 141
463	21 43 69	99 252 847	21.5174 348	7.7361 877
464	21 52 96	99 897 344	21.5406 592	7.7417 532
465	21 62 25	100 544 625	21.5638 587	7.7473 109
466	21 71 56	101 194 696	21.5870 331	7.7528 606
467	21 80 89	101 847 563	21.6101 828	7.7584 023
468	21 90 24	102 503 232	21.6333 077	7.7639 361
469	21 99 61	103 161 709	21.6564 078	7.7694 62
470	22 09 00	103 823 000	21.6794 834	7.7749 801
471	22 18 41	104 487 111	21.7025 344	7.7804 904
472	22 27 84	105 154 048	21.7255 31	7.7859 928
473	22 37 29	105 823 817	21.7485 632	7.7914 875
474	22 46 76	106 496 424	21.7715 411	7.7969 745
475	22 56 25	107 171 875	21.7944 947	7.8024 538
476	22 65 76	107 850 176	21.8174 242	7.8079 254
477	22 75 29	108 531 333	21.8403 297	7.8133 892
478	22 84 84	109 215 352	21.8632 111	7.8188 456
479	22 94 41	109 902 239	21.8860 686	7.8242 942
480	23 04 00	110 592 000	21.9089 023	7.8297 353
481	23 13 61	111 284 641	21.9317 122	7.8351 688
482	23 23 24	111 980 168	21.9544 984	7.8405 949
483	23 32 89	112 678 587	21.9772 61	7.8460 134
484	23 42 56	113 379 904	22.	7.8514 244
485	23 52 25	114 084 125	22.0227 155	7.8568 281
486	23 61 96	114 791 256	22.0454 077	7.8622 242
487	23 71 69	115 501 303	22.0680 765	7.8676 13
488	23 81 44	116 214 272	22.0907 22	7.8729 944
489	23 91 21	116 930 169	22.1133 444	7.8783 684
490	24 01 00	117 649 000	22.1359 436	7.8837 352
491	24 10 81	118 370 771	22.1585 198	7.8890 946
492	24 20 64	119 095 488	22.1810 73	7·8944 468
493	24 30 49	119 823 157	22.2036 033	7.8997 917
494	24 40 36	120 553 784	22.2261 108	7.9051 294
495	24 50 25	121 287 375	22.2485 955	7.9104 599
496	24 60 16	122 023 936	22.2710 575	7.9157 832
497	24 70 09	122 763 473	22.2934 968	7.9210 994
498	24 80 04	123 505 992	22.3159 136	7.9 085
499	24 90 01	124 251 499	22.3383 079	7.9
500	25 00 00	125 000 000	22.3606 798	7.
501	25 10 01	125 751 501	22.3830 293	7
502	25 20 04	126 506 008	22.4053 565	7
503	25 30 09	127 263 527	22.4276 615	

TABLE—(Continued)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
504	25 40 16	128 024 064	22.4499 443	7.9581 144
505	25 50 25	128 787 625	22.4722 051	7.9633 743
506	25 60 36	129 554 216	22.4944 438	7.9686 271
507	25 70 49	130 323 843	22.5166 605	7.9738 731
508	25 80 64	131 096 512	22.5388 553	7.9791 122
509	25 90 81	131 872 229	22.5610 283	7.9843 444
510	26 01 00	132 651 000	22.5831 796	7.9895 697
511	26 11 21	133 432 831	22.6053 091	7.9947 883
512	26 21 44	134 217 728	22.6274 17	8.
513	26 31 69	135 005 697	22.6495 033	8.0052 049
514	26 41 96	135 796 744	22.6715 681	8.0104 032
515	26 52 25	136 590 875	22.6936 114	8.0155 946
516	26 62 56	137 388 096	22.7156 334	8.0207 794
517	26 72 89	138 188 413	22.7376 340	8.0259 574
518	26 83 24	138 991 832	22.7596 134	8.0311 287
519	26 93 61	139 798 359	22.7815 715	8.0362 935
520	27 04 00	140 608 000	22.8035 085	8.0414 515
521	27 14 41	141 420 761	22.8254 244	8.0466 03
522	27 24 84	142 236 648	22.8473 193	8.0517 479
523	27 35 29	143 055 667	22.8691 933	8.0568 862
524	27 45 76	143 877 824	22.8910 463	8.0620 18
525	27 56 25	144 703 125	22.9128 785	8.0671 432
526	27 66 76	145 531 576	22.9346 899	8.0722 62
527	27 77 29	146 363 183	22.9564 806	8.0773 743
528	27 87 84	147 197 952	22.9782 506	8.0824 8
529	27 98 41	148 035 889	23.	8.0875 794
530	28 09 00	148 877 000	23.0217 289	8.0926 723
531	28 19 61	149 721 291	23.0434 372	8.0977 589
532	28 30 24	150 568 768	23.0651 252	8.1028 39
533	28 40 89	151 419 437	23.0867 928	8.1079 128
534	28 51 56	152 273 304	23.1084 4	8.1129 803
535	28 62 25	153 130 375	23.1300 67	8.1180 414
536	28 72 96	153 990 656	23.1516 738	8.1230 962
537	28 83 69	154 854 153	23.1732 605	8.1281 447
538	28 94 44	155 720 872	23.1948 37	8.1331 87
539	29 05 21	156 590 819	23.2163 735	8.1382 23
540	29 16 00	157 464 000	23.2379 001	8.1432 529
541	29 26 81	158 340 421	23.2594 067	8.1482 765
542	29 37 64	159 220 088	23.2808 935	8.1532 939
543	29 48 49	160 103 007	23.3023 604	8.1583 051
544	29 59 36	160 989 184	23.3238 076	8.1633 102
545	29 70 25	161 878 625	23.3452 351	8.1683 092

TABLE—*(Continued)*

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
546	29 81 16	162 771 336	23.3666 429	8.1733 02
547	29 92 09	163 667 323	23.3880 311	8.1782 888
548	30 03 04	164 566 592	23.4093 998	8.1832 695
549	30 14 01	165 469 149	23.4307 49	8.1882 441
550	30 25 00	166 375 000	23.4520 788	8.1932 127
551	30 36 01	167 284 151	23.4733 892	8.1981 753
552	30 47 04	168 196 608	23.4946 802	8.2031 319
553	30 58 09	169 112 377	23.5159 52	8.2080 825
554	30 69 16	170 031 464	23.5372 046	8.2130 271
555	30 80 25	170 953 875	23.5584 38	8.2179 657
556	30 91 36	171 879 616	23.5796 522	8.2228 985
557	31 02 49	172 808 693	23.6008 474	8.2278 254
558	31 13 64	173 741 112	23.6220 236	8.2327 463
559	31 24 81	174 676 879	23.6431 808	8.2376 614
560	31 36 00	175 616 000	23.6643 191	8.2425 706
561	31 47 21	176 558 481	23.6854 386	8.2474 74
562	31 58 44	177 504 328	23.7065 392	8.2523 715
563	31 69 69	178 453 547	23.7276 21	8.2572 635
564	31 80 96	179 406 144	23.7486 842	8.2621 492
565	31 92 25	180 362 125	23.7697 286	8.2670 294
566	32 03 56	181 321 496	23.7907 545	8.2719 039
567	32 14 89	182 284 263	23.8117 618	8.2767 726
568	32 26 24	183 250 432	23.8327 506	8.2816 255
569	32 37 61	184 220 009	23.8537 209	8.2864 928
570	32 49 00	185 193 000	23.8746 728	8.2913 444
571	32 60 41	186 169 411	23.8956 063	8.2961 903
572	32 71 84	187 149 248	23.9165 215	8.3010 304
573	32 83 29	188 132 517	23.9374 184	8.3058 651
574	32 94 76	189 119 224	23.9582 971	8.3106 941
575	33 06 25	190 109 375	23.9791 576	8.3155 175
576	33 17 76	191 102 976	24.	8.3203 353
577	33 29 29	192 100 033	24.0208 243	8.3251 475
578	33 40 84	193 100 552	24.0416 306	8.3299 542
579	33 52 41	194 104 539	24.0624 188	8.3347 553
580	33 64 00	195 112 000	24.0831 891	8.3395 509
581	33 75 61	196 122 941	24.1039 416	8.3443 41
582	33 87 24	197 137 368	24.1246 762	8.3491 256
583	33 98 89	198 155 287	24.1453 929	8.3539 047
584	34 10 56	199 176 704	24.1660 919	8.3586 784
585	34 22 25	200 201 625	24.1867 732	8.3634 466
586	34 33 96	201 230 056	24.2074 369	8.3682 095
587	34 45 69	202 262 003	24.2280 829	8.3729 668

TABLE—(*Concluded*)

OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS, ETC.

Number.	Square.	Cube.	Square Root.	Cube Root.
588	34 57 44	203 297 472	24.2487 113	8.3777 188
589	34 69 21	204 336 469	24.2693 222	8.3824 653
590	34 81 00	205 379 000	24.2899 156	8.3872 065
591	34 92 81	206 425 071	24.3104 916	8.3919 423
592	35 04 64	207 474 688	24.3310 501	8.3966 729
593	35 16 49	208 527 857	24.3515 913	8.4013 981
594	35 28 36	209 584 584	24.3721 152	8.4061 180
595	35 40 25	210 644 875	24.3926 218	8.4108 326
596	35 52 16	211 708 736	24.4131 112	8.4155 419
597	35 64 09	212 776 173	24.4335 834	8.4202 46
598	35 76 04	213 847 192	24.4540 385	8.4249 448
599	35 88 01	214 921 799	24.4744 765	8.4296 383
600	36 00 00	216 000 000	24.4948 974	8.4343 267
601	36 12 01	217 081 801	24.5153 013	8.4390 098
602	36 24 04	218 167 208	24.5356 883	8.4436 877
603	36 36 09	219 256 227	24.5560 583	8.4483 605
604	36 48 16	220 348 864	24.5764 115	8.4530 281
605	36 60 25	221 445 125	24.5967 478	8.4576 906
606	36 72 36	222 545 016	24.6170 673	8.4623 479
607	36 84 49	223 648 543	24.6373 7	8.467
608	36 96 64	224 755 712	24.6576 56	8.4716 471
609	37 08 81	225 866 529	24.6779 254	8.4762 892
610	37 21 00	226 981 000	24.6981 781	8.4809 261
611	37 33 21	228 099 131	24.7184 142	8.4855 579
612	37 45 44	229 220 928	24.7386 338	8.4901 848
613	37 57 69	230 346 397	24.7588 368	8.4948 065
614	37 69 96	231 475 544	24.7790 234	8.4994 233
615	37 82 25	232 608 375	24.7991 935	8.5040 35
616	37 94 56	233 744 896	24.8193 473	8.5086 417
617	38 06 89	234 885 113	24.8394 847	8.5132 435
618	38 19 24	236 029 032	24.8596 058	8.5178 403
619	38 31 61	237 176 659	24.8797 106	8.5224 321
620	38 44 00	238 328 000	24.8997 992	8.5270 189

Any number multiplied into itself 3 times is cubed; as, $3\times3\times3=27$, which is the cube of 3.

The square root of any number is that number which, multiplied into itself, will be equal to the given number; as, $\sqrt{9}=3\times3$; hence 3 is the square root of 9.

Use of Letters in Calculation.—It is extremely convenient to present quantities by letters, as has been done in various cases the earlier chapters of this book, as, for example, on pages 7, 8, 2, and 33. On pages 7 and 8 we have the formula $h = g\frac{t^2}{2}$, here

$h =$ height from which a body will fall in any number of seconds.

$t =$ number of seconds it has been falling.

$g =$ acceleration produced by gravity, which by experiment we know to be about 32.2 feet per second.

$\frac{gt^2}{2}$ written out in full would be $\frac{g \times t \times t}{2}$, or, in words, g multiplied y t, again multiplied by t, and the whole divided by 2. The ultiplication signs are omitted in writing a formula, but are ways to be understood.

The little index figure ² placed at the upper right hand of t as the same meaning as when used with a figure.

Thus 3^2 means 3 squared, or 3×3,
and 3^3 " 3 cubed, or $3 \times 3 \times 3$,
so t^2 " t squared, or $t \times t$.

When a letter has a figure in front of it it means that the uantity represented by the letter is to be multiplied by the fig-re. Thus 3 T means $3 \times T$, and if T had a particular value of 4 et, 3 T would equal 12 feet.

Another formula on page 8 is $v = \sqrt{2gh}$. This means that $v =$ he square root of $2 \times g \times h$, or that two times g is multiplied by and the product has its square root taken, and this square root s equal to v.

On page 10 is the formula $F = Ma$, showing the relation be-ween *force*, *mass*, and acceleration. This means that the force is umerically equal to the product of the mass by the acceleration.

[illegible] Formulas

[illegible] equation [illegible] quanti-

[illegible]

$$[illegible]$$

[illegible] more [illegible] The solu- [illegible] value of [illegible] were [illegible]

$$[illegible]$$

[illegible] The fol- [illegible]

[illegible] sides of the equa- [illegible] Thus we may add or [illegible] sides of the equation, [illegible] the same number, raise both [illegible] same power of both sides, [illegible] equation

$$[illegible]$$

[illegible]

$$[illegible]$$

[illegible]

$$[illegible]$$

[illegible] sides

$$[illegible]$$

[illegible]

[illegible] may be transposed from one side [illegible] provided the sign is changed from

---

[illegible] considered in this book. For a more [illegible] any text book of alge- [illegible] Elementary Algebra.

plus to minus, or *vice versa,* in transposing, without disturbing the equality, thus:

$$(4 \times 6) + x = 193 - 131,$$

$$x - 193 = -(4 \times 6) - 131,$$

$$(4 \times 6) + 131 = 193 - x,$$

or

$$(4 \times 6) + x - 193 + 131 = 0,$$

are all equally true.

To solve a simple equation with one unknown quantity, transpose all of the terms containing the unknown quantity to one side of the equation, and all of the remaining terms to the other. Combine the terms and divide both sides by the coefficient of the unknown quantity.

Examples.—Required the value of x in

$$18x - 224 + 113 + x = (24 - x)\,2.$$

Transposing:

$$18x + x - (24 - x)\,2 = 224 - 113.$$

Simplifying:

$$18x + x - 48 + 2x = 224 - 113.$$

Transposing again:

$$18x + x + 2x = 224 + 48 - 113.$$

Combining terms:

$$21x = 159.$$

Dividing both sides by 21, the co-efficient of x,

$$x = 7\tfrac{4}{7}.\text{—}\textit{Answer.}$$

Required the value of x in

$$2x - 3(2x - 3) = 1 - 10(x - 2).$$

Simplifying:

$$2x - 6x + 9 = 1 - 10x + 20.$$

Transposing:

$$2x - 6x + 10x = 20 + 1 - 9.$$

Collecting terms:

$$6x = 12.$$

Dividing by 6, the co-efficient of x,

$$x = 2.\text{—Answer.}$$

Example.—If a certain number is increased by 16, the sum will be seven times as great as one-third of the number. Required the number. Let $x =$ the number.

Then since $(x + 16)$ is seven times as great as one-third of the number, we have

$$(x + 16) = 7 \times \tfrac{1}{3} x,$$

or

$$x + 16 = \frac{7x}{3}.$$

First multiply every term by 3 to clear the equation of fractions:

$$3x + 48 = 7x.$$

Transposing and collecting terms:

$$48 = 4x,$$

and hence

$$x = 12.\text{—}\textit{Answer.}$$

Example.—If the circumference of the driving wheel of a locomotive is 18 feet and that of one of the car wheels 6 feet, how far will the train have moved when the car-wheel has made 500 revolutions more than the driving-wheel?

Let $x =$ the required distance.

For each revolution of the driving-wheel the train moves a distance of 18 feet, and for each revolution of the car wheel the train moves a distance of 6 feet. Hence we have for the number of revolutions made by each, while the train is moving over the distance x,

$$\frac{x}{18} \text{ and } \frac{x}{6} \text{ respectively.}$$

But the required distance x is traversed when the number of revolutions of the latter is 500 more than the former. Hence we write the equation:

$$\frac{x}{18} + 500 = \frac{x}{6}.$$

To clear of fractions, we multiply every term of the equation

$$x + 9000 = 3x.$$

Transposing and combining:

$$2x = 9000,$$

hence $$x = 4500 \text{ feet.—}\textit{Answer.}$$

Examples of Use of Formulas.—On pages 7 and 8 we have $h = \frac{gt^2}{2}$. Suppose we wanted to know how many seconds it would take a falling body to pass over a distance of 1660 feet. t is the quantity for which we want to solve the equation, g being known, and h being given by the conditions of the problem as 1660.

Multiplying both sides of the equation by 2 we have $2h = gt^2$.

Dividing by g we have $t^2 = \frac{2h}{g}$.

Extracting the square root $t = \sqrt{\frac{2h.}{g}}$ This is in the form which we want, in order to get the value of t, which is

$$t = \sqrt{\frac{2 \times 1660}{32.2}} = 10 \text{ seconds.}$$

Logarithms.

Logarithms are intended to simplify the operations of multiplication, division, involution (raising numbers to higher powers), and evolution (extracting roots), by reducing these operations respectively to addition, subtraction, multiplication, and division.

The logarithm of a number is the power to which 10 must be raised to equal that number. It consists of two separate parts, an integral portion, called the *characteristic*, and a decimal portion, called the *mantissa*. In the tables mantissas only are given.

The characteristic or index of the logarithm is always one less than the number of figures in the number which lie to the left of the decimal point; thus take the number 958. From the table the mantissa is .98136, and since the number contains three figures to the left of the decimal point, the characteristic is 2, and hence the complete logarithm is 2.98136. If the number contained only one *figure to the left of the* decimal point, the characteristic would

Annex 9 to 628, making 6289. Since the characteristic is zero, there must be one figure to the left of the decimal; therefore we put the decimal between 6 and 2 and obtain for the answer 6.289 as the number corresponding to the logarithm 0.79804.

To multiply by logarithms:

Rule.—Add together the logarithms of the factors, and the sum will be the logarithm of the product.

Example.—Multiply 79600 × 0.435.

log. 79600 = 4.90091
log. .435 = .63848 − 1
5.53939 − 1 = 4.53939 = log. 34690
34690—*Answer.*

To divide by logarithms:

Rule.—From the logarithm of the dividend deduct the logarithm of the divisor, and the difference will be the logarithm of the quotient.

Examples.—Divide 43800 by 368.

log. 43800 = 4.64147
log. 368 = 2.56584
2.07563 = log. 119
119—*Answer.*

Divide .05638 by 250.

log. .05638 = 0.75112 − 2 = 8.75112 − 10
log. 25 = 2.39794 = 2.39794
6.35318 − 10

Or .35318 − 4 = log. .0002255
.0002255—*Answer.*

to Powers—Involution by Logarithms.—

ltiply the logarithm of the number by the power to be r[illegible] and the product will be the logarithm of number.

Example.—What is the third power of 619?

$$\begin{array}{rl} \log.\ 619 = & 2.79169 \\ & \underline{3} \\ & 8.37507 = \log.\ 23780000.^* \end{array}$$

Extracting Roots—Evolution by Logarithms.—

Rule.—Divide the logarithm of the number by the index of the root which is to be extracted and the quotient will be the logarithm of the required root.

Example.—What is the seventh root of .08937?

$$\log.\ .08937 = 0.95119 - 2.$$

Since the negative index is not evenly divisible by 7, the root to be extracted, it is customary to add a number until it becomes divisible, which may be done without altering the logarithm, thus:

$$\begin{array}{l} \log.\ .08937 = 0.95119 = 5.95119 - 7 \\ \text{Dividing by 7 we have } 0.85017 - 1 = \log.\ \sqrt[7]{.08937} \\ \hfill = \log.\ .70821.\text{—}\textit{Answer.} \end{array}$$

Example.—Find by logarithms the value of

$$\frac{\sqrt{2.1} \times 86 \times \overline{.0034}^2}{86.8 \times \sqrt[4]{150}}$$

$$\begin{array}{rl@{\qquad\qquad}rl} \tfrac{1}{2}\log.\ \ 2.1 = & .16111 & \log.\ 86.8 = & 1.93852 \\ \log.\ \ 86 = & 1.93449 & \tfrac{1}{4}\log.\ 150 = & \underline{.54402} \\ 2\log.\ .0034 = & \underline{1.06296 - 6} & & 2.48254 \\ & 3.15856 - 6 & & \\ & \underline{2.48254} & & \\ & 0.67602 - 6 = \log.\ .000004744.\text{—}\textit{Answer.} & & \end{array}$$

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* As the table is not accurate above 5 places, we must add ciphers at the end of the results until the required number of figures, as indicated by the characteristic, is had.

TABLE

OF LOGARITHMS OF NUMBERS FROM 0 TO 1000.*

N.	0	1	2	3	4	5	6	7	8	9	Prop.
[illegible]	0	00000	30103	47712	60206	69897	77815	84510	90309	95424	
10	00000	00432	00860	01283	01703	02118	02530	02938	03342	03742	415
11	[illegible]	04532	04921	05307	05690	06069	06445	06818	07188	07554	379
[illegible]	[illegible]	[illegible]	08636	08990	09342	09691	10037	10380	10721	11059	349
[illegible]	[illegible]	11727	12057	12385	12710	13033	13353	13672	13987	14301	323
[illegible]	[illegible]	[illegible]	15228	15533	15836	16136	16435	16731	17026	17318	300
[illegible]	[illegible]	[illegible]	18184	18469	18752	19033	19312	19590	19865	20139	281
[illegible]	[illegible]	[illegible]	[illegible]	21218	21484	21748	22010	22271	22530	22788	264
[illegible]	[illegible]	[illegible]	[illegible]	23804	24054	24303	24551	24797	25042	25285	249
[illegible]	[illegible]	[illegible]	[illegible]	26245	26481	26717	26951	27184	27415	27646	236
[illegible]	[illegible]	[illegible]	[illegible]	28555	28780	29003	29225	29446	29666	29885	223
[illegible]	[illegible]	[illegible]	[illegible]	30749	30963	31175	31386	31597	31806	32014	212
[illegible]	[illegible]	[illegible]	[illegible]	32838	33041	33243	33445	33646	33845	34044	202
[illegible]	[illegible]	[illegible]	[illegible]	34830	35024	35218	35410	35602	35793	35983	194
[illegible]	[illegible]	[illegible]	[illegible]	36735	36921	37106	37291	37474	37657	37839	185
[illegible]	[illegible]	[illegible]	[illegible]	38560	38739	38916	39093	39269	39445	39619	177
[illegible]	[illegible]	[illegible]	[illegible]	40312	40483	40654	40824	40993	41162	41330	171
[illegible]	[illegible]	[illegible]	[illegible]	41995	42160	42324	42488	42651	42813	42975	164
[illegible]	[illegible]	[illegible]	[illegible]	43616	43775	43933	44090	44248	44404	44560	158
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45331	45484	45636	45788	45939	46089	153
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46834	46982	47129	47275	47421	47567	148
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48287	[illegible]	48572	48713	48855	48995	143
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50242	50379	138
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51188	51321	51454	51587	51719	134
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	52504	52633	52763	52891	53020	130
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	53781	[illegible]	54033	54157	54282	126
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	55022	55145	55266	55388	55509	122
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	56229	56348	[illegible]	56584	56702	119
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	57287	57403	57519	57634	57749	57863	116
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	58659	58771	58883	58995	113
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59769	59879	59988	60097	110
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60959	61066	61172	107
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	62013	62117	62221	104
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	62941	63042	63144	63245	102
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	64048	64147	64246	99
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	65030	65127	65224	98
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	65896	65991	66086	66181	96
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	66931	67024	67117	94
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	67851	67942	68033	92
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	68752	68842	68930	90
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	69635	69722	69810	88
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	70415	70500	70586	70671	86
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	71349	71433	71516	84
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	72181	72263	72345	82
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	72997	73078	73158	81
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	73798	73878	73957	80
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	74585	74663	74741	78

[illegible] have the decimal sign (.) before it.

TABLE—(*Continued.*)

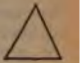
No.	0	1	2	3	4	5	6	7	8	9	Prop.
56	74818	74896	74973	75050	75127	75204	75281	75358	75434	75511	77
57	75587	75663	75739	75815	75891	75966	76042	76117	76192	76267	75
58	76342	76417	76492	76566	76641	76715	76789	76863	76937	77011	74
59	77085	77158	77232	77305	77378	77451	77524	77597	77670	77742	73
60	77815	77887	77959	78031	78103	78175	78247	78318	78390	78461	72
61	78533	78604	78675	78746	78816	78887	78958	79028	79098	79169	71
62	79239	79309	79379	79448	79518	79588	79657	79726	79796	79865	70
63	79934	80002	80071	80140	80208	80277	80345	80413	80482	80550	69
64	80618	80685	80753	80821	80888	80956	81023	81090	81157	81224	68
65	81291	81358	81424	81491	81557	81624	81690	81756	81822	81888	67
66	81954	82020	82805	82151	82216	82282	82347	82412	82477	82542	66
67	82607	82672	82736	82801	82866	82930	82994	83058	83123	83187	65
68	83250	83314	83378	83442	83505	83569	83632	83695	83758	83281	64
69	83884	83947	84010	84073	84136	84198	84260	84323	84385	84447	63
70	84509	84571	84633	84695	84757	84818	84880	84941	85003	85064	62
71	85125	85187	85248	85309	85369	85430	85491	85551	85612	85672	61
72	85733	85793	85853	85913	85973	86033	86093	86153	86213	86272	60
73	86332	86391	86451	86510	86569	86628	86687	86746	86805	86864	59
74	86923	86981	87040	87098	87157	87215	87273	87332	87390	87448	58
75	87506	87564	87621	87679	87737	87794	87852	87909	87966	88024	57
76	88081	88138	88195	88252	88309	88366	88422	88479	88536	88592	56
77	88649	88705	88761	88818	88874	88930	88986	89042	89098	89153	56
78	89209	89265	89320	89376	89431	89487	89542	89597	89652	89707	55
79	89762	89817	89872	89927	89982	90036	90091	90145	90200	90254	54
80	90309	90363	90417	90471	90525	90579	90633	90687	90741	90794	54
81	90848	90902	90955	91009	91062	91115	91169	91222	91275	91328	53
82	91381	91434	91487	91540	91592	91645	91698	91750	91803	91855	53
83	91907	91960	92012	92064	92116	92168	92220	92272	92324	92376	52
84	92427	92479	92531	92582	92634	92685	92737	92788	92839	92890	51
85	92941	92993	93044	93095	93146	93196	93247	93298	93348	93399	51
86	93449	93500	93550	93601	93651	93701	93751	93802	93852	93902	50
87	93951	94001	94051	94101	94151	94200	94250	94300	94349	94398	49
88	94448	94497	94546	94596	94645	94694	94743	94792	94841	94890	49
89	94939	94987	95036	95085	95133	95182	95230	95279	95327	95376	48
90	95424	95472	95520	95568	95616	95664	95712	95760	95808	95856	48
91	95904	95951	95999	96047	96094	96142	96189	96236	96284	96331	48
92	96378	96426	96473	96520	96507	96614	96661	96708	96754	96801	47
93	96848	96895	96941	96988	97034	97081	97127	97174	97220	97266	47
94	97312	97359	97405	97451	97497	97543	97589	97635	97680	97726	46
95	97772	97818	97863	97909	97954	98000	98045	98091	98136	98181	46
96	98227	98272	98317	98362	98407	98452	98497	98542	98587	98632	45
97	98677	98721	98766	98811	98855	98900	98945	98989	99033	99078	45
98	99122	99166	99211	99255	99299	99343	99387	99431	99475	99519	44
99	99563	99607	99657	99694	99738	99782	99825	99869	99913	99956	44

Mensuration of Surfaces and Volumes.

A polygon is a surface bounded by three or more lines which close on each other. These lines are called the sides of the polygon.

Their sum, or the distance around the figure, is called the *perimeter* of the polygon. If the sides and angles are equal, the polygon is said to be *regular*. The following varieties occur:

A triangle has 3 sides and 3 angles..........................



Its altitude is the perpendicular distance from the vertex of an angle to the opposite side or the opposite produced.

A quadrilateral has 4 sides and 4 angles.

A trapezoid is a quadrilateral having two of the sides parallel.

A parallelogram has the opposite sides, two and two parallel.

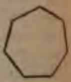
A rectangle is a parallelogram whose angles are all right angles.

A square is a rectangle whose sides are equal......... ....

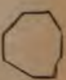
A pentagon has 5 sides and 5 angles..........................

A hexagon has 6 sides and 6 angles... ....

A heptagon has 7 sides and 7 angles............. ... .



An *octagon* has 8 sides and 8 angles..........................

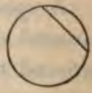


A circle is a polygon of an infinite number of sides.

The diameter of a circle is a straight line drawn through its centre, touching both sides, thus................

The radius of a circle is a line drawn from the centre to the circumference and is half the diameter...............

A chord is a straight line joining any two points in the circumference of a circle......... ....



An arc is any part of the circumference of a circle......

A segment is the surface included between an arc and the chord joining its ends.

A sector is the surface included between an arc and the radii drawn to its ends.

A prism is a solid two of whose faces are similar polygons, lying in parallel planes, and whose other sides are parallelograms. The two polygons are called the bases of the prism.

In a right prism these other sides are rectangles, the corresponding sides of the polygons being vertically over each other.

A cube is a right prism whose bases are squares and whose other faces are also squares.

A pyramid is a solid whose base is a polygon and whose other faces are triangles. The vertices of these triangles meet in a common point. The altitude of the pyramid is the perpendicular distance from this point to the base.

A cone may be regarded as a pyramid with an infinite number of triangular faces. Its base is a circle.

A right cone has its vertex perpendicularly above the centre of its base. It is the solid figure which would be generated by revolving a right triangle about one of the sides adjacent to the right angle.

A *cylinder may* be regarded as a prism having an infinite ber of faces. Its bases are circles. If the centre of the upper base is vertically over that of the lower base, it is called a right cone.

A right cylinder is the solid which would be generated by the revolution of a rectangle about one of its sides.

A sphere is the solid generated by revolving a circle around its diameter.

A spheroid is a solid generated by the revolution of an ellipse around one of its axes. It is *prolate* if the revolution is made around the shorter axis of the ellipse, and *oblate* if around the other axis.

Rules.

To find the area of a triangle, multiply the base by the altitude and take half the product.

To find the area of any quadrilateral figure, divide the quadrilateral into two triangles; the sum of the areas of the triangles is the area.

To find the area of any polygon, divide the polygon into triangles and trapezoids by drawing diagonals; find the areas of these, as above shown, for the area.

To find the area of a regular polygon, multiply half the perimeter of the polygon by the perpendicular drawn from the centre to the centre of one of the sides.

To find the area of a trapezoid, multiply half the sum of the parallel sides by the perpendicular distance between them; the product will be the area.

To find the area of a parallelogram, multiply the length by the height or perpendicular breadth.

To find the circumference of a circle, multiply the diameter by 3 1416; the product is the circumference.

To find the diameter of a circle, divide the circumference by 3 1416, the quotient is the diameter; or multiply the square root of the area by 1·12837, the product is the diameter.

To find the area of a circle, multiply the square of the diamet [illegible]854, the product is the area; or multiply half the circumference by half the diameter, the product is the area; or multiply the diameter by the circumference, and divide by 4; the quotient is the area.

To find the area of a sector of a circle, multiply half the length of the arc of the sector by the radius. Or, multiply the number of degrees in the arc by the square of the radius, and by ·008727.

To find the area of a segment of a circle, find the area of the sector which has the same arc as the segment; also the area of the triangle formed by the radial sides of the sector and the chord of the arc; the difference or the sum of these areas will be the area of the segment, according as it is less or greater than a semicircle.

To find the area of an ellipse or oval, multiply the long diameter by the short diameter; multiply this product by ·7854, and the product will be the superficial area of the ellipse.

To find the circumference of an ellipse or oval, add the squares of the long and short diameters, divide the sum by 2, extract the square root, and multiply by 3·1416.

To find the area of any irregular figure divide it by parallel lines at equal distances from each other. The small sections thus formed may be considered to be trapezoids and their areas separately calculated by the rule for trapezoids. The sum of the areas of the assumed trapezoids will be quite accurately the area of the figure. If a planimeter is available, this will measure the area. Another method is to draw or copy the figure on cross-section paper and count the number of small squares enclosed by it, computing the total area from their number.

To find the surface of a prism or a cylinder, the perimeter of the end multiplied by the height gives the upright surface; add twice the area of an end.

To find the surface of a pyramid or a cone, multiply the perimeter of the base by half the slant height, and add the area of the base.

To find the cubic contents of a prism or a cylinder, multiply *the area of the base by* the height.

[illegible] of a cone, multiply the [illegible] perpendicular height.

[illegible] of a cone, mul- [illegible] the ends [illegible] the sum [illegible] the ends.

[illegible] frustum of a pyramid or a [illegible] the ends, and the mean pro- [illegible] square root of their pro- [illegible] of the perpendicular

[illegible] segment of a sphere, from three [illegible] twice the height of the [illegible] square of the height,

[illegible] frustum or zone of a sphere.— [illegible] of the ends add one-third [illegible] multiply the sum by the height and

[illegible] sphere, multiply the square of the di-

[illegible] segment or zone of a sphere, [illegible] sphere by the height of the zone or

[illegible] contents of a sphere, multiply the cube of [illegible]

[illegible] of a spheroid, multiply the square of the [illegible] axis and the product by ·5236.

[illegible] contents of any irregular solid, fill a vessel to [illegible] sink the body in the water, catching the [illegible] and measuring it.

To find the cubic contents of a cask, multiply the square of the mean diameter by the length in inches and by ·0034. The [illegible] will be the approximate number of U. S. gallons which [illegible]

TABLE

OF DIAMETERS AND AREAS OF SMALL CIRCLES.

M.	AREA.	DIAM.	AREA.	DIAM.	AREA.
	·0000008	·027	·0005726	·0625	·0030680
	·0000031	·028	·0006158	·065	·0033183
	·0000071	·029	·0006605	·070	·0038485
	·0000126	·030	·0007069	·075	·0044179
	·0000196	·031	·0007548	·080	·0050266
	·0000283	·03125	·0007670	·085	·0056745
	·0000385	·032	·0008043	·090	·0063617
	·0000503	·033	·0008553	·095	·0070882
	·0000639	·034	·0009079	·100	·0078540
	·0000785	·035	·0009621	·125	·0122719
	·0000950	·036	·0010179	·150	·0176715
	·0001131	·037	·0010752	·200	·0314159
	·0001327	·038	·0011341	·250	·0490875
	·0001539	·039	·0011946	·300	·0706858
	·0001767	·040	·0012566	·350	·0962115
625	·0001917	·041	·0013203	·400	·1256637
	·0002016	·042	·0013855	·450	·1590435
	·0002270	·043	·0014522	·500	·1963495
	·0002545	·044	·0015205	·550	·2375835
	·0002835	·045	·0015904	·600	·2827440
	·0003142	·046	·0016619	·650	·3318315
	·0003464	·047	·0017349	·700	·3848441
	·0003801	·048	·0018096	·750	·4417875
	·0004155	·049	·0018857	·800	·5026548
	·0004524	·050	·0019635	·850	·5674515
	·0004909	·055	·0023758	·900	·6361725
	·0005309	·060	·0028274	·950	·7088235

To find the cubic contents of a pyramid or a cone, multiply the area of the base by one-third of the perpendicular height.

To find the surface of a frustum of a pyramid or a cone, multiply the sum of the perimeters of the ends by half the slant height, and add the areas of the ends.

To find the cubic contents of a frustum of a pyramid or a cone, add together the areas of the two ends and the mean proportional between them, that is, the square root of their product, and multiply the sum by one-third of the perpendicular [illegible]

[illegible]

To find the cubic contents of a segment of a sphere, from three times the diameter of the sphere subtract twice the height of the segment, multiply the difference by the square of the height, [illegible]

To find the cubic contents of a frustum or zone of a sphere.— To the sum of the squares of the radii of the ends add one-third of the square of the height, multiply the sum by the height and [illegible]

To find the surface of a sphere, multiply the square of the di- [illegible]

To find the convex surface of any segment or zone of a sphere, multiply the circumference of the sphere by the height of the zone or [illegible]

To find the cubic contents of a sphere, multiply the cube of [illegible]

To find the contents of a spheroid, multiply the square of the [illegible] axis and the product by ·5236.

To find the cubic contents of any irregular solid, fill a vessel to [illegible] sink the body in the water, catching the [illegible] and measuring it.

To find the contents of a cask, multiply the square of [illegible] by the length in inches and by ·0034. The [illegible] the approximate number of U. S. gallons which

TABLE

OF DIAMETERS AND AREAS OF SMALL CIRCLES.

M.	AREA.	DIAM.	AREA.	DIAM.	AREA.
	·0000008	·027	·0005726	·0625	·0030680
	·0000031	·028	·0006158	·065	·0033183
	·0000071	·029	·0006605	·070	·0038485
	·0000126	·030	·0007069	·075	·0044179
	·0000196	·031	·0007548	·080	·0050266
	·0000283	·03125	·0007670	·085	·0056745
	·0000385	·032	·0008043	·090	·0063617
	·0000503	·033	·0008553	·095	·0070882
	·0000639	·034	·0009079	·100	·0078540
	·0000785	·035	·0009621	·125	·0122719
	·0000950	·036	·0010179	·150	·0176715
	·0001131	·037	·0010752	·200	·0314159
	·0001327	·038	·0011341	·250	·0490875
	·0001539	·039	·0011946	·300	·0706858
	·0001767	·040	·0012566	·350	·0962115
625	·0001917	·041	·0013203	·400	·1256637
	·0002016	·042	·0013855	·450	·1590435
	·0002270	·043	·0014522	·500	·1963495
	·0002545	·044	·0015205	·550	·2375835
	·0002835	·045	·0015904	·600	·2827440
	·0003142	·046	·0016619	·650	·3318315
	·0003464	·047	·0017349	·700	·3848441
	·0003801	·048	·0018096	·750	·4417875
	·0004155	·049	·0018857	·800	·5026548
	·0004524	·050	·0019635	·850	·5674515
	·0004909	·055	·0023758	·900	·6361725
	·0005309	·060	·0028274	·950	·7088235

To find the cubic contents of a pyramid or a cone, multiply the area of the base by one-third of the perpendicular height.

To find the surface of a frustum of a pyramid or a cone, multiply the sum of the perimeters of the ends by half the slant height, and add the areas of the ends.

To find the cubic contents of a frustum of a pyramid or a cone, add together the areas of the two ends, and the mean proportional between them (that is, the square root of their product), and multiply the sum by one-third of the perpendicular height.

To find the cubic contents of a segment of a sphere, from three times the diameter of the sphere subtract twice the height of the segment; multiply the difference by the square of the height, and by ·5236.

To find the cubic contents of a frustum or zone of a sphere.—To the sum of the squares of the radii of the ends add one-third of the square of the height; multiply the sum by the height and by 1·5708.

To find the surface of a sphere, multiply the square of the diameter by 3·1416.

To find the curve surface of any segment or zone of a sphere, multiply the diameter of the sphere by the height of the zone or segment and by 3·1416.

To find the cubic contents of a sphere, multiply the cube of the diameter by ·5236.

To find the volume of a spheroid, multiply the square of the revolving axis by the fixed axis and the product by ·5236.

To find the cubic contents of any irregular solid, fill a vessel to the brim with water; sink the body in the water, catching the water which is displaced and measuring it.

To find the cubic contents of a cask, multiply the square of the mean diameter by the length in inches and by ·0034. The product will be the approximate number of U. S. gallons which it will hold.

TABLE—(*Continued*)

CONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
13/16	15.1189	18.1900	7/16	23.3656	43.4455
7/8	15.3153	18.6655	1/2	23.5620	44.1787
15/16	15.5716	19.1472	9/16	23.7583	44.9181
5	15.7080	19.6350	5/8	23.9547	45.6636
1/16	15.9043	20.1290	11/16	24.1510	46.4153
1/8	16.1007	20.6290	3/4	24.3474	47.1730
3/16	16.2970	21.1252	13/16	24.5437	47.9370
1/4	16.4934	21.6475	7/8	24.7401	48.7070
5/16	16.6897	22.1661	15/16	24.9364	49.4833
3/8	16.8861	22.6907	8	25.1328	50.2656
7/16	17.0824	23.2215	1/16	25.3291	51.0541
1/2	17.2788	23.7583	1/8	25.5255	51.8486
9/16	17.4751	24.3014	3/16	25.7218	52.8994
5/8	17.6715	24.8505	1/4	25.9182	53.4562
11/16	17.8678	25.4058	5/16	26.1145	54.2748
3/4	18.0642	25.9672	3/8	26.3109	55.0885
13/16	18.2605	26.5348	7/16	26.5072	55.9138
7/8	18.4569	27.1085	1/2	26.7036	56.7451
15/16	18.6532	27.6884	9/16	26.8999	57.5887
6	18.8496	28.2744	5/8	27.0963	58.4264
1/16	19.0459	28.8665	11/16	27.2926	59.7762
1/8	19.2423	29.4647	3/4	27.4890	60.1321
3/16	19.4386	30.0798	13/16	27.6853	60.9943
1/4	19.6350	30.6796	7/8	27.8817	61.8625
5/16	19.8313	31.2964	15/16	28.0780	62.7369
3/8	20.0277	31.9192	9	28.2744	63.6174
7/16	20.2240	32.5481	1/16	28.4707	64.5041
1/2	20.4204	33.1831	1/8	28.6671	65.3968
9/16	20.6167	33.8244	3/16	28.8634	66.2957
5/8	20.8131	34.4717	1/4	29.0598	67.2007
11/16	21.0094	35.1252	5/16	29.2561	68.1120
3/4	21.2058	35.7847	3/8	29.4525	69.0293
13/16	21.4021	36.4505	7/16	29.6488	69.9528
7/8	21.5985	37.1224	1/2	29.8452	70.8823
15/16	21.7948	37.8005	9/16	30.0415	71.8181
7	21.9912	38.4846	5/8	30.2379	72.7599
1/16	22.1875	39.1749	11/16	30.4342	73.7079
1/8	22.3839	39.8713	3/4	30.6306	74.6620
3/16	22.5802	40.5469	13/16	30.8269	75.6223
1/4	22.7766	41.2825	7/8	31.0233	76.5887
5/16	22.9729	41.9974	15/16	31.2196	77.5613
3/8	23.1693	42.7184	10	31.4160	78.5400

TABLE

CONTAINING THE DIAMETERS, CIRCUMFERENCES, AND AREAS OF CIRCLES FROM $\frac{1}{16}$ OF AN INCH TO 100 INCHES, ADVANCING BY $\frac{1}{16}$ OF AN INCH UP TO 10 INCHES, AND BY $\frac{1}{8}$ OF AN INCH FROM 10 TO 100 INCHES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
$\frac{1}{16}$	.1963	.0030	$\frac{7}{16}$	7.6576	4.6664
$\frac{1}{8}$	.3927	.0122	$\frac{1}{2}$	7.8540	4.9087
$\frac{3}{16}$	.5890	.0276	$\frac{9}{16}$	8.0503	5.1573
$\frac{1}{4}$	.7854	.0490	$\frac{5}{8}$	8.2467	5.4119
$\frac{5}{16}$	.9817	.0767	$\frac{11}{16}$	8.4430	5.6727
$\frac{3}{8}$	1.1781	.1104	$\frac{3}{4}$	8.6394	5.9395
$\frac{7}{16}$	1.3744	.1503	$\frac{13}{16}$	8.8357	6.2126
$\frac{1}{2}$	1.5708	.1963	$\frac{7}{8}$	9.0321	6.4918
$\frac{9}{16}$	1.7671	.2485	$\frac{15}{16}$	9.2284	6.7772
$\frac{5}{8}$	1.9635	.3068	3	9.4248	7.0686
$\frac{11}{16}$	2.1598	.3712	$\frac{1}{16}$	9.6211	7.3662
$\frac{3}{4}$	2.3562	.4417	$\frac{1}{8}$	9.8175	7.6699
$\frac{13}{16}$	2.5525	.5185	$\frac{3}{16}$	10.0138	7.9798
$\frac{7}{8}$	2.7489	.6013	$\frac{1}{4}$	10.2120	8.2957
$\frac{15}{16}$	2.9452	.6903	$\frac{5}{16}$	10.4065	8.6179
1	3.1416	.7854	$\frac{3}{8}$	10.6029	8.9462
$\frac{1}{16}$	3.3379	.8861	$\frac{7}{16}$	10.7992	9.2806
$\frac{1}{8}$	3.5343	.9940	$\frac{1}{2}$	10.9956	9.6211
$\frac{3}{16}$	3.7306	1.1075	$\frac{9}{16}$	11.1919	9.9678
$\frac{1}{4}$	3.9270	1.2271	$\frac{5}{8}$	11.3883	10.3206
$\frac{5}{16}$	4.1233	1.3529	$\frac{11}{16}$	11.5846	10.6796
$\frac{3}{8}$	4.3197	1.4848	$\frac{3}{4}$	11.7810	11.0446
$\frac{7}{16}$	4.5160	1.6229	$\frac{13}{16}$	11.9773	11.4159
$\frac{1}{2}$	4.7124	1.7671	$\frac{7}{8}$	12.1737	11.7932
$\frac{9}{16}$	4.9087	1.9175	$\frac{15}{16}$	12.3700	12.1768
$\frac{5}{8}$	5.1051	2.0739	4	12.5664	12.5664
$\frac{11}{16}$	5.3014	2.2365	$\frac{1}{16}$	12.7627	12.9622
$\frac{3}{4}$	5.4978	2.4052	$\frac{1}{8}$	12.9591	13.3640
$\frac{13}{16}$	5.6941	2.5801	$\frac{3}{16}$	13.1554	13.7721
$\frac{7}{8}$	5.8905	2.7611	$\frac{1}{4}$	13.3518	14.1862
$\frac{15}{16}$	6.0868	2.9483	$\frac{5}{16}$	13.5481	14.6066
2	6.2832	3.1416	$\frac{3}{8}$	13.7445	15.0331
$\frac{1}{16}$	6.4795	3.3411	$\frac{7}{16}$	13.9408	15.4657
$\frac{1}{8}$	6.6759	3.5465	$\frac{1}{2}$	14.1372	15.9043
$\frac{3}{16}$	6.8722	3.7582	$\frac{9}{16}$	14.3335	16.3492
$\frac{1}{4}$	7.0686	3.9760	$\frac{5}{8}$	14.5299	16.8001
$\frac{5}{16}$	7.2640	4.2001	$\frac{11}{16}$	14.7262	17.2573
$\frac{3}{8}$	7.4613	4.4302	$\frac{3}{4}$	14.9226	17.7205

TABLE—(*Continued*)

CONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
5/8	64.7955	334.1018	7/8	81.2889	525.8375
3/4	65.1882	338.1637	26	81.6816	530.9304
7/8	65.5809	342.2503	1/8	82.0743	536.0477
21	65.7936	346.3614	1/4	82.4670	541.1896
1/8	66.3663	350.4970	3/8	82.8597	546.3561
1/4	66.7590	354.6571	1/2	83.2524	551.5471
3/8	67.1517	358.8419	5/8	83.6451	556.7627
1/2	67.5444	363.0511	3/4	84.0378	562.0027
5/8	67.9371	367.2849	7/8	84.4305	567.2674
3/4	68.3298	371.5432	27	84.8232	572.5566
7/8	68.7225	375.8261	1/8	85.2159	577.8703
22	69.1152	380.1336	1/4	85.6086	583.2085
1/8	69.5079	384.4655	3/8	86.0013	588.5714
1/4	69.9006	388.8220	1/2	86.3940	593.9587
3/8	70.2933	393.2031	5/8	86.7867	599.3706
1/2	70.6860	397.6087	3/4	87.1794	604.8070
5/8	71.0787	402.0388	7/8	87.5721	610.2680
3/4	71.4714	406.4935	28	87.9648	615.7536
7/8	71.8641	410.9728	1/8	88.3575	621.2636
23	72.2568	415.4766	1/4	88.7502	626.7982
1/8	72.6495	420.0049	3/8	89.1429	632.3574
1/4	73.0422	424.5577	1/2	89.5356	637.9411
3/8	73.4349	429.1352	5/8	89.9283	643.5494
1/2	73.8276	433.7371	3/4	90.3210	649.1821
5/8	74.2203	438.3636	7/8	90.7137	654.8395
3/4	74.6130	443.0146	29	91.1064	660.5214
7/8	75.0057	447.6992	1/8	91.4991	666.2278
24	75.3984	452.3904	1/4	91.8918	671.9587
1/8	75.7911	457.1150	3/8	92.2845	677.7143
1/4	76.1838	461.8642	1/2	92.6772	683.4943
3/8	76.5765	466.6380	5/8	93.0699	689.2989
1/2	76.9692	471.4363	3/4	93.4626	695.1280
5/8	77.3619	476.2592	7/8	93.8553	700.9817
3/4	77.7546	481.1065	30	94.2480	706.8600
7/8	78.1473	485.9785	1/8	94.6407	712.7627
25	78.5400	490.8750	1/4	95.0334	718.6900
1/8	78.9327	495.7960	3/8	95.4261	724.6419
1/4	79.3254	500.7415	1/2	95.8188	730.6183
3/8	79.7181	505.7117	5/8	96.2115	736.6193
1/2	80.1108	510.7063	3/4	96.6042	742.6447
5/8	80.5035	515.7255	7/8	96.9969	748.6948
3/4	80.8962	520.7692	31	97.3896	754.7694

TABLE—(*Continued*)

CONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
1/8	31.8087	80.5157	3/8	48.3021	185.6612
1/4	32.2014	82.5160	1/2	48.6948	188.6923
3/8	32.5941	84.5409	5/8	49.0875	191.7480
1/2	32.9868	86.5903	3/4	49.4802	194.8282
5/8	33.3795	88.6643	7/8	49.8729	197.9330
3/4	33.7722	90.7627	16	50.2656	201.0624
7/8	34.1649	92.8858	1/8	50.6583	204.2162
11	34.5576	95.0334	1/4	51.0510	207.3946
1/8	34.9503	97.2053	3/8	51.4437	210.5976
1/4	35.3430	99.4021	1/2	51.8364	213.8251
3/8	35.7357	101.6234	5/8	52.2291	217.0772
1/2	36.1284	103.8691	3/4	52.6218	220.3537
5/8	36.5211	106.1394	7/8	53.0145	223.6549
3/4	36.9138	108.4342	17	53.4072	226.9806
7/8	37.3065	110.7536	1/8	53.7999	230.3308
12	37.6992	113.0976	1/4	54.1926	233.7055
1/8	38.0919	115.4660	3/8	54.5853	237.1049
1/4	38.4846	117.8590	1/2	54.9780	240.5287
3/8	38.8773	120.2766	5/8	55.3707	243.9771
1/2	39.2700	122.7187	3/4	55.7634	247.4500
5/8	39.6627	125.1854	7/8	56.1561	250.9475
3/4	40.0554	127.6765	18	56.5488	254.4696
7/8	40.4481	130.1923	1/8	56.9415	258.0161
13	40.8408	132.7326	1/4	57.3342	261.5872
1/8	41.2338	135.2974	3/8	57.7269	265.1829
1/4	41.6262	137.8867	1/2	58.1196	268.8031
3/8	42.0189	140.5007	5/8	58.5123	272.4479
1/2	42.4116	143.1391	3/4	58.9056	276.1171
5/8	42.8043	145.8021	7/8	59.2977	279.8110
3/4	43.1970	148.4896	19	59.6904	283.5294
7/8	43.5897	151.2017	1/8	60.0831	287.2723
14	43.9824	153.9384	1/4	60.4758	291.0397
1/8	44.3751	156.6995	3/8	60.8685	294.8312
1/4	44.7676	159.4852	1/2	61.2612	298.6483
3/8	45.1605	162.2956	5/8	61.6539	302.4894
1/2	45.5532	165.1303	3/4	62.0466	306.3550
5/8	45.9459	167.9896	7/8	62.4393	310.2452
3/4	46.3386	170.8735	20	62.8320	314.1600
7/8	46.7313	173.7820	1/8	63.2247	318.0992
15	47.1240	176.7150	1/4	63.6174	322.0630
1/8	47.5167	179.6725	3/8	64.0101	326.0514
1/4	47.9094	182.6545	1/2	64.4028	330.0643

TABLE—(Continued)

CONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
⅝	130.7691	1360.8159	⅞	147.2625	1725.7324
¾	131.1618	1369.0012	47	147.6552	1734.9486
⅞	131.5545	1377.2111	⅛	148.0479	1744.1893
42	131.9472	1385.4456	¼	148.4406	1753.4545
⅛	132.3399	1393.7045	⅜	148.8333	1762.7344
¼	132.7326	1401.9880	½	149.2260	1772.0587
⅜	133.1253	1410.2961	⅝	149.6187	1781.3976
½	133.5180	1418.6287	¾	150.0114	1790.7610
⅝	133.9107	1426.9859	⅞	150.4041	1800.1490
¾	134.3034	1435.3675	48	150.7968	1809.5616
⅞	134.6961	1443.7738	⅛	151.1895	1818.9986
43	135.0888	1452.2046	¼	151.5822	1828.4602
⅛	135.4815	1460.6599	⅜	151.9749	1837.9364
¼	135.8742	1469.1397	½	152.3676	1847.4571
⅜	136.2669	1477.6342	⅝	152.7603	1856.9924
½	136.6596	1486.1731	¾	153.1530	1868.5521
⅝	137.0523	1494.7266	⅞	153.5457	1876.1365
¾	137.4450	1503.3046	49	153.9384	1885.7454
⅞	137.8377	1511.9072	⅛	154.3311	1895.3788
44	138.2304	1520.5344	¼	154.7238	1905.0367
⅛	138.6231	1529.1860	⅜	155.1165	1914.7093
¼	139.0158	1537.8622	½	155.5092	1924.4263
⅜	139.4085	1546.5530	⅝	155.9019	1934.1579
½	139.8012	1555.2883	¾	156.2946	1943.9140
⅝	140.1939	1564.0382	⅞	156.6873	1953.6947
¾	140.5866	1572.8125	50	157.0800	1963.5000
⅞	140.9793	1581.6115	⅛	157.4727	1973.3297
45	141.3720	1590.4350	¼	157.8654	1983.1840
⅛	141.7647	1599.2830	⅜	158.2581	1993.0529
¼	142.1574	1608.1555	½	158.6508	2002.9663
⅜	142.5501	1617.0427	⅝	159.0435	2012.8943
½	142.9428	1625.9743	¾	159.4362	2022.8467
⅝	143.3355	1634.9205	⅞	159.8289	2032.8238
¾	143.7382	1643.8912	51	160.2216	2042.8254
⅞	144.1209	1652.8865	⅛	160.6143	2052.8515
46	144.5136	1661.9064	¼	161.0070	2062.9021
⅛	144.9063	1670.9507	⅜	161.3997	2072.9764
¼	145.2990	1680.0196	½	161.7924	2083.0771
⅜	145.6917	1689.1031	⅝	162.1851	2093.2014
½	146.0844	1698.2311	¾	162.5778	2103.3502
⅝	146.4771	1707.3737	⅞	162.9705	2113.5236
¾	146.8698	1716.5407	52	163.3632	2123.7216

TABLE—(*Continued*)

CONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
⅛	163.7559	2133.9440	⅜	180.2493	2585.4509
¼	164.1486	2144.1910	½	180.6423	2596.7287
⅜	164.5413	2154.4626	⅝	181.0347	2608.0311
½	164.9340	2164.7587	¾	181.4274	2619.3580
⅝	165.3267	2175.0794	⅞	181.8201	2630.7095
¾	165.7194	2185.4245	58	182.2128	2642.0856
⅞	166.1121	2195.7943	⅛	182.6055	2653.4861
53	166.5048	2206.1886	¼	182.9982	2664.9112
⅛	166.8975	2216.6074	⅜	183.3909	2676.3609
¼	167.2902	2227.0507	½	183.7836	2687.8351
⅜	167.6829	2237.5187	⅝	184.1763	2699.3338
½	168.0756	2248.0111	¾	184 5690	2710.8571
⅝	168.4683	2258.5281	⅞	184.9617	2722.4050
¾	168.8610	2269.0696	59	185.3544	2733.9774
⅞	169.2537	2279.6357	⅛	185.7471	2745.5743
54	169.6464	2290 2264	¼	186.1398	2757.1957
⅛	170.0391	2300.8415	⅜	186.5325	2768.8418
¼	170.4318	2311.4812	½	186.9252	2780.5123
⅜	170.8245	2322.1455	⅝	187.3179	2792.2074
½	171.2172	2332.8343	¾	187.7106	2803.9270
⅝	171.6099	2343.5477	⅞	188.1033	2815.6712
¾	172.0026	2354.2855	60	188.4960	2827.4400
⅞	172.3593	2365.0480	⅛	188.8887	2839.2332
55	172.7880	2375.8350	¼	189.2814	2851.0510
⅛	173.1807	2386.6465	⅜	189.6741	2862.8934
¼	173.5734	2397.4825	½	190.0668	2874.7603
⅜	173.9661	2408.3432	⅝	190.4595	2886.6517
½	174.3588	2419.2283	¾	190.8522	2898.5677
⅝	174.7515	2430.1833	⅞	191.2419	2910.5083
¾	175.1442	2441.0772	61	191.6376	2922.4734
⅞	175.5369	2452.0310	⅛	192.0303	2934.4630
56	175.9296	2463.0144	¼	192.4230	2946.4771
⅛	176.3323	2474.0222	⅜	192.8157	2958.5139
¼	176.7150	2485.3546	½	193.2084	2970.5791
⅜	177.1077	2496.1116	⅝	193.6011	2982.6669
½	177.5004	2507.1931	¾	193.9931	2994.7792
⅝	177.8931	2518.2992	⅞	194.3865	3006.9161
¾	178.2858	2529.4297	62	194.7792	3019.0776
[illegible]	178.6785	2543.5849	⅛	195.1719	3031.2635
[illegible]	79.0712	2551.7646	¼	195.5646	3043.4740
[illegible]	.4639	2562.9688	⅜	195.9573	3055.7091
[illegible]	8566	2574.1975	½	196.3500	3067.9687

TABLE E—(*Continued*)

ONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
⅝	196.7427	3080.2529	⅞	213.2361	3618.3300
¾	197.1354	3092.5615	68	213.6288	3631.6896
⅞	197.5281	3104.8948	⅛	214.0215	3645.0536
63	197.9208	3117.2526	¼	214.4142	3658.4402
⅛	198.3135	3129.6349	⅜	214.8069	3671.8554
¼	198.7062	3142.0417	½	215.1996	3685.2931
⅜	199.0989	3154 4732	⅝	215.5923	3698.7554
½	199.4916	3166.9291	¾	215.9850	3712.2421
⅝	199.8843	3179.4096	⅞	216.3777	3725.7535
¾	200.2770	3191.9146	69	216.7704	3739.2894
⅞	200.6697	3204.4442	⅛	217.1631	3752.8498
64	201.0624	3216.9984	¼	217.5558	3766.4327
⅛	201.4551	3229.5770	⅜	217.9485	3780.0443
¼	201.8478	3242.1782	½	218.3412	3793.6783
⅜	202.2405	3254.8080	⅝	218.7339	3807.3369
½	202.6332	3267.4603	¾	219.1266	3821.0200
⅝	203.0259	3280.1372	⅞	219.5193	3834.7277
¾	203.4186	3292.8385	70	219.9120	3848.4600
⅞	203.8113	3305.5645	⅛	220.3047	3862.2167
65	204.2040	3318.3151	¼	220.6974	3875.9960
⅛	204.5917	3331.0900	⅜	221.0901	3889.8039
¼	204.9894	3343.8875	½	221.4828	3903.6343
⅜	205.3821	3356.7137	⅝	221.8755	3917.4893
½	205.7748	3369.5623	¾	222.2682	3931.3687
⅝	206.1675	3382.4355	⅞	222.6609	3945.2728
¾	206.5602	3395.3332	71	223.0536	3959.2014
⅞	206.9529	3408.2555	⅛	223.4463	3973.1545
66	207.3456	3421.2024	¼	223.8390	3987.1301
⅛	207.7383	3434.1737	⅜	224.2317	4001.1344
¼	208.1310	3447.1676	½	224.6244	4015.1611
⅜	208.5237	3468.1901	⅝	225.0171	4029.2124
½	208.9164	3473.2351	¾	225.4098	4043.2882
⅝	209.3091	3486.3047	⅞	225.8025	4057.3886
¾	209.7018	3499.3987	72	226.1952	4071.5136
⅞	210.0945	3512.5174	⅛	226.5879	4085.6631
67	210.4872	3525.6606	¼	226.9806	4099.8350
⅛	210.8799	3538.8283	⅜	227.3733	4114.0356
¼	211.2726	3552.0185	½	227.7660	4128.2587
⅜	211.6653	3565.2374	⅝	228.1587	4142.5064
½	212.0580	3578.4787	¾	228.5514	4156.7785
⅝	212.4507	3591.7446	⅞	228.9441	4171.0753
¾	212.8434	3605.0350	73	229.3368	4185.3966

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	262,[illegible]	[illegible]51

TABLE—(*Continued*)

ONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

DIAM.	CIRCUM.	AREA.	DIAM.	CIRCUM.	AREA.
Inch.			Inch.		
5/8	262.7163	5492.4118	7/8	279.2097	6203.6905
3/4	263.1090	5508.8446	89	279.6024	6221.1534
7/8	263.5017	5525.3012	1/8	279.9951	6238.6408
84	263.8944	5541.7824	1/4	280.3878	6256.1507
1/8	264.2871	5558.2881	3/8	280.7805	6273.6893
1/4	264.6798	5574.8162	1/2	281.1732	6291.2503
3/8	265.0725	5591.3730	5/8	281.5659	6308.8351
1/2	265.4652	5607.9523	3/4	281.9586	6326.4460
5/8	265.8579	5624.5554	7/8	282.3513	6344.0807
3/4	266.2506	5641.1845	90	282.7440	6361.7400
7/8	266.6433	5657.8357	1/8	283.1367	6379.4238
85	267.0360	5674.5150	1/4	283.5294	6397.1300
1/8	267.4287	5691.2170	3/8	283.9221	6414.8649
1/4	267.8214	5707.9415	1/2	284.3148	6432.6223
3/8	268.2141	5724.6947	5/8	284.7075	6450.4039
1/2	268.6068	5741.4703	3/4	285.1002	6468.2107
5/8	268.9997	5758.2697	7/8	285.4929	6486.0418
3/4	269.3922	5775.0952	91	285.8856	6503.8974
7/8	269.7849	5791.9445	1/8	286.2783	6521.7772
86	270.1776	5808.8184	1/4	286.6710	6539.6801
1/8	270.5703	5825.7168	3/8	287.0637	6557.6114
1/4	270.9630	5842.6376	1/2	287.4564	6573.5651
3/8	271.3557	5859.5871	5/8	287.8491	6593.5431
1/2	271.7484	5876.5591	3/4	288.2418	6611.5462
5/8	272.1411	5893.5549	7/8	288.6345	6629.5736
3/4	272.5338	5910.5767	92	289.0272	6647.6258
7/8	272.9265	5927.6224	1/8	289.4199	6665.7021
87	273.3192	5944.6926	1/4	289.8125	6683.8010
1/8	273.7119	5961.7873	3/8	290.2053	6701.9286
1/4	274.1046	5978.9045	1/2	290.5980	6720.0787
3/8	274.4973	5996.0504	5/8	290.9907	6738.2530
1/2	274.8900	6013.2187	3/4	291.3834	6756.4525
5/8	275.2827	6030.4108	7/8	291.7661	6774.6763
3/4	275.6754	6047.6290	93	292.1688	6792.9248
7/8	276.0681	6064.8710	1/8	292.5615	6811.1974
88	276.4608	6082.1376	1/4	292.9542	6829.4927
1/8	276.8535	6099.4287	3/8	293.3469	6847.8167
1/4	277.2462	6116.7422	1/2	293.7396	6866.1631
3/8	277.6389	6134.0844	5/8	294.1323	6884.5338
1/2	278.0316	6151.4491	3/4	294.5350	6902.9296
5/8	278.4243	6169.8376	7/8	294.9177	6921.3497
3/4	278.8170	6186.2591	94	295.3104	6939.7946

TABLE—(Concluded.)

CONTAINING THE DIAM., CIRCUMFERENCES, AND AREAS OF CIRCLES.

Diam.	Circum.	Area.	Diam.	Circum.	Area.
Inch.			Inch.		
1/8	295.7031	6958.2636	1/8	305.1279	7408.8868
1/4	296.0958	6976.7562	1/4	305.5206	7427.9675
3/8	296.4885	6995.2755	3/8	305.9133	7447.0769
1/2	296.8812	7013.8183	1/2	306.3060	7466.2087
5/8	297.2739	7032.3853	5/8	306.6987	7485.3648
3/4	297.6666	7050.9775	3/4	307.0914	7504.5460
7/8	298.0593	7069.5940	7/8	307.4841	7523.7515
95	298.4520	7088.2350	98	307.8768	7542.9818
1/8	298.8447	7106.9005	1/8	308.2695	7562.2362
1/4	299.2374	7125.5906	1/4	308.6622	7581.5132
3/8	299.6301	7144.3052	3/8	309.0549	7600.8189
1/2	300.0228	7163.0443	1/2	309.4476	7620.1471
5/8	300.4155	7181.8077	5/8	309.8403	7639.4995
3/4	300.8082	7200.5962	3/4	310.2330	7658.8771
7/8	301.2009	7219.4090	7/8	310.6257	7678.2790
96	301.5936	7238.2466	99	311.0184	7697.7056
1/8	301.9863	7257.1083	1/8	311.4111	7717.1563
1/4	302.3790	7275.9926	1/4	311.8038	7736.6297
3/8	302.7717	7294.9056	3/8	312.1965	7756.1318
1/2	303.1644	7313.8411	1/2	312.5892	7775.6563
5/8	303.5571	7332.8008	5/8	312.9819	7795.2051
3/4	303.9498	7351.7857	3/4	313.3746	7814.7790
7/8	304.3425	7370.7949	7/8	313.7673	7834.3772
97	304.7352	7389.8288	100	314.1600	7854.0000

For circumference of circles larger than those given in the table, multiply the diameter by 3,1416.

Example.—Diameter 101″ × 3,1416 = 317,3016.

For areas larger than those in the table, multiply the square of the diameter by the decimal .7854.

Example.—101 inches × 101 = 10201 × .7854 = 8011,86 sq. in.

Weights and Measures.

There have been innumerable systems of weights and measures, each country, until recently, having its own system. In fact, in former years different provinces of the same country often used widely differing systems. Of late years, however, the tendency has been toward the adoption of a common decimal system,—that is, a system in which one unit contains ten of the units of the next smaller denomination. The metric system, which is a decimal system, based on the *meter*, a certain fixed unit of length, and the *gram*, the weight of a fixed volume of water at a certain fixed temperature, has been adopted by many of the European and American countries. Great Britain and the United States, however, still retain their old system of weights and measures, but it is to be hoped that the much simpler metric system will be adopted in time. The following tables contain the units in both systems and their equivalents.

American System.

MEASURES OF LENGTH.

Mile.	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	0.45454	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	0.00277777	0.083333	1

MEASURES OF SURFACE.

Sq. Mile.	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

MEASURES OF CAPACITY.

DRY MEASURE.

Cub. Yard.	Bushels.	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

LIQUID MEASURE.

Gallon.	Quarts.	Pints.	Gills.	Cub. Inch.
1	4	8	32	221
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	0.017315	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.

Pound.	Ounces.	Drams.	Scruples.	Grains.
	12	96	288	5760
	1	8	24	480
	0.125	1	3	60
	[illegible]	0.3333	1	20
		0.016666	0.05	1

Metric System.

MEASURES OF LENGTH.

10 *millimeters* (mm.)	= 1 *centimeter*,	cm.,	= .3937 inch.
10 centimeters,	1 decimeter,	dcm.,	3.937 inches.
10 decimeters,	1 METER,	me.,	39.37 inches.
10 meters,	1 dekameter,	dkm.,	393.7 inches.
10 dekameters,	1 hectometer,	hm.,	328 ft. 1 in.
10 hectometers,	1 *kilometer*,	km.,	3280 ft. 10 in.
10 kilometers,	1 myriameter,	mym.,	6.2137 miles.

MEASURES OF SURFACE.

100 *sq. millimeters* (mm^2.)	= 1 *sq. centimeter*,	cm^2.,	= .00155 sq. in.
100 sq. centimeters,	1 sq. decimeter,	dcm^2.,	.1076 sq. ft.
100 sq. decimeters,	1 SQ. METER,	m^2.,	11.96 sq. yd.

Also,

100 centiares (ca.), or sq. me.,	= 1 ARE,	ar.,	= 119.6 sq. yd.
100 ares,	1 *hectare*	ha.,	2.471 acres.

MEASURES OF CAPACITY.

1000 *cu. millimeters* (mm^3.),	1 *cu. centimeter*,	cm^3.,	= .061 cu. in.
1000 cu. centimeters,	1 cu. decimeter,	dcm^3.,	61.022 cu. in.
1000 cu. decimeters,	1 CU. METER,	m^3.,	1.308 cu. yd.

Also,

10 decisteres (dcs.)	= 1 STERE, or cu. meter,	st.,	= 1.308 cu. yd.
10 steres,	1 dĕkastere,	dks.,	13.08 cu. yd.

And

LIQUID MEASURE.

10 milliliters (ml.)	= 1 *centiliter*,	cl.,	= .338 fluid oz.
10 centiliters,	1 deciliter,	dcl.,	.845 liq. gill.
10 deciliters,	1 LITER,	lt.,	1.0567 liq. qt.
10 liters,	1 dekaliter,	dkl.,	2.6417 liq. gal.
10 dekaliters,	1 *hectoliter*,	hl.,	2 bu. 3.35 pk.
10 hectoliters,	1 kiloliter,	kl.,	1.308 cu. yd

MEASURES OF WEIGHT.

10 *milligrams* (mg.)	= 1 centigram,	cg.,	= .1543 grain.
10 centigrams,	1 decigram,	dcg.,	1.543 grains.
10 decigrams,	1 GRAM,	gm.,	15.432 grains.
10 grams,	1 dekagram,	dkg.,	.3527 av. oz.
10 dekagrams,	1 hectogram,	hg.,	3.5274 av. oz.
10 hectograms,	1 *kilogram*,	k.,	2.2046 av. lb.
10 kilograms,	1 myriagram,	myg.,	22.046 av. lb.
10 myriagrams,	1 quintal,	q.,	220.46 av. lb.
10 quintals,	1 *tonneau*,	t.,	2204.6 av. lb.

COMPARATIVE TABLE OF THE ENGLISH (AMERICAN) AND METRIC SYSTEMS.

An inch	= 2.54 centimeters.	A gallon	= 3.786 liters.
A foot	= 30.48 centimeters.	A bushel	= 3524 hectoliter.
A mile	= 1.6094 kilometers.	A cu. inch	= .01639 liter.
A sq. inch	= .0006452 sq. meter.	A cu. yard	= .7646 stere.
A sq. foot	= .0929 sq. meter.	A cord	= 3.625 stere.
A sq. yd.	= .8362 sq. meter.	A grain	= .0648 gram.
A sq. rod	= .2529 are.	A Troy lb.	= .373 kilo.
An acre	= .4047 hectares.	An av. lb.	= .4536 kilo.
A sq. mile	= 259 hectares.	A com. ton	= .9071 tonneau.

MISCELLANEOUS MEASURES.

1 cord = 4 ft. × 4 ft. × 8 ft. = 128 cubic feet.
1 knot or nautical mile = 6080.26 feet.
1 gallon (U. S.) = 231 cubic inches.
1 barrel = 31½ gallons,
1 hogshead = 63 "
1 pound avoirdupois = 7000 grains.
1 " troy = 5760 "
1 " apothecaries = 5760 "
1 board foot = 12 in. × 12 in. × 1 in. thick—*i. e.*, in board measure, boards are assumed to be one inch thick. Hence to find the board feet in any piece of timber, multiply length in by breadth in feet by thickness in inches.

QUESTIONS.

What does the sign + mean?

What is the sign of a proportion?

What is the Roman notation corresponding to 27?

What does 4 : 2 mean? What is it equal to?

What is the rule of three?

What is the sixth power of 5?

What is the cube root of 125?

What is the square of 10.1?

What is the square root of 198 from the tables?

Find the value of x in the equation $10x + 9 = 4x + 21$.

What is the logarithm of 74.6?

Divide, using logarithms, 64.2 by 2.34.

What is the 10th power of 1.2?

What is the square root of 8.64?

What is a regular polygon?

What is a hexagon?

Define a circle.

Define a sphere.

How would you calculate the area of any parallelogram?

How find the area of a circle?

How find the cubical contents of a cylinder?

How obtain the volume of a sphere?

What is a spheroid? How obtain its volume?

How obtain the area of an ellipse?

Give rule for obtaining the volume of a pyramid.

How obtain the contents of the frustum of a cone?

How would you obtain the cubic contents of an irregular piece f stone?

How could you obtain the number of gallons contained in a ısk?

What is the relation between a pound Troy, a pound avoirdu- ɔis, and a pound apothecaries weight?

What is the relation between a foot and a centimetre?

How many litres are equivalent to 10 gallons?

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