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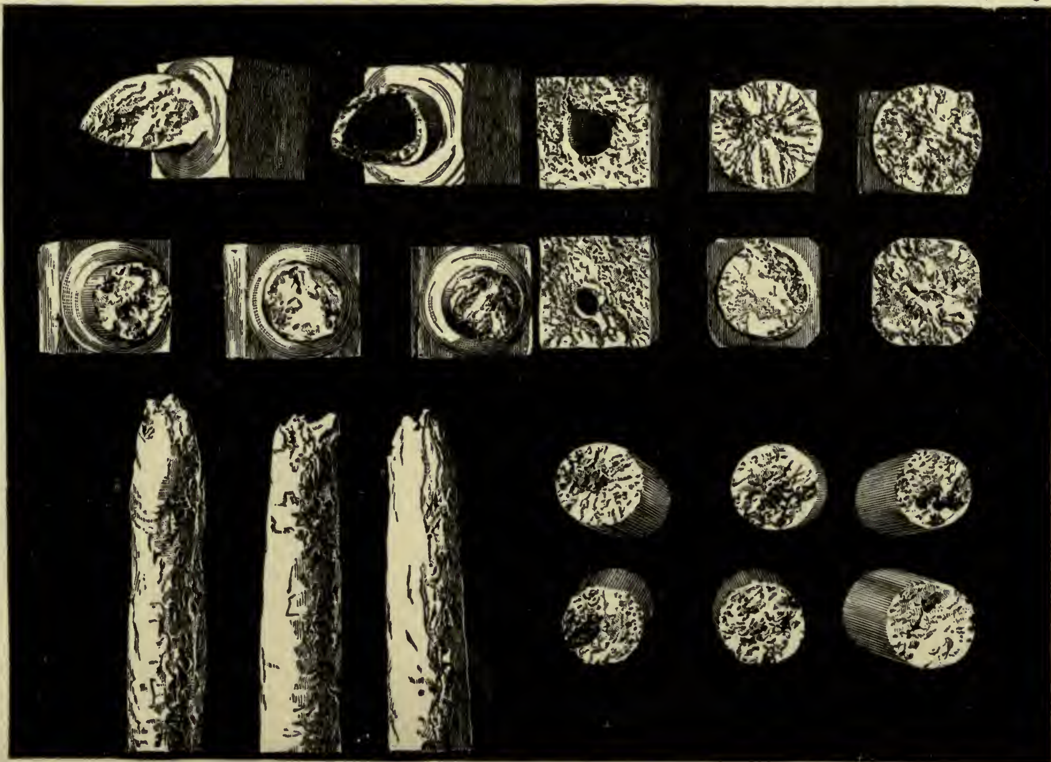

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ON

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AND OTHER

ALLOYS,

AND THEIR

CONSTITUENT METALS.

PART III.

MATERIALS OF ENGINEERING.

BY

ROBERT H. THURSTON, M.A., LL.D., DR. ENG'G,

Late Director of Sibley College, Cornell University; First President American Society of Mechanical Engineers; Member of American Society Civil Engineers; American Institute Mining Engineers; Société des Ingénieurs Civils; Verein Deutscher Ingenieure; Oesterreichischer Ingenieur- und Architekten Verein; British Institution of Naval Architects; Fellow of Am. Assoc. for Advancement of Science; Swedish Academy of Sciences, Etc., Etc., Etc.

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PREFACE TO THE THIRD, REVISED, EDITION.

THE Author and the Publishers of this work have been agreeably surprised to find that the sale of the several volumes of the treatise has been such as to compel the publication of, now, three editions of the part which, it was at the first supposed, would find least demand. They take the opportunity, while issuing this revised edition, to express gratification and appreciation. The work has apparently come to be accepted as standard, and it has become their duty to see that it is kept fully up to the requirements of the profession of engineering, and of those architects and those metallurgists who find a place for it in their libraries and on the list of their reference books.

The present edition has been improved by the correction of every error as yet discovered by the writer, the publishers or the readers, both professional and critical; many of whom have taken much trouble to comply with the request printed in the inserted slip, which will be found in every copy, asking for such aid. It has also been given greater value, it is thought, by the introduction of much new matter in the body of the work, under appropriate heads, and by the extension of the appendix ; where will be found some valuable matter relating to recent discoveries and developments in the metallurgy of the rarer of the useful metals, such as aluminium and magnesium, and their alloys.

It has been a source of gratification to all interested in the work to observe that its contents have proved useful to writers of other treatises on this and allied subjects, and that it has furnished so large a proportion, especially, of the information given in later publications, relative to the alloys. The very general scrupulousness and courtesy of the authors of such works in crediting their quotations and abstracts to this source is a credit to such writers and a gratification to the Author which is here heartily acknowledged.

SIBLEY COLLEGE, CORNELL UNIVERSITY,
November 10, 1897.

PREFACE TO NEW EDITION.

In the revision of this volume for an "end of the century edition" the author and the publishers have sought to bring the work fully up to date in contents and make-up. The data and statistics have been checked by reference to the latest official reports relative to production, manufacture, and use of the "Useful Alloys and their Constituents"; new illustrations have been introduced; new and improved processes are described, and the development of the manufacture of recently introduced and formerly rare metals and their alloys has been traced. The Appendix will be found to contain matter of hardly less value than the body of the book.

Advantage has been taken of this opportunity to correct all errors of composition which have been detected, and to repair all known errors of omission as well as of commission. The aim of author and of publishers alike has been to maintain the standing of this treatise on the materials of engineering as a work of reference, and to constantly improve it as a standard in its class.

The attention of the reader unfamiliar with the older editions is particularly called to the unexampled collection of statistics here compiled relative to the useful properties of these materials; the tables, especially, containing, it is believed, all needed data relative to all known metals and alloys finding important place in the field of engineering. The metals and compositions employed for bearings and rubbing surfaces generally in machinery of all kinds will be seen to include those now adopted as standards in all departments of construction, and by the engineers and constructors in all parts of the world. The enormously extensive, yet by no means complete, work of the U. S. Board appointed to test the materials of construction, of which Board the author was secretary and editor, as well as member, is fully exhibited and all important facts reported by its committees are here recorded in the most compact form possible, and the index to the volume permits prompt discovery of every desired detail of information.

The author and publishers desire to express their full appreciation of the favor with which this work has been received by the profession of engineering and by constructors generally, and will endeavor to continue to justify that favor in future editions, should new issues be called for in the future.

They reiterate their earlier and repeated request to every reader to assist their work by reporting promptly any error detected, and any suggestion that may lead to still further improvement.

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NON-FERROUS METALS.

NON-FERROUS METALS.

CHAPTER I.

HISTORY AND CHARACTERISTICS OF THE METALS AND THEIR ALLOYS.*

1. **The knowledge of metals** possessed by the early races of mankind was of the most inexact and unsatisfactory character. They were probably led to seek a method of utilizing them, first, by the demands of their fighting classes. Their structures, their implements of agriculture and war, and their domestic utensils were, in the earliest stages of their race-history, of wood, bone, and stone. All races are found to have advanced to their present condition of civilization from a primitive state of barbarism, in which they were entirely ignorant of the use of metals, and knew nothing of even the simplest processes of reduction.

The weapons of mankind, in prehistoric times, were at first made of hard wood, of bone, or of stone, fashioned with long and patient labor into rude and inefficient forms. As the race advanced in knowledge and intelligence, they acquired, by some fortunate circumstance, a knowledge of the methods of reducing from the ores the more easily deoxidized metals, and, still later, those which cling with tenacity to oxygen, and require considerable knowledge and skill, and special apparatus for their reduction to the metallic state; and at a still very early period, they applied the more common and more generally useful metals in their rude manufactures.

* This introduction has been in part prefaced to Part II. on Iron and Steel, as the volumes are published and sold separately.

It has thus happened, that mankind has passed through what are designated by the geologists as the ages of stone, of bronze, and of iron, and may be considered as having just entered upon an age of steel.

The ancients, at the commencement, and immediately before the Christian era, were familiar with but seven metals.

The earliest of historical records indicate that, long previous to their date, some metals were worked, although with rude apparatus, and in an exceedingly unintelligent manner. Tubal Cain was an artificer in brass and in iron ; and several sacred writers refer to the use of these metals and of gold and silver, in very early times. Profane writers also present similar testimony; and the discovery of implements of metal among the ruins of the ancient cities of Asia and Africa, and in the copper mines and other localities of North America, indicate that some knowledge of metallurgy was acquired many centuries before our era.

The Hebrews were familiar with gold, silver, brass (bronze ?), iron, tin, and lead, and possibly copper and other metals.

Bronze and brass were not always distinguished by ancient writers, but both alloys were known at a very early date. Phillips gives analyses * of a number of samples of the latter dating from B.C. 20 to B.C. 165, and bronze was certainly made much earlier. Zinc was known in the metallic state at some early date, while tin was known in the earliest historic times.

The Chinese, at a time far back of even their oldest historical records and traditions, seem to have been workers in iron and in bronze.

Evidence has been found, in Hindostan, that the inhabitants of the Indian peninsula, at an era of their history of which we have lost every trace, were able not only to reduce these metals from their ores by rude metallurgical processes, but that they actually constructed in metal, works which are looked upon as remarkable for their magnitude.

The Chaldeans, four thousand years ago, the Persians, the

* Metallurgy, 1874, p. 6.

Egyptians, and the Aztec inhabitants of America, if not an earlier race, had some knowledge of the reduction and of the manufacture of metals.

The "Bronze Age," in Europe, is supposed to have originated in the south of England, and to have gradually spread over Europe, a knowledge of the methods of working copper and bronze finally becoming very general. The bronze age of Central America antedated that of Northern America, where the contemporaneous age was that of copper.

It is probable that copper may have been the first metal worked by these early metallurgists, and that tin was next discovered and used to harden the copper, as is done at the present time. In the manufacture of bronze, the ancients became very skilful, probably long before the discovery and use of iron. The bronze implements discovered on both continents have sometimes nearly the hardness and sharpness of our steel tools.

It is only within a comparatively recent period, however, that metallurgy has become well understood. To insure its rapid and uninterrupted progress, it was necessary that the science of chemistry should be first placed upon a solid basis, and this was only done when, about a century ago, Lavoisier introduced the use of the balance, and by his example led his brother chemists to employ exact methods of research.

2. **The valuable qualities of the metals** used in construction are very greatly influenced by the presence of impurities, and by their union with exceedingly minute quantities of the other elements, both metallic and nonmetallic.

In the processes by which the metals are reduced from their ores and prepared for the market, there is always greater or less liability of producing variations of quality and differences of grade, in consequence of the impossibility of always avoiding contamination by contact with injurious elements during these operations, even where the ore was originally pure.

In the time of Lavoisier, but seventeen substances were classed as metals, and of these the characteristics upon which the classification was based were principally physical, and the place of newly discovered elements was long uncertain; potassium and sodium were at first (1807) classed as non-metals.

The distinction between metals and metalloids remains somewhat indefinite, and the type metal is considered, necessarily, ideal. The metals are usually solid, mercury being an exception; they are usually liquefiable by heat, but arsenic is volatile without fusing; they are generally opaque, but gold is, in very thin leaves, translucent; they are nearly all malleable and ductile, but in very variable degrees. The metals are good conductors; the metalloids are not. The metals are electro-positive, as a rule; the metalloids electro-negative.

Metallurgy is the art of separating the metals from the chemical combinations in which they are met in nature, freeing them from impurities with which they may be mechanically mingled, and reducing them to the state in which they are found in our markets, and in which they are adapted for application in construction.

The chemical combinations from which the useful metals are obtained, are usually either the sulphides or the oxides. The common ores of iron are peroxides, either hydrated or anhydrous, and copper is generally, except in the Lake Superior mining region of the United States, reduced from the state of sulphide.

Lead is usually found combined with sulphur, forming a sulphide known as galena.

Zinc is found and mined as an oxide, as a sulphide, and also as carbonate and silicate.

The sulphide of iron is rarely or never mined as an ore of iron, although abundantly distributed in the form of pyrites.

The following table* illustrates the general character of the chief chemical processes employed for the purpose of reducing metals of ordinary occurrence from their ores.

* *Metals and Applications.* G. A. Wright, London, 1878.

TABLE I.

REDUCTION PROCESSES IN USE.

I.—*NATIVE METALS.*

By mechanical means............	*e.g.* gold washing.
By simple fusion (liquefaction)....	*e.g.* bismuth.
By solution in mercury..........	*e.g.* gold-quartz.
By solution in aqueous chemicals..	*e.g.* gold-quartz.

II.—*SIMPLE ORES;* i. e., *containing only one metal.*

A.—Oxides.

Analytic.....	By simple heating................	*e.g.* mercury, silver.
Single decomposition...	By heating in hydrogen...........	*e.g.* nickel, iron.
	By heating in carbon oxide.......	*e.g.* iron (blast furnace).
	By heating with carbon (coal, coke, etc.)..................	*e.g.* tin, arsenic, zinc, iron, antimony.

B.—Chlorides, Fluorides, etc.

Analytic.....	By heating alone.................	*e.g.* platinum, gold.
Single decomposition...	By heating in hydrogen...........	*e.g.* silver.
	By action of cheaper metal, etc.	
	By (*a*) wet processes.............	*e.g.* copper, gold.
	By (*b*) dry processes.............	*e.g.* magnesium, aluminium.
	By (*c*) amalgamation processes....	*e.g.* silver.

C.—Sulphides.

Single decomposition...	By heating with air..............	*e.g.* mercury, copper, lead.
	By heating with cheaper metal, etc.	*e.g.* mercury, antimony, lead.
Double decomposition followed by single decomposition	By roasting to oxide and reducing as above....................	*e.g.* iron, zinc, antimony.
	By converting into chloride and treating as above............	*e.g.* silver.

D.—Carbonates.

Single decomposition...	By heating with carbon..........	*e.g.* zinc, sodium, potassium.
Double decomposition followed by single decomposition	By roasting to oxide and reducing as above....................	*e.g.* iron.
	By converting into chloride and treating as above............	*e.g.* copper.

III.—*COMPLEX ORES;* i. e., *containing more than one metal.*

I. Alloy extracted by some or other process, as above....	*e.g.* silver-lead alloy, spiegeleisen.
II. Special processes adopted for extraction of metals separately.....................	*e.g.* cupriferous pyrites.

It is not the purpose of the Author to describe these processes at length.

In the reduction of metallic ores, the earthy impurities are separated as completely as possible by selection, and by mechanical methods, and the operation of smelting follows, during which, by chemical processes, the remaining impurities, whether mechanically or chemically united with the metal are removed. Earthy matters are removed in the furnace, by the use of properly selected and skilfully proportioned fluxes.

The ores, in their then purified condition, are deoxidized by the action of carbon, or of carbonic oxide, at high temperatures. The sulphides are decomposed by burning out their sulphur, as it is usually found that the affinity of sulphur for the oxygen of the atmosphere is greater than for the metal with which it is found in combination.

In these processes, high temperatures are requisite, as the chemical reaction to be secured can usually only occur satisfactorily when one or all of the substances treated are in either the liquid or the gaseous state.

In the reduction of ores, the flux must be melted, as must be the silica with which it is to unite, and which it is to remove from the ore, before this desired union can take place; and also in order that the silicate formed may flow to the bottom and out of the tap hole of the furnace.

The oxide left after the removal of earthy matters must usually be brought in contact with carbon in the gaseous state as carbonic oxide, to insure its reduction; and the finally reduced metal must be retained liquid, in order that it may be conveniently removed from the furnace.

The temperatures required and allowable in reducing the various ores are widely different. Iron, copper, bismuth, lead, and nickel are reduced at a bright red heat; while ores of tin, zinc, and manganese must be made white hot—zinc being volatilized in the process of smelting.

The process of reduction of a metal from its ores, and its separation from earthy or metallic impurities, sometimes consists of a single operation, sometimes of two or more.

3. Calcination or Roasting.—The first process to which the ore is subjected, after leaving the mine, is frequently that of *Calcination* or of *Roasting*, by which the ore is disintegrated, and during which sulphur, carbonic acid, and other volatile elements and compounds are eliminated.

In this process the ores are not mixed with a flux, and the temperature is not raised so high as to produce either fusion or reduction. This is found to be an economical process with nearly all ores of iron, and it is also adopted in the reduction of lead and zinc. The operation is performed either in the open air or in kilns. The former method is adopted with ores capable of withstanding somewhat elevated temperatures, such as the ores of iron.

Roasting in heaps in the open air is conducted as follows: The ground selected is first covered with a layer of wood, or of coal six inches or more in depth. Over this is spread a layer of ore from one to two feet thick, the quantity being determined for each case by experience, and varying with the character of the ore. Another layer of fuel is added, and this is covered with another layer of ore. Alternate layers are thus added to the pile, until it has reached the desired height. The pile is then fired, and the ore, under the action of the moderate temperature produced by the smouldering fire, is slowly roasted and becomes well prepared for the succeeding process of reduction.

It loses its water, whether of combination or free, gives up its carbonic acid, loses a portion, if not all, of the sulphur which may have been united with it, and the disintegration produced fits it for more thorough intermixture with fluxes, and for more rapid and complete reduction.

The second, and the most usually satisfactory, method, with iron ores, is that of roasting in kilns.

The fuel and the ore are charged alternately into the kilns in such a manner as to become intimately mixed, and the process is similar in all respects to that which goes on in the previously described method. With kilns, however, the operation can be carried on continuously, the roasted ore being removed at the bottom, and new material supplied at the top as required. This method requires comparatively little space, and does not necessitate the accumulation of immense masses of ore " in stock," as does calcination by the other method. The expense of the construction of the kilns is an objection which is usually more than counterbalanced by the advantages of the process.

Roasting to produce oxidation is a common process in the ordinary work of reduction of sulphides and of protoxides in special cases. The sulphides are usually converted either into sulphates or into a mixture of sulphate and oxide, of which the former often decomposes at high temperature into sulphurous acid and oxide, or oxide and basic sulphate, as with iron or zinc ores. Arsenides and phosphides are similarly treated.

Roasting to volatilize the sulphur is a common method of treatment of iron pyrites, which yield sulphur freely by partial decomposition. Carbonates and hydrated ores are also thus treated to drive off carbonic acid and water. The most common process of reduction of ores is a refined method of reducing by roasting in a deoxidizing atmosphere, and in contact with other reducing agents, as carbon.

The metals which are treated of in this work are all usually found only in a state of combination with either oxygen or sulphur, with the single exception of copper, which is often found native, and deposits of which are sometimes very extensive, furnishing the market with large quantities of that metal. These oxides and sulphides are mixed with other minerals of less valuable, of valueless, or even often of injurious, character. It becomes usually necessary to melt the " ores," as these minerals are called, to effect the separation and reduction of the metal. This operation is called " smelting." The " wet " or " humid " processes of reduction are but little practised in ordinary metallurgical work, although those methods and electrolysis are occasionally found useful and commercially economical.

The melting of common ores is not usually practised, except as a sequel to an earlier roasting process, except in the case of oxides of iron, which are often smelted without calcination or roasting except such as occurs within the furnace previous to fusion. When melting does take place, it results in reduction of the metal and its separation from the gangue that may have accompanied it. This separation is usually accomplished partly by the formation of a fusible slag, by union of the gangue with a flux, which is either siliceous, aluminous or calcareous, according to circumstances.

Melting to reduce the ore is effected by the combined action of heat and of chemical affinity, and by the use, with oxides generally, of carbon both as a fuel and as a reducing agent. Sulphides of other metals than iron are reduced by melting with that metal. Smelting with oxidation sometimes takes place, as in separating metals, or removing sulphur, or in the manufacture of litharge, a lead oxide; this substance is also used as an oxidizing agent with sulphides of other metals.

Melting to effect solution is sometimes practised to secure a separation of compounds into constituent elements or compounds. Thus fused lead oxide dissolves some of the sulphides and many oxides. Lead itself is used in dissolving silver and gold out of some of their ores. The alkaline carbonates dissolve the oxides of the metals, and borax, fluorspar, and other substances similarly used as fluxes act in the same manner when employed in the production of slags. The silicates of alkalies and alkaline earths perform the same office as the other fluxes, and are especially valuable in the treatment of oxides, as solvents both of some oxides and of the gangue; the most easily reduced oxides are dissolved by the silicate, and go into the slag, while the less readily reducible oxides of the compound give up the metal.* Slags are necessarily more fusible than the metal to be reduced.

Melting is often a process preliminary to volatilization, as in the reduction of ores of arsenic and of zinc, or to separation by liquefaction and crystallization.

4. **Smelting.**—The final process of reduction, that of *Smelting*, which usually requires still higher temperature, and which immediately succeeds calcination, is conducted in

* Watts.

various ways, the outlines of which will be given in those chapters relating to the several metals.

5. **Fluxes** are used in nearly all of the metallurgical processes, and their characteristics are determined by the special requirements of each case.

Fluxes are, as the name (from *fluo*, to flow) indicates, substances which assist in reducing the solid materials in the smelting furnace to the liquid state, forming a compound known as slag, or sometimes as cinder.

It frequently happens that two substances, having a powerful affinity for each other, will unite chemically, when brought in contact, and fuse into a new compound at a much lower temperature than that at which either will melt alone.

Silica fuses only at an extremely high temperature, if isolated, or if heated in contact with bodies for which it has no affinity; but, if mixed with an alkali, as potash, soda, or lime, the mixture fuses readily. The two first-named alkalies are too expensive for general use in metallurgy; but the latter is plentifully distributed, as a carbonate, and it is, therefore, the flux generally used in removing silica from ores, by fusion.

Borax similarly unites with oxide of iron to produce a readily fusible glass; and it is, therefore, often used by the blacksmith as a *flux* when welding iron.

Quartz sand is also used by the blacksmith for precisely the same purpose. Being composed almost purely of silicic acid, it forms a readily fusible silicate with the oxides of iron, and it is used wherever the mass of iron is of considerable size, and is capable of bearing, without injury, the high temperature necessary for its fusion.

Fluor-spar, a native fluoride of calcium, has been frequently and extensively used as a flux. Its name was given to it in consequence of that fact. It is a very valuable fluxing material, and is used where the expense of obtaining it does not forbid its application. It has special advantages arising from the fact that it is composed of two elements, both of which perform an active and a useful part in the removal of the non-metallic constituents of ores. In the removal of sulphur and phosphorus from iron, it also possesses the great advantage that the resulting compounds produced by its union with those elements are gaseous, and pass off up the chimney, instead of remaining either solid or liquid in the furnace and contaminating the iron by their contact.

Since the aim, in selecting a flux, is usually to form, with the impurities to be removed, a readily fusible glass, such materials are selected, in each case, as are found, by analysis or by trial, to unite in those proportions which produce such a compound.

The "*slag*" thus formed should usually be a compound silicate of lime and alumina, as free as possible from refractory substances, like magnesia, and from the oxides of the metal treated.

The flux used, therefore, where an ore contains excess of silex, is a mixture of lime and alumina—as, for example, limestone and clay.

Where the ore already contains alumina, limestone only may be needed. In the reduction of iron ores, limestone is very generally the only material added as a flux.

6. **The Fuels** used in engineering and metallurgy are considered very fully in Chapter IV., Part I., of this work.

7. **Mechanical Processes.**—Metallurgy includes both mechanical and chemical processes. The former consist in crushing and washing ores, or the gangue with which they are associated, to render the processes of reduction or of separation more easy, complete, and economical. The "stone-breaker," or "rock-crusher," is the form of crushing apparatus used for breaking rock into pieces of fixed size. It often consists of an arrangement of vibrating jaw, *J* (Fig. 1), hung from the centre, *K*, and operated by a knee-joint, *GEG*, the connecting-rod of which, *E*, is raised and depressed by a crank, *C*, driven by a steam engine. A fly-wheel, *B*, gives regularity of motion, and stores energy needed at the instant when the squeeze occurs. Steel or cast-iron faces, *PP*, receive the wear. The breadth of opening at *I*, which determines the maximum size of pieces crushed, is adjusted by a wedge at *OW*, set by a screw at *N*. The jaw is pulled back

by a spring *R*. Many modifications of this, the Blake crusher, are now made.

Stamps consist of heavy weights carried at the ends of vertical rods, which are lifted either by cams on a continuously revolving shaft, or by the action of a steam piston. The former are the older, and for many kinds of work the most effective style; the latter are, however, found vastly more economical for other cases, as in the crushing of some of the copper-bearing rock of the Lake Superior district.

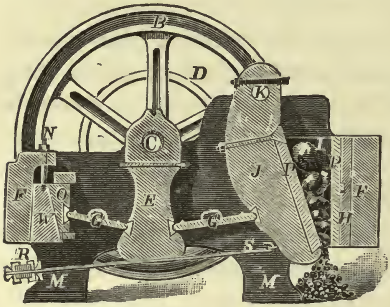

FIG. 1.—STONE-CRUSHER.

Washing machinery is largely used in silver mining and reduction, and less generally in working the ores of the "useful" metals. It takes many forms, according to the kind of work to be done; this is usually the washing of earthy matter from harder ores or the separation of heavy masses from an earthy mass in which it is imbedded.

8. **The Working of Metals**, as an art, antedated, unquestionably, the very earliest historic periods, and introduced the "age of bronze." The first metal-work was done in gold, silver, copper, bronze, brass, lead, and iron, and possibly tin. The East Indians, the Egyptians, the early Greeks, and perhaps other nations, were familiar with methods of working these metals and alloys, and are said to have been conversant with a now unknown art of hardening and tempering bronze, to give cutting edges on knives and weapons, which were only equalled by those of steel. Copper was much used during the Middle Ages, and from A.D. 1100 to 1500 especially, for a great variety of objects. Bronze was the most common material for works in art among the older nations.

The metals were worked both by casting and by the "*repoussé*" method. The earliest castings were solid, and the art of economizing cost and weight by "coring out" the inner portions was one of later introduction. The first "cores" in bronzes were of iron, and were left in in the casting; still later, removable clay and wax cores were used.

The finest Greek art-castings and those of the Romans, and later the Italian artists, were made by the method called, by French workers in bronze, that "*à cire perdue*." The statue or other object was first roughly modelled in clay, and in size slightly less than that proposed for the finished piece. On this clay model was laid a coating of wax, which was worked to exactly the intended finished size and form, and was frequently even given the smoothness of surface desired in the finished casting; this formed a thin skin over the clay. A clay, or earthy, wash was next applied, covering the wax surface, and over this was placed a thick and strong mass of clay, worked on in soft state and allowed to dry and set. The whole was then baked slowly; the wax melted and flowed out from between the two masses of clay, leaving a space into which molten bronze was finally poured to form the casting. The two parts of the clay mould were secured together by stays of bronze which were built, or afterward driven, into both parts, and thus connected them together. When the casting had cooled, the clay was torn away from the outside and removed from the interior of the bronze; the surface was finished up as required, and the work was done. The finest antique bronzes were thus made.

The hammered, or "*repoussé*," work of the Greeks was wonderfully perfect at a date which is supposed to have been earlier than that of their large castings. The first efforts in this direction were rude; the sheet metal was hammered into shape over blocks of wood, which had been roughly given the desired form. Later, a bed of pitch, or of soft kinds of cement, was prepared, and the sheets hammered into form by striking them on the back side, the bed yielding to the blow and thus allowing the metal to assume the desired shape without being broken by the hammer or by the punch used. The work was often reversed and the final finish given on the front side. This method produced some of the largest and the finest of the ancient Asiatic bronzes, and fine work in gold, silver, and copper. The Greeks excelled in this method of metal-working. In many cases, the thickness of the metal was reduced nearly to that of paper, without injury to its surface. The Siris bronzes of about B.C. 400 are of this kind.

Tin was probably worked into vessels for domestic use by the natives of Cornwall before the settlement of the country by the Romans. Lead was used throughout Europe, in the mediæval period, in sheets for roof-coverings, and cast into objects of complicated form. Specimens remain of the former, exhibiting its great durability when exposed to the weather.

Like the modern Chinese and Japanese artists, the ancient workers in metal used gold and silver to adorn and give relief to their castings in bronze. Mirrors, of fine surface and thus ornamented, are common among collections of the products of Greek art. The bronzes of the Italian artists of the Middle Ages are remarkable for their beauty as art work in metal, as well as for their beauty of design; even their work in iron is famous for its unexcelled beauty and the skill exhibited in forging it. Modern work has not equalled that of the Middle Ages, or even that of the early Greeks.

9. **Metal** is the name applied to above fifty of the chemical elements. The larger number of the metals are but little known, and many are found in such extremely minute quantities, that we are not well acquainted with either their chemical or their physical characteristics. Some approach the non-metallic elements so nearly in their properties, that they are placed, sometimes in the one class, and sometimes in the other. Very few of the metals are well fitted for use in construction; but, fortunately, those few are comparatively widely distributed, and are readily reduced from their oxides or sulphides, in which states of combination they are almost invariably found in nature.

10. **The "Useful Metals"** are iron—in its various forms of cast iron, malleable or wrought iron, and steel—copper, lead, tin, zinc, antimony, bismuth and nickel, and occasionally aluminium and rarer metals are used for similar purposes.

From this list of metals, and from their alloys, the engineer can almost invariably obtain precisely the quality of material which he requires in construction. He finds here substances that exceed the stones in strength, in durability under the ordinary conditions of mechanical wear, and in the readiness and firmness with which they may be united. They are superior to timber of the best varieties in strength, hardness, elasticity and resilience, and have, in addition, the important advantages, that they may be given any desired form without sacrificing strength, and may be united readily and firmly to resist any kind of stress.

By proper selection or combination, the engineer may secure any desired strength, from that of lead, at the lower, to the immense tenacity of tempered steel, at the upper limit. He obtains any degree of hardness, or fusibility, and almost any desired immunity from injury by natural destroying agencies. Elasticity, toughness, density, resonance, and varying shades of color, smoothness, or lustre, may also be secured.

11. **The Laws Governing Distribution of the Ores** of the metals are comprehended in the science of geology. The detection of their presence in any locality, and bringing them to the surface of the ground, free from the foreign earthy substances which accompany them, is the work of the mining engineer, and of the miner. The "reduction" of the metals from ores, by chemical and mechanical processes, constitutes the business of the metallurgist. The engineer takes the metals as they are brought into the market, and makes use of them in the construction of permanent or movable structures.

12. **The Requirements of the Engineer** include some acquaintance with the general principles, and with the experimental knowledge, which are to be obtained by the study of geology, of mining, and of metallurgy, to aid him in selecting the metals used in his constructions; since their qualities cannot always be determined by simple inspection, and it is not always possible to subject them to such tests as he may consider desirable before purchasing. In such cases, a knowledge of the localities whence the ores were obtained.

familiarity with the processes of manufacture, and with the nature of the materials employed by the metallurgist, coupled with a knowledge of the effects of various foreign substances upon the quality of the metal, may enable the engineer to judge with some accuracy what metal will best suit his purposes, and what will be likely to prove valueless. He is also thus enabled to judge, should the purchased material prove defective, where the defect in quality originated, and to place the responsibility where it belongs.

The student will seek this knowledge in special works on geology and metallurgy. But brief reference can be made to these subjects here.

All the metals possess, as a whole, a number of properties which define the class, although few of these properties are common to all. The metals all unite chemically with oxygen to form basic oxides, and some of them take higher proportions of oxygen, forming acids. All metals are capable of similarly uniting with chlorine. All are capable of fusion and liquefaction at certain temperatures, fixed for each, which are usually high. Mercury, however, is liquid at ordinary temperatures. The metals are also capable of vaporization, and their vapors have some physical characteristics quite different from those of the solid metal. Thus, silver, white when solid or liquid, becomes blue as a vapor; mercury vapor is colorless, potassium is green. All are opaque, except in exceedingly thin films, when some become apparently translucent. Gold transmits green light, mercury blue, and silver remains opaque in the thinnest leaf yet made.

13. **The Special Qualities of the Useful Metals** which give them their importance as materials of construction are: their *strength*, *hardness*, *density*, *ductility*, *malleability*, *fusibility*, *lustre*, and *conductivity*.

Strength, or the resistance offered to distortion and fracture, is their most valuable quality. The strength of metals and alloys in general use has been very carefully determined by experiment, and will be given hereafter.

Of the metals in our list, lead is the least tenacious, and steel is the strongest.

14. **The Non-Ferrous Metals,** which are to-day of comparatively little importance to the engineer in the construction of machines or of structures, and which have been so generally superseded by iron and steel in every department of art, were, in earlier times, in some cases, as copper, tin, lead, the most common materials of construction. The three just mentioned were known in prehistoric times, and the Greeks were also familiar with mercury, as well as with iron. Valentinus discovered and described antimony in the 15th century, and bismuth and zinc became known at about the same time or a little later. Brande discovered arsenic and cobalt about the middle of the 18th century, and Ward discovered cobalt.* Cronstedt discovered nickel and Scheele manganese in 1774, and tungsten was prepared in 1783 by the brothers D'Elhujart. Palladium, rhodium, iridium and osmium were isolated and described by Wollaston and others in 1803. The alkaline earths, recognized as oxides by Davy in 1807–8, were soon after deoxidized, and potassium and sodium became known. Aluminium and magnesium were separated in 1828 and 1829, respectively by Wöhler and by Bussy, and cadmium had already been discovered by Stromeyer in 1818. The rarer and more unfamiliar metallic elements were found later. The properties of these metals have been referred to in a general way in an abridged account of them given in Part II. of this work. A more detailed account of those used in construction will occupy the greater part of this volume. The following is a *resumé* of the general characteristics of these metals.

15. **The Relative Tenacities** are approximately as below, lead being taken as the standard.

TABLE II.

RELATIVE TENACITIES OF METALS.

Lead	1.0	Cast iron	7 to 12
Tin	1.3	Wrought iron	20 to 40
Zinc	2.0	Steel	40 to 100
Worked copper	12 to 20		

* Encyclopædia Britannica, 1883, art. Metals.

No two pieces of metal, even nominally of the same grade, have precisely the same strength. The figures can therefore only represent approximate ratios, as every variation of purity, structure, or even of temperature, is found to affect their strength.

Cast metal is usually weaker than the same metal after having passed through the rolls or under the hammer; those which can be drawn into wire are still more considerably strengthened by that process. Metals are stronger at ordinary temperatures than when highly heated, and "annealing" is found to reduce the strength of iron and steel, although frequently increasing their ductility, and produces an opposite effect on copper and its alloys. "Hardening," produces the contrary effect. The presence of impurities and the formation of alloys produce changes of strength, sometimes increasing, sometimes diminishing it.

Copper alloyed with tin or zinc, in certain proportions, is strengthened; and the addition of a small percentage of phosphorus to the alloy has a marked effect in increasing its tenacity and ductility.

16. Hardness varies in the metals as considerably as their tenacity, and, like the latter quality, is greatly influenced in the same metal by very slight changes, either physical or chemical.

Thus metals are hardened by cold hammering and softened by sudden change of temperature. The addition of scarcely more than a trace of impurity often produces a marked change in the degree of hardness of metals.

The scale of hardness, according to Gollner,* is as follows:

Soft lead	1	Cast iron	10–11
Tin	2	Mild steel	12–13
Hard lead	3	Tool " blue	14
Copper	4–5	" " violet	15
Alloy for bearings (C., 85; T., 10; Z., 5)	6	" " straw	16
Soft cast iron	7	Hard bearings (C., 83; Z., 17)	17
Wrought iron	8	Very hard steel	18

* Tech. Blaetter; London Engineering, June 1, 1883, p. 519.

The hardness of metals, as determined by Dumas, is exhibited in the following table of their order.

TABLE III.

HARDNESS OF THE METALS.

Metal	Hardness	Metal	Hardness
Titanium	Scratch steel.	Chromium	Scratch glass.
Manganese		Rhodium	
Platinum	Scratched by Calc Spar.	Nickel	Scratched by glass.
Palladium		Cobalt	
Copper		Iron	
Gold		Antimony	
Silver		Zinc	
Tellurium		Lead	Scratched by the nail.
Bismuth		Potassium	Soft as wax.
Cadmium		Sodium	
Tin		Mercury,	Liquid.

17. **Conductivity,** or their power of transmitting molecular vibrations of either heat or electricity, is another property of the metals, upon which is founded many useful applications.

Of the "useful" metals, copper has by far the highest conductivity, and is only second in this respect to gold and silver, the best known conductors. Its conductivity is greatly reduced by the presence of foreign substances.

The powers of conduction for heat and electricity seem to have very similar relative values. Conductivity is reduced by increase of temperature and by presence of impurities.

The following table of relative conductivities was determined by the experiments of Despretz, and very closely confirmed by Forbes.

TABLE IV.

RELATIVE THERMAL CONDUCTIVITIES OF METALS.

Gold	1,000	Zinc	360
Silver	973	Tin	304
Copper	878	Lead	180
Iron	374	Marble	25

The *electric conductivities* obtained by Becquerel, and the thermal conductivities given by Wiedmann and Franz, are as below: *

TABLE IV*a*.

CONDUCTIVITIES OF METALS.

	Electric.	Thermal.	
		In Vacuo.	In Air.
Silver	1,000	1,000	1,000
Copper	....	....	....
" commercial	915	748	736
Gold	649	548	532
Brass	....	240	236
Tin	140	154	145
Platinum	79.3	84	840
Lead	82.7	79	85
Bismuth	....	....	18

The resistance to the voltaic current has been found by Mr. K. Hedges † as follows, wire and foil being used, and strength of the current so adjusted that on increasing it 20 per cent. the metal would fuse. The experiments continued 24 hours and the temperature was 69° F. (21° C.)

TABLE V.

RESISTANCES OF METALS TO ELECTRIC CURRENTS.

Metal.	Resistances as Measured.	
	Before Heating.	Change in 24 Hours.
1. Commercial tin, wire	0.815 Ohms.	— 0.003
2. Lead, soft	0.835 "	— 0.005
3. Copper, soft	0.810 "	+ 0.000
4. Tin-foil, pure	0.860 "	+ 0.000
5. Tin and lead	0.800 "	— 0.160
6. Aluminium ("Albo") alloy, foil	0.835 "	+ 0 000
7. Aluminium and tin	0.820 "	+ 0.0008

* Part II., p. 8, § 10.

† Brit. Assoc. Reports, 1883, Sec. G.

Commercial copper (Rio Tinto), has been found to have, in some cases, but one-seventh the conductivity of pure copper.

Conductivity is reduced by increase of temperature, according to Forbes, and at rates varying with the character of the metal.

M. Benoit has measured the electrical resistance of various metals at temperatures from 0° to 860° C. The mean of the figures obtained is given in the following table, the second column giving the resistance in ohms of a wire 39.37 inches (1 metre) long, and having a cross section of 0.03 inch (1 sq. cm.), and column three the same quantity in Siemens units. Column four gives the conductivity compared with silver:

TABLE V*a*.

METAL.	OHMS.	SIEMENS.	
Silver, A	.0154	.0161	100
Copper, A	.0171	.0179	90
Silver, A.(1)	.0193	.0201	80
Gold, A	.0217	.0227	71
Aluminium, A	.0309	.0324	49.7
Magnesium, H	.0423	.0443	36.4
Zinc, A., at 350°	.0565	.0591	27.5
Zinc, H	.0594	.0621	25.9
Cadmium, H	.0685	.0716	22.5
Brass, A. (2)	.0691	.0723	22.3
Steel, A	.1099	.1149	14
Tin	.1161	.1214	13.3
Aluminium bronze, A. (3)	.1189	.1243	13
Iron, A	.1216	.1272	12.7
Palladium, A	.1384	.1447	11.1
Platinum, A	.1575	.1647	9.77
Thallium	.1831	.1914	8.41
Lead	.1985	.2075	77.60
German silver, A. (4)	.2654	.2775	5.80
Mercury	.9564	1.0000	1.61

A, annealed; H. hardened; (1) silver .75; (2) copper 64.2, zinc 33.1, lead 0.4, tin 0.4; (3) copper 90, aluminium 10; (4) copper 50, nickel 25, zinc 25.

These results, are all taken at 0° C., and agree closely with those obtained by other observers. The resistance increases regularly for all metals up to their points of fusion. This increase, however, differs for different metals. Tin, thallium, cadmium, zinc, lead, are found to vary similarly; at 200° to 230° their resistance has doubled. The resistance of iron and steel doubles at 180°, quadruples at 430°, and at 860° is about nine times that at 0°. Palladium and platinum increase much less, their resistance becoming twice that at 0° C., at 400° to 450°. Gold, copper, and silver form an intermediate group. In general conductibility decreases more rapidly the lower its point of fusion. Iron and steel are exceptions to this rule. In alloys the variation is less than in their constituents, and this is especially the case with German silver.

The thermal conductivity of brass was found by Isherwood to be 556.8 thermal units (British) per hour per square foot and per 1° Fahr., and to vary at the difference of temperature.

Silicon-bronze may be given a conductivity but little less than that of copper, but its tenacity then diminishes considerably; that having 95 per cent. the conductivity of copper, has but one half the strength of that of which the conductivity is 25 per cent.

18. **The Lustre** of these metals is measured by their power of reflecting light. Thus, according to Jamin, silver may reflect 0.9 of the light sent between surfaces of mirrors made of that metal; after ten normal reflections it yields from 0.24 to 0.48, the former figure being that for violet, and the latter for red light. The figures for speculum metal are 0.6 to 0.7, 0.006 and 0.035; those for steel, 0.6, 0.006, and 0.007.

Estimating weights of metal in various forms as used by the engineer is a simple operation. Thus: if

d = diameter of a circular section, or the minor diameter of an ellipse;
d' = major diameter of ellipse;
l = length of piece, section uniform;
b = breadth;
k = a constant;
W = total weight.

The weight of any piece of uniform section is

$$W = kd^2l \text{ for cylindrical bars;}$$
$$= kdd'l \text{ " elliptical sections;}$$
$$= kbdl \text{ " rectangular sections.}$$

The values of k when l is in feet, other dimensions in inches and W in pounds, are

VALUES OF k IN

	$W = kdd'l.$	$W = kbdl.$
Brass, sheet	2.906	3.700
Iron, wrought	2.618	3.333
Lead, sheet	3.888	4.950
Steel, soft	2.670	3.400

For pipes, $W = k(d_2^2 - d_1^2)$ when $d_1 d_2$ represent the inner and outside diameters in inches.

To obtain weights in kilogrammes when measures are in centimeters, multiply the above by 0.00241.

The " metallic lustre " is a property of the metals almost peculiar to them, and constitutes one of their marked characteristics.

Polished steel, and an alloy of copper and tin known as *speculum metal,* burnished copper and aluminium, as well as the precious metals, gold and silver, exhibit this beautiful and peculiar lustre very strikingly.

Tin, lead, and zinc, are lustrous, but they are not capable of taking a sufficiently high polish to exhibit this quality in such a degree as the metals first named.

19. **The Specific Gravities** of the commercial metals are as follows:

THE DENSITIES OF PURE METALS according to Fownes,* are

* Chemistry, 10th ed., p. 297.

TABLE VI.

SPECIFIC GRAVITIES OF PURE METALS.

(Water at 60° F. (15.5 C.) = 1.)

Platinum	21.50	Cobalt	8.54
Iridium	21.15	Manganese	8.00
Gold	19.50	Iron	7.79
Tungsten	17.60	Tin	7.29
Mercury	13.59	Zinc	7.10
Palladium	11.80	Antimony	6.80
Lead	11.45	Tellurium	6.11
Silver	10.50	Arsenic	5.88
Bismuth	9.90	Aluminium	2.67
Copper	8.96	Magnesium	1.75
Nickel	8.80	Sodium	0.97
Cadmium	8.70	Potassium	0.87
Molybdenum	8.63	Lithium	0.59

For the purposes of the engineer, the densities and the weights per unit of volume of commercial materials are the data desired. The following table gives such a set of figures. As is seen by comparing the tables, authorities differ somewhat in these figures.

TABLE VII.

WEIGHTS AND DENSITIES OF COMMERCIAL METALS.

NAME.	S. G.	LBS. IN CU. FT.	KILOG'S IN CU. M.
Aluminium, cast	2.56	160	2,560
" sheet	2.67	167	2,670
Antimony, cast	6.7	418	6,700
Bismuth, "	9.8	614	9,800
Brass,* cast	8.4	525	8,400
" sheet	8.5	532	8,500
" wire	8.54	533	8,540
Bronze * (ordinary)	8.4	524	8,400
Copper,* bolts	8.85	548	8,850
" cast	8.60	537	8,600
" sheet	8.88	549	8,800
" wire	8.88	550	8,800
Gold, hammered	19.4	1,205	19,400
" standard	17.65	1,103	17,650
Gun metal (bronze)	8.153	510	8,153

TABLE VII.—*Continued.*

NAME.	S. G.	LBS. IN CU. FT.	KILOG'S IN CU. M.
Iron, cast, from	6.955	435	6,955
" " to	7.295	456	7,295
" " average	7.125	445	7,125
" wrought, from	7.560	473	7,560
" " to	7.800	488	7,800
" " average	7.680	480	7,680
Lead, cast	11.352	710	11,352
" sheet	11.4	712	11,400
Mercury, fluid	13.6	848	13,600
" solid	15.632	977	15,632
Nickel, cast	7.807	488	7,807
Pewter	11.600	725	11,600
Platinum, mass	19.550	1,219	19,500
" sheet	20.337	1,271	20,337
Silver, mass	10.5	655	10,500
" standard	10.534	658	10,534
Steel, hard	7.82	496	7,820
" soft	7 834	491	7,834
Tin,* cast	7.3	456	7,300
Type metal, cast	10.450	653	10,450
Zinc,* cast	7.03	439	7,030
" sheet	7.29	456	7,290

20. **Ductility and Malleability** are properties of the metals scarcely less important to the engineer than that of tenacity. The ductility of a metal or an alloy is its capacity for being drawn out into wire, by being pulled through holes in the wire-drawers' plates, each hole being slightly smaller than the preceding, until the wire reaches a limit of fineness which is determined by the degree of its ductility, and, as well, by the skill of the workman.

Great tenacity, in proportion to the degree of hardness, or high tenacity, a low elastic limit and a certain viscosity, is the combination of qualities required to insure durability.

Gold has been drawn until the wire measured but $\frac{1}{5000}$ inch in diameter, and silver and platinum are nearly as ductile. Iron and copper are the most ductile of the common metals.

* See text later.

The *malleability* of a metal, or the power which it possesses of being rolled into sheets without tearing or breaking, is determined by its relative tenacity and softness.

The malleability of the non-ferrous metals is determined by their plasticity simply, and this quality is observable in all metals having no defined elastic limit. It is also often determined to some extent by the physical condition of the metal; thus zinc, brittle in the ingot, is malleable at the boiling temperature of water, and, if worked at that temperature, becomes permanently malleable in the sheet or the bar. Hardening and tempering are operations which can be performed on many metals with the effect of modifying their malleability and other properties; but while sudden cooling from high temperature hardens steel, it softens copper and the bronzes and brasses. Ductility, being dependent upon tenacity largely, is not as generally observed as malleability.

Gold is the most malleable of all metals, and has been beaten into sheets of which it would require 300,000 to make up a thickness of one inch.

Wrought iron of good quality, and the softer grades of steel, are very malleable; the former has been rolled to less than $\frac{1}{1000}$ of an inch (0.00254 centimetre) thickness. Cast iron and hard steels are neither malleable nor ductile.

Copper is very malleable, as well as ductile, if kept soft by frequent annealing; tin possesses this property, also; and zinc, although quite brittle when cold, becomes malleable at a temperature somewhat exceeding the boiling point of water; its temperature being still further elevated, it again becomes brittle, so much so that it may be powdered in a mortar. Some of the copper-tin alloys exhibit the same peculiarity.

21. **Odor and Taste** characterize many metals. Brass, for example, possesses a very marked taste and perceptible odor when applied to the tongue and when rubbed. These qualities may indicate solubility and volatility, but no direct experiment has revealed their precise nature. Many of the lighter metals are quite volatile at moderately high temperature.

Lead can be rolled into quite thin sheets, but it is less malleable than either copper, tin, or the precious metals.

The following is a table of the relative ductility of metals:

TABLE VIII.

ORDER OF DUCTILITY OF METALS.

1. Gold,	4. Iron,	7. Zinc,
2. Silver,	5. Copper,	8. Tin,
3. Platinum,	6. Aluminium,	9. Lead.

In the following list, the metals named are placed in the order of their malleability.

TABLE IX.

ORDER OF MALLEABILITY OF METALS.

1. Gold,	4. Tin,	7. Zinc,
2. Silver,	5. Platinum,	8. Iron,
3. Copper,	6. Lead,	9. Nickel.

Prechtl gives the following as the order in which the metals stand in this respect :*

TABLE IX*a*.

MALLEABILITY.		DUCTILITY.
Hammered.	Rolled.	Wire-drawn.
1. Lead,	Gold,	Platinum,
2. Tin,	Silver,	Silver,
3. Gold,	Copper,	Iron,
4. Zinc,	Tin,	Copper,
5. Silver,	Lead,	Gold,
6. Copper,	Zinc,	Zinc,
7. Platinum,	Platinum,	Tin,
8. Iron.	Iron.	Lead.

Authorities differ, however, in their statements in regard to the order of the metals in these respects, and the preceding figures as given in tables are often quoted from Regnault.†

* Encyclopædia Britannica.

† Regnault's Chemistry.

22. The following table of the principal metals and their properties is extracted from Watts:*

TABLE X.

CHARACTERISTICS OF METALS.

NAME.	DATE OF DISCOVERY.	NAME OF DISCOVERER.	S. G. Water = 1.	SP. HEAT.	MELTING POINT.	CONDUCTIVITY. Thermal.	CONDUCTIVITY. Elect.
Platinum	1741	Wood	21.5	0.0324	....	8.4	18.
Iridium	1803	Descotils	21.15	0.0326	....	......	......
Gold	....	....	19.26	0.0324	1200° C. (?)	53.2	78.
Mercury	....	....	15.60	0.0319	−39° C.	......	......
Palladium	1803	Wollaston	11.80	0.0593	....	6.3	18.4
Lead	....	....	11.33	0.0314	332° C.	8.5	8.3
Silver	....	....	10.57	0.0570	1000° C.	100	100
Bismuth	....	....	9.80	0.0308	270° C.	1.8	1.2
Copper	....	....	8.94	0.0952	1200° C. (?)	73.5	99.9
Nickel	1751	Cronstedt	8.82	0.1086	....	......	13.1
Manganese	1774	Gahn; Scheele.	8.02	0.1217	....	......	......
Iron	....	....	7.84	0.1138	2000° C. (?)	11.9	16.8
Tin	....	....	7.30	0.0562	....	14.5	12.4
Zinc	....	....	7.13	0.0955	433° C.	......	29.
Antimony	....	....	6.72	0.0508	450° C.	......	4.6
Aluminium	1828	Wöhler	2.56	0.2143	....	......	56.1
Magnesium	1829	Bussey	1.74	0.2499	433° C.	......	41.2

23. Crystallization is always observed in metal when deposited from solution or when solidifying from fusion when the conditions are favorable. Gold, silver, copper, antimony and bismuth, and many alloys, as those of copper and of iron, are found in crystalline form in nature. Deposition by the voltaic current often produces very large and perfect crystals. Lead is precipitated from solutions in beautiful crystalline forms when displaced by zinc. Iron forms well-defined crystals when kept heated at nearly the temperature of fusion for a considerable time, and is supposed by some authorities to take on the cubic form when exposed to severe and long-continued jarring. This tendency to crystallization is

* Dictionary of Chemistry; Lond., 1868; vol. iii.; p. 936.

increased by the presence of manganese or of phosphorus. Zinc, in the ingot, is often very distinctly crystalline.

The precious metals, aluminium, cobalt, copper, iron, lead and nickel are so nearly amorphous, or if crystalline in structure in their ordinary state, have such small and uniform crystals that they may be considered compact and homogeneous. Antimony, bismuth, manganese, and zinc, and some of their alloys often exhibit distinct crystallization, which may also be produced in all metals by prolonged heating or slow cooling, and, as supposed by some observers, by long-continued vibration or jarring.

24. **Specific Heats.**—The effect of heat upon metallic substances in the production of changes of volume and of temperature varies considerably.

The *Specific Heats* of a number are given in Table XI.; they measure in thermal units the quantity of heat required to change the temperature of a pound or a kilogramme of the metal one degree.

TABLE XI.

SPECIFIC HEATS OF METALS.

	SPECIFIC HEAT.	AUTHORITY.
Wrought iron	.1138	Regnault.
" 32—212 F.	.1098	Dulong & Petit.
" 32—392 F.	.1150	"
" 32—572 F.	.1218	"
" 32—662 F.	.1255	"
Cast iron	.1298	Regnault.
Steel, soft	.1165	"
" tempered	.1175	"
Copper	.09515	"
" 32—212 F.	.0927	Dulong & Petit.
" 32—572 F.	.1013	"
Cobalt	.10696	Regnault.
" carburetted	.11714	"
Nickel	.1086	"
" carburetted	.1119	"
Tin, English	.05695	"
" Indian	.05623	"
Zinc	.09555	"
" 32—212 F	.0927	Dulong & Petit.
" 32—572 F	.1015	"

TABLE XI.—*Continued.*

	SPECIFIC HEAT.	AUTHORITY.
Brass	.0939	Regnault.
Lead	.0314	"
Platinum, sheet	.03243	"
" 32—212 F	.0335	Dulong & Petit.
" at 572 F	.03434	Pouillet.
" " 932 F	.03518	"
" " 1832 F	.03718	"
" " 2192 F	.03818	"
Mercury, solid	.0319	Regnault.
" liquid	.03332	"
" 32—212 F	.033	Dulong & Petit.
" 32—572 F	.035	"
Antimony	.05077	Regnault.
" 32—572 F	.0547	Dulong & Petit.
Bismuth	.03084	Regnault.
Gold	.03244	"
Silver	.05701	"
" 32—572 F	.0611	Dulong & Petit.
Manganese	.14411	Regnault.
Iridium	.1887	"
Tungsten	.03636	"

The following table exhibits the relationship between the combining numbers and specific heats of the metals; the product of specific heat and of combining number is seen to be very nearly constant, as shown by Kopp, who also makes this product, or the "atomic specific heat," 6.4 for 42 elements, including all in this table. Kopp also verifies the law of Woestyn and Garnier, finding the specific heat of the molecule equal to the sum of the specific heats of the constituent atoms.

TABLE XI*a*.

SPECIFIC HEATS AND COMBINING NUMBERS.

METALS.	COMBINING NUMBERS.	SPECIFIC HEAT (REGNAULT).	PRODUCT.
Aluminium	27	0.2143	5.8
Antimony	122	0.0508	6.1
Arsenic	75	0.0814	6.1
Bismuth	210	0.0308	6.5
Cadmium	112	0.0567	6.3
Copper	63.5	0.0951	6.0
Gold	196	0.0324	6.4
Lead	207	0.0314	6.4
Iron	56	0.1138	6.1
Magnesium	24	0.2499	6.0
Manganese	55	0.1217	6.7
Mercury (solid)	200	0.325	6.5
Nickel	59	0.1089	6.4
Palladium	106	0.0593	6.3
Platinum	197.6	0.0329	6.5
Potassium	39.1	0.1695	6.5
Silver	108	0.0570	6.2
Sodium	23	0.2934	6.7
Tin	118	0.0562	6.6
Zinc	65	0.0956	6.2

The specific heats are slightly variable with change of temperature. This change has been carefully studied only in a few cases. Holman deduces,* by collating results of experiments published by known authorities, for the specific heat of iron:

$$\left.\begin{array}{l} k = 0.10687 + 0.0000304(t - 32) + 0.0000000238(t-32)^2 \\ k = 0.10687 + 0.0000547t + 0.0000000428t^2 \end{array}\right\} \quad . \quad . \quad (1)$$

for the Fahrenheit and Centigrade scales respectively.

For platinum he obtains:

$$k = 0.0328 + 0.000003022(t - 32) + 0.000000000009\,(t - 32)^2,$$
$$k = 0.0328 + 0.00000544t + 0.000000000016t^2,$$

or, very nearly,

$$\left.\begin{array}{l} k = 0.03208 + 0.00000304\,(t - 32) \\ k = 0.03208 + 0.00000547t \end{array}\right\} \quad . \quad . \quad . \quad . \quad (2)$$

* *Journal Franklin Institute*, August, 1882.

The figures given in Table XI. are mean values between the temperatures of freezing and of boiling, of the quantity of heat, in thermal units, required to produce a change of temperature of one degree. Their values have been shown by Dulong and Petit to increase with the rise of temperature, as does the specific heat of water itself. When melted their specific heats are greater than when solid.

The specific heats represent the number of units of water which would be raised in temperature one degree by the addition of the amount of heat which would raise one unit of weight of the metal one degree. Specific heat is sometimes called "Capacity for heat."

25. **The Expansion of the Metals** by increase of temperature is exhibited by the following table of *coefficients of linear expansion.*

The figures represent the extension, in parts of its own length, of a bar of the given metal during a rise in temperature from the freezing to the boiling point of water.

TABLE XII.

LINEAR EXPANSIONS OF SOLIDS.

	EXPANSION BETWEEN 32° F. (0° C.) AND 212° F. (100° C.)	AUTHORITY.
Glass	0.000872 to 0.000918	Lavoisier and Laplace.
"	0.000776 to 0.000808	Roy and Ramsden.
Copper	0.001712 to 0.001722	Lavoisier and Laplace.
Brass	0.001867 to 0.001890	" "
"	0.001855 to 0.001895	Roy and Ramsden.
Iron	0.001220 to 0.001235	Lavoisier and Laplace.
Steel (untempered)	0.001079 to 0.001080	" "
" (tempered)	0.001240	" "
Cast Iron	0.001109	Roy and Ramsden.
Lead	0.002849	Lavoisier and Laplace.
Tin	0.001938 to 0.002173	" "
Silver (fine)	0.001909 to 0.001910	" "
Gold	0.001466 to 0.001552	" "
Platinum	0.000884	Dulong and Petit.
Zinc	0.002976	Daniell.

Chaney gives* the following values of the coefficients of linear expansion, at ordinary temperature, as recalculated by him, and corrected for the author, from selected data, for the Standards Office of the British Board of Trade.

TABLE XII*a*.

EXPANSIONS OF SOLIDS.

	For 1° F.	For 1° C.	Authority.
Aluminium, cast	0.00001234	0.00002221	Fizeau.
" cryst	0.00000627	0.00001129	"
Brass, cast	0.00000957	0.00001722	Sheepshanks
" plate	0.00001052	0.00001894	Ramsden.
" sheet	0.00000306	0.00000550	Kater.
Bronze, Baileys, Cop., 17 ; tin, 25 ; zinc, 1.	0.00000986	0.00001774	Clarke.
Same	0.00000975	0.00001775	Hilgard.
Copper	0.00000887	0.00001596	Fizeau.
Gold	0.00000786	0.00001415	Chandler & Roberts.
Iridium	0.00000356	0.c0000641	Fizeau.
Lead	0.00001571	0.00002828	"
Mercury (cubic expan.)	0.00009984	0.00017971	Regnault & Miller.
Nickel	0.00004695	0.00001251	Fizeau.
Osmium	0.00000317	0.00000570	"
Palladium	0.00000556	0.00001000	Wollaston.
Pewter	0.00001129	0.00002033	Daniell.
Platinum	0.00000479	0.00000863	Fizeau.
" 90 ; iridium, 10	0.00000476	0.00000857	"
" 85 ; " 15	0.00000453	0.00000815	"
Silver	0.00001079	0.00001943	Chandler & Roberts.
Tin	0.00001163	0.00002094	Fizeau.
Zinc	0.00001407	0.00002532	Baeyer.
" 8, tin 1	0.00001496	0.00002692	Smeaton.

These coefficients are not absolutely constant, but vary with the physical conditions of the metals. They are not the same with the same material in its forms of cast, rolled, hammered, hardened, or annealed metal. The value of the coefficient of expansion also increases slightly with increase of temperature.

To determine the length, L', of a bar at any given temperature, t', knowing its length, L, at any other temperature, t, we have the formulas :

* Calculations of densities and expansions ; report by the Board of Trade ; printed for the House of Commons, London, 1883.

$$L' = \frac{L\left(1 + \frac{at'}{180}\right)}{1 + \frac{at}{180}}, \text{ for Fahr. scale, } \quad . \quad . \quad . \quad . \quad (3)$$

$$L' = \frac{L\left(1 + \frac{at'}{100}\right)}{1 + \frac{at}{100}}, \text{ for Cent. scale, } \quad . \quad . \quad . \quad . \quad (4)$$

where a is the coefficient given above.

TABLE XIII.

EXPANSIONS OF VOLUME.

	PER DEGREE CENT.*	0° C. (32° F.) to 100° C. (212° F.).
Glass	.00002 to .00003	.002 to .003
Iron	.000035 to .000044	.0035 to .0044
Copper................	.000052 to .000057	.0052 to .0057
Platinum	.000026 to .000029	.0026 to .0029
Lead	.000084 to .000089	.0084 to .0089
Tin....................	.000058 to .000069	.0059 to .0069
Zinc	.000087 to .000090	.0087 to .0090
Brass	.000053 to .000056	.0053 to .0056
Steel..................	.000032 to .000042	.0032 to .0042
Cast Iron ....about	.000033	.0033

These results are partly from direct observation, and partly calculated from observed linear expansion, which is one-third the cubical expansion.

26. **The Fusibility of the Metals,** or their property of becoming liquid at a temperature which is always the same for the same metal, is a quality which has an important bearing upon their useful applications in the arts.

All solids which do not undergo decomposition by heat before reaching that temperature have definite "melting points."

The metals differ more widely in their temperatures of

* Abridged from Watts's "Dictionary of Chemistry."

fusion than even in density. Solidified mercury melts at nearly 40° below zero, Fahr. (– 40° Cent.); while platinum requires the highest temperature attainable with the oxy-hydrogen blow-pipe. The more common metals fuse at temperatures quite readily attainable, although none of them melt at temperatures approaching those ordinarily met with in nature.

Some of the metals may even be readily volatilized, and probably all are vaporized, to a slight degree at least, at very high temperatures. Mercury boils at 330° Cent. (626° Fahr.). Zinc can be distilled at a bright red heat, and copper and gold are known to give off minute quantities of vapor at temperatures frequently occurring during the process of manufacture.

The low temperatures of fusion of tin, lead, bismuth, and antimony, allow of their being readily applied as solders, either alloyed or separately. Cast iron, copper and its alloys, and other metals, melt at temperatures which are easily reached, and the iron and the brass founders are thus enabled by the process of moulding and casting, to produce the most intricate forms readily and cheaply, and thus, when desired, to obtain large numbers of precise copies of the same pattern.

The melting points of some of the more important metals are as follows:

TABLE XIV.

TEMPERATURE OF FUSION OF COMMERCIAL METALS.

	FAHR.	CENT.
Mercury	–39°	–39°
Tin	420	216
Bismuth	490	254
Lead	630	332
Zinc	700	371
Silver	1,280	693
Brass	1,870	1,021
Copper	2,550	1,118
Cast Iron	2,750	1,510
Wrought Iron	4,000 (?)	2,201 (?)

The temperatures of fusion of pure iron, or of wrought iron, are very high, and are not precisely known, no means of accurate measurement having yet been applied to their determination.

The following very complete table will serve for reference in more extended work.*

TABLE XV.

MELTING POINTS OF PURE METALS.

FUSIBLE ABOVE RED HEAT.			FUSIBLE BELOW RED HEAT.		
	F.	C.		F.	C.
Silver	+ 1873°	+ 1023°	Mercury	−39°	−39°.8
Copper	1996	1091	Rubidium	+101.3	+38.5
Gold	2016	1102	Potassium	144.5	62.5
Cast Iron	2786	1530	Sodium	207.7	97.6
Pure Iron, Nickel, Cobalt, Manganese, Palladium,	? Highest heat of the forge.		Lithium	356	180
			Tin	442	227.8
			Cadmium	442.5	228
			Bismuth	497	259
			Thallium	561	294
Molybdenum, Uranium, Tungsten, Chromium,	Do not melt in the forge.		Lead	617	325
			Tellurium	615 (?)	324
			Arsenic	?	?
			Zinc	773	412
Titanium, Cerium, Osmium, Iridium, Rhodium, Platinum, Tantalum,	Fusible only in Oxyhydrogen flame.		Antimony	red heat.	

Latent Heat.—In passing from the solid to the liquid state, a certain amount of heat disappears, being expended in producing this change of physical conditions.

Latent Heat, as this is called, varies in amount with dif-

* For approximate values of temperatures of fusion of alloys, see later.

ferent substances. In Table XVI. are the latent heats of several, as obtained by M. Person, expressed in thermal units.*

TABLE XVI.

LATENT HEATS OF METALS.

	CENT.	FAHR.
Tin	14.25	25.65
Bismuth	12.64	22.75
Lead	5.37	9.67
Water	79.25	142.65
Silver	21.07	37.93
Cadmium	13.66	24.59

27. **Chemical Character.**—Chemically, the metals exhibit the same variation of properties as physically, and the line of demarcation between the metals and the metalloids is no more definitely fixed. They are acid or basic in combination, and resemble the metalloids more or less nearly in chemical action, according to the proportion as well as the nature of the elements with which they combine. Their oxides are usually basic, but often acid. The alkaline metals unite with oxygen with great rapidity to form alkaline oxides ; the common "useful" metals are oxidized readily, but less freely than the preceding, and gold, silver, platinum, and others, have little affinity for oxygen, and do not easily corrode. Nearly all metals combine freely with sulphur, and their sulphides form, in some cases, extensive deposits which are worked for the market.

28. **Alloys** are formed by fusing together two or more metals. In the alloys, metallic qualities and chemical properties are not always completely altered or masked, as is the case in chemical combinations with the non-metals.

* This thermal unit is the quantity of heat required to raise the temperature of unity in weight of water at maximum density, one degree in temperature. For values of constants, relating to the non-ferrous metals, expressed in "C. G. S." units, see Appendix, Part I.

The physical properties of the alloys are, however, sometimes quite different from those of the constituent metals, notwithstanding the fact that the compounds formed are apparently not definite, as in cases of purely chemical combinations. It would appear probable that the force of chemical affinity performs some part in the formation of the alloy. It is not improbable that a definite compound is usually formed which either dissolves, or is dissolved in, any excess of either constituent which may be present.

Examples of alloys are seen, in gold and silver coins, in which the precious metals are hardened by alloying them with copper, to give them greater durability. Copper is too soft and tough to allow of its being conveniently worked, and it is, therefore, for most purposes, alloyed with tin or zinc, and these alloys—bronze and brass—are, by varying the proportions of the metals used, adapted to a wide range of useful application. Alloys of copper and tin exhibit strikingly the fact, noted above, that the alloy may have widely different properties from either constituent.

Speculum metal is composed of 33 per cent. of tin fused with 67 per cent. of copper. Its color is nearly white, it is extremely hard, exceedingly brittle, and takes a magnificent polish. The latter property gives it value for reflectors of telescopes. Its metallic lustre resembles neither of its constituents, and its tenacity is but about 20 per cent. of that of the weaker metal.

Type metal, also, formed by alloying lead and antimony, in the proportions of four of the former and one of the latter, is a hard alloy, capable of being cast in moulds, taking form very perfectly, and it differs greatly in its properties from either lead or antimony.

It is usually found that the temperature of fusion of an alloy is below, and often considerably below, that of either constituent metal. The strength of alloys is often greater than that of the metals composing them.

The characteristics of the alloys will be discussed at greater length when treating of those compounds hereafter.

The minimum percentage of metal in paying ores varies with the value of the metal in the market, and the cost of reduction and transportation; the following may be taken as fair averages:

Iron	25 to 40 per cent.
Lead	20 to 25 "
Zinc	20 to 25 "
Antimony	20 to 25 "
Copper	2 to 2.5 "
Tin	1 to 1.5 "
Mercury	1 to 2.5 "
Silver	0.0005 to 0.0010 per cent.
Platinum	0.0001 to 0.0002 "
Gold	0.000001 to 0.00001 "

Where two metals exist together, as copper and silver, lead and silver, iron and manganese, the ore may be reduced for the one, and the other obtained incidentally, at less expense, when in even smaller quantities than above given.

CHAPTER II.

COPPER, TIN, ZINC, LEAD, ANTIMONY, BISMUTH, NICKEL, ALUMINIUM, ETC.

29. **Copper** (Latin *Cuprum*, Cu.) has been known to mankind from some very early, and even prehistoric, period, and was applied in the manufacture of tools and useful implements, probably long before iron was used, or even known. It exists native and is comparatively easily reduced from its ores and worked, and hence could be obtained and worked at a time when the art of reducing the comparatively refractory ores of iron had not been acquired.

Tubal Cain worked " in brass and in iron "; the ancient Egyptians mined copper in the neighborhood of Sinai, and of it made an alloy which was used in making their mining and quarrying tools and are supposed by Wilkinson and other Egyptologists, to have been able to temper it as we temper steel. It is more likely, however, that they knew only how to produce and harden the alloys of copper and tin.

All the more civilized nations succeeding those contemporary with Cheops used bronze extensively in making statuary and monuments, and the Greeks and Romans made a statuary bronze, taking a " patina " unexcelled in later times. Their foundry-work was fully equal to that of the moderns. It was also used in coinage by these nations as it is used to-day.

The prehistoric nations of America used large quantities of copper, quarrying it in all those districts in the neighborhood of Lake Superior which have been recently worked for mass copper, and their tools are still occasionally found in the old workings. It was worked in Mexico by the Aztecs, and by the same race in Chili and Peru, before the discovery of those countries by the Spaniards. The bronze used by the Aztecs was of similar composition to that made by their Asiatic contemporaries, and that used frequently in modern times when a tough, as well as strong, bronze is desired—94 per cent. copper, 6 per cent. tin. Bronze implements of great age have been found in all parts of Europe, and so extensively was it used in the period preceding that in which iron became common that that period has been denominated the "Bronze Age."

According to Lubbock,* copper was mined in many localities, and the knowledge of mining, alloying it and of casting in bronze was brought into Europe from the East. The tin with which it was alloyed was obtained, in the time of the Phœnicians, from Cornwall. The forms of the bronze implements found in Europe and in America are often strikingly similar. Bancroft † states that the American Indians were reported by Cabot, in 1598, to be familiar with this metal and its use.

30. **Qualities.**—The metal has a deep red color, the only metal as yet known having that color, is heavy (S. G. 8.8 to 8.93), very malleable and ductile and has considerable tenacity. Its hardness is usually rated at 2.5 or 3. When warm, and when rubbed with the hand, it gives out a strong odor of a peculiar and somewhat disagreeable character. Commercial copper is contaminated with silver, lead, antimony and iron; although the native copper, as much of that obtained from Lake Superior, is sometimes almost chemically pure.

The melting point of copper is given by Pouillet as 2050° Fahr. (1121° C.) and vaporization occurs at the white heat, the vapors burning with the green flame which gives the characteristic lines of this metal in the spectroscope. It is a remarkably good conductor both of heat and electricity. Copper does not oxidize in dry air at ordinary temperatures, but does so rapidly in a moist or acid atmosphere, and at temperatures approaching the red heat.

Of this metal from 225,000 to 250,000 tons are annually

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* "Prehistoric Times."

† Vol. i. p. 12 (Ed. 1856.)

consumed, principally from the United States, Cornwall, Chili and Bolivia. It is supplied in the form of bars, wire, sheet and ingots, which latter are re-melted to obtain copper and alloys in castings. It is, next to iron, the most important and useful of the metals. Its valuable properties will be described at greater length, presently.

31. **Copper Ores** are distributed very widely over the earth's surface and are found in every large political division of the world. It exists in a great variety of forms, usually as sulphide or oxide; but in some cases, as in the United States, on the south shore of Lake Superior, is found in the form of native copper and in enormous quantities. Very large quantities are now mined in Montana, Arizona, and other western districts.

Metallic copper occurs in masses, in flakes and sheets, in threads, and in spongy masses dissemimated through rock crevices, earthy gangue or even solid rock masses. Enormous blocks and extensive masses are found and worked in several of the mines of Lake Superior. These great blocks sometimes weigh several hundred tons. In this condition it is one of the most expensive ores of copper; for the metal is excessively tough, and cannot be blasted, but must be prepared for the market by being cut up with tools; and the presence of siliceous gangue in the mass renders this operation very difficult. In the deposits worked in and near the Calumet and Hecla mine of that district, it exists in the red conglomerate in a peculiar form, permeating the rock very uniformly in just such a proportion as gives maximum ease and cheapness of mining and preparation.

The metallurgists find that comparatively few of the copper minerals are of much importance, by far the largest proportion of this metal annually produced by the mines of the world being obtained from copper pyrites.

Phillips gives the following list of the commercial ores of copper.*

Native Copper is cubical, occurs crystallized in octahedrons, sometimes modified, lamellar, filiform, or arborescent, and has a specific gravity = 8.83. No known locality produces such

* *Vide* "Elements of Metallurgy;" J. A. Phillips. Lond., 1874.

large quantities as the region of Lake Superior, where it occurs in veins intersecting trap rocks, frequently associated with metallic silver. In small quantities, native copper is of frequent occurrence, but except in the region above mentioned, it is not of much importance as an ore. It is generally remarkable for great toughness.

Cuprite (red oxide of copper)—composition, Cu_2O—is cubical, generally in cubes and octahedrons, of a ruby-red color, with a specific gravity = 6, and contains, when pure, 88.80 per cent. of copper.

Melaconite (black oxide of copper)—composition, CuO—is cubical; rarely found crystallized, but more commonly earthy; is massive, or pulverulent, affording, when pure, 79.82 per cent. of copper.

Malachite (green carbonate of copper) crystallizes in the oblique system, the crystals being often very complicated; occurs more frequently massive or incrusting the surface, being botryoidal or stalactitic. The specific gravity = 3.7 to 4.1. Its composition is $CuCO_3$, CuH_2O_2, yielding, when pure, 57.33 per cent. of copper. This mineral frequently occurs near the surface, in veins producing sulphides and other ores of copper, and has probably been derived therefrom by atmospheric agencies.

Azurite (blue carbonate of copper)—composition, $2CuCO_3$, CuH_2O_2—crystallizes according to the oblique system, and also occurs massive. Its specific gravity is 3.5 to 8.81; containing, when pure, 55.16 per cent. of metallic copper. It occurs largely in South Australia, and formerly at Chessy, near Lyons; and is hence sometimes called Chessylite.

Chalcopyrite (copper pyrites)—composition, Cu_2S, Fe_2S_3—is prismatic, often in hemihedral forms, though more commonly massive, with specific gravity = 4.2; containing, when pure, 34.81 per cent. of copper. This, which is the most important ore, rarely contains, as sent to market, more than 12 per cent. of that metal, and frequently less.

Bornite (purple copper ore) crystallizes in the cubical system, and has a specific gravity 4.4 to 5.5. Its composition varies, sometimes $3Cu_2S$, Fe_2S_3; copper from 50 to 70 per cent.

Chalcocite (gray sulphide of copper) is prismatic, and of specific gravity 5.7; its composition is Cu_2S, yielding, when pure, 79.70 per cent. of copper.

The copper sent into the market from the Lake Superior district is principally derived from crushed low-grade rock, containing native copper; that coming from the southern Rocky Mountains is derived from oxides, and that from the Butte district of Montana and from Arizona is obtained from argentiferous ores. The copper smelted in the Appalachian sections is from pyritous ores. Altogether they yield about 200,000 or 300,000 tons annually. The output in 1845 was but 100 tons,* that in 1899 was about 600 millions of pounds (nearly 325,000,000 kilogs.), valued at 15 cents per pound, or over $50,000,000, and was increasing at the rate of 10 to 15 per cent. annually. Much of this product is exported. The refining is done in works situated at Baltimore, Md., Orford, N. Y., and in various other scattered localities in the United States, as well as by the mining companies.

The production of Great Britain is very small, and that of Spain and Chili is enormously great.

Copper smelting in the United States is conducted, by three principal methods, according to the character of the ores. These are: †

Fusion of native copper and refining;

Fusion of carbonates and refining;

Reduction of sulphuretted ores and refining.

Lake Superior copper is of the first class. It is melted down as received with its gangue and with 6 or 8 per cent. limestone and 10 per cent. refinery slags. The charges are about 12 tons each, which are worked in a large reverberatory furnace about 12 hours. The slags are skimmed and the richer grades are refined, while the remainder form a part of the next charge. The refining and ladling take 5 hours.

Cupola furnaces are sometimes used, which take 20 tons at a run, of which 40 or 45 per cent. is limestone, 30 to 35 per

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* "Metallic Wealth of the U. S.": Whitney.

† J. Douglas, Jr., in "Mineral Resources of the U. S." Gov't Print. (Geol. Survey; Interior Dept.), Washington, D.C., 1883.

cent. anthracite coal and 4 per cent. copper. The lining furnishes a considerable amount of silica and is rapidly cut out. The Bessemer process is also used in reducing copper.

32. **The Processes of Reduction** of copper ores differ with their composition. The oxides and carbonates are easily reduced, by fusion, in presence of carbon, with a siliceous flux. The copper is promptly reduced to the metallic state. Some loss is usually met with in consequence of the tendency of the oxide to form a silicate, and this is checked by supplying either an alkaline base, usually lime, or by mixing with sulphuretted ores, of which the sulphur unites with the oxygen present and thus permits complete reduction.

The sulphides are usually first roasted and thus converted to a considerable extent into oxide. This roasted ore is then smelted, sometimes in reverberatory and sometimes in blast furnaces, and this roasting and smelting is repeated until a "regulus" is obtained consisting of a nearly pure sulphide. This product is finally roasted with free access of air until, having been brought to a certain state, in which sulphide and oxide exist in the right proportion, a double decomposition occurs, yielding sulphurous acid and metallic copper ($2CuS + Cu_2O = SO_2 + Cu_6$) which latter is of fair degree of purity, and is known either as "coarse copper," or "blister copper," etc., etc. This is finally purified before it is sent into the market as ingot copper. The final process consists in melting down in the presence of an oxidizing flame and with fluxes, and, after removal of slag, "poling" or stirring with birch poles. This last process of refining is the only one necessary in the treatment of the native copper of Lake Superior. Argentiferous ores, as those of Montana, are now extensively reduced by electrolytic methods, electric currents of enormous volume being supplied by dynamos of large capacity. Gold and silver are in some instances thus produced in considerable quantity as a "by-product" and at no important expense.

33. **Details of Reduction of Copper Ores.**—In detail, these processes are very complex, although sufficiently simple in their theory. The process of reduction usually practised consists of roasting to expel sulphur and arsenic, melting to

flux out iron oxide by siliceous fluxes, and roasting and smelting in one operation to obtain the commercial metal.

The first operation is that of breaking up the ore into small and, as nearly as may be, uniform pieces, removing useless gangue and assorting the ore in such a manner as to facilitate the processes of reduction. The next process is that of calcining, roasting, about three tons at a time, in a reverberatory furnace on a long and wide level hearth—often 15 or 16 feet by 12 or 14 (4.6 or 4.9 metres by 3.7 or 4.3)—where it is spread in a thin layer and exposed to the action of the flame. The hearth is bricked over and cemented with fire-clay and the roof is a low arch. Openings from the fire-place admit the heating gases; others from the atmosphere provide for oxidation by the admission of air; and others at each side are arranged for the discharge of the roasted ore into a low arched space, or chamber, under the furnace. The ore is admitted through openings in the top surmounted by hoppers, into which it is filled and left to heat gradually until dropped into the furnace.

The fuel, a soft coal or a mixture of bituminous and semi-bituminous coal, is burned with restricted air-supply, and the resulting carbonic oxide passes into the furnace, where, meeting the required air, it burns to carbon dioxide, and the long flame sweeping over the hearth, heats the ore to the temperature needed to roast it. While thus exposed to the heat of the burning gas, the ore is continually stirred and raked over to bring all parts of the charge into contact with the flame.

During this process, any sulphur present is exposed to oxygen at high temperature, and a part, but never all, is oxidized, passing off as sulphurous acid; or oxidizing in small amount still further, it unites with the copper to form a sulphate. The arsenic passes off as white arsenic, arsenious acid, in the form of vapor. The copper also combines, to a slight extent, with oxygen, to form the suboxide of copper, and any salt of iron present in sulphides becomes changed to oxide.

In some cases, the roasting is accomplished by indirect heating and out of contact with the flame from the grate.

and the vapors thus isolated are diverted for the purpose of converting the sulphurous acid into sulphuric acid, which latter is collected in the usual way in leaden chambers. Where the gases from the fuel mingle with the vapors of sulphur, and other products of roasting, they are often all carried into a " condenser," in which a spray of water is introduced to wash the air clean before discharging it into the atmosphere.

The ore is now ready to be smelted. If any ores are to be treated which are free from arsenic and sulphur, they are not roasted, but are mixed with the other ores after the latter are calcined, and the mixture is then smelted.

The smelting furnace, called often the " ore furnace," is a small reverberatory furnace, fitted with a comparatively large grate, and having a hearth so formed that the molten ore may lie on it in a shallow pool, deepest near the middle of one side of the furnace. The charge is about one and a half tons of ore, flux and slag derived from a later operation, of which the ore amounts to about two-thirds, while the flux and slags make up the other third. This being charged upon the bed of the furnace, the slag soon melts, and the whole charge later becomes molten and " boils " rapidly with disengagement of sulphurous acid. In the course of four hours, or less, the attendant uses his rubble, stirring the charge thoroughly, and at the same time raising the heat of the furnace until the coarse metal and slag separate. When this is done, the " matt " or " regulus " of partly refined or " coarse metal " is tapped off into a cast-iron box having a perforated bottom, through which it runs into a tank containing water, and thus becomes granulated. The slag is run into moulds, and the blocks so formed—of silicate of iron, principally—are useful in building.

The regulus is only one-third copper, the rest being sulphur and iron, and the whole being a sulphide of copper and iron. It is charged again into the roasting furnace, and calcined for twenty-four hours, the workmen raking it over en or twelve times in the interval, as the sulphur burns out of the more exposed portions. The loss of about one-half the sulphur reduces the charge to a mixture of iron oxide, copper sulphide, and some iron sulphide.

This calcined regulus is then charged with slags from later processes in equal or greater quantity, and with any pure oxides or carbonates at hand, into a melting furnace, and there held in fusion about six hours, when the resulting regulus and slag are tapped off. The former may be run into water as before, and thus made "fine metal," or cast in pigs as "blue metal," containing about seventy-five per cent. of copper. The best copper is found in the pigs last cast, the first producing a less pure metal called, later, "bottoms," or "tile copper." When less rich in copper, it is again calcined and melted to obtain block or coarse copper, containing more metal. The slag, or "metal slag," as it is called, contains, usually, enough of copper to make it advisable to re-work it with the ores, as already described, or separately.

Still another repetition of the calcining and melting processes removes a part of the remaining sulphur, and yields what is called "blistered copper;" the "blisters" on the surface of the ingots giving evidence of the escape of sulphurous acid while solidifying.

Finally, this blistered copper is re-heated in charges of six or eight tons weight, with free access of air, and the arsenic and sulphur remaining are converted into arsenious and sulphurous acid, and the iron, lead, tin, and other oxidizable impurities are converted into oxides before the charge is allowed to melt, this preliminary operation occupying about six hours. The metal is then melted down and sampled to determine how the process of "toughening" shall be conducted. This consists in "poling," or stirring the molten charge with poles, from young saplings of birch, usually, until sample ingots exhibit the density, toughness, fineness of grain, and pure copper color which indicate the desired quality. When right, or at "tough-pitch," it is run into ingot moulds and becomes "tough-cake." The process of poling results in the removal of the oxygen taken up by the copper in the earlier processes by contact with the hydrocarbons and the pure carbon of the wood. Overpoling causes the absorption of bismuth, and gives the same brittleness which had been caused by oxygen; and the avidity with which copper takes up both these elements makes this operation one demanding great care and skill.

Where sheet copper is to be made, lead is often added before casting, to give greater malleability, by fluxing out the tin and other alloy; this lead is oxidized, and is all removed again with other oxides in the slag.

Modifications of this process are adopted with leaner ores; and the melting and poling only is necessary with pure native copper, such as is mined in the Lake Superior region in the United States.

Copper is reduced at Ore Knob, N. C., from very pure but lean ores, containing from two to five per cent. copper. These ores are picked over carefully, and sent to the calcining ground, where they are roasted in heaps, under sheds 240 to 300 feet long and 34 feet wide, the piles measuring 100 tons of fresh, or 50 tons of roasted ore. The roasted ore contains four to five per cent. copper.

Fusion of the ores takes place in furnaces resembling cupolas, and the mattes are smelted in the same kind of furnace. The latter contain twenty or twenty-five per cent. copper. These "single mattes" are roasted in heaps, and fused in shaft-furnaces for black, or pig copper, and "double," or concentrated mattes. This black copper contains ninety to ninety-five per cent. metallic copper, some iron, and other elements.

The mattes are re-worked, and the crude copper is refined in reverberatory furnaces, taking five tons at a charge; the product consists of 99.8 per cent. metallic copper.

The wet processes of copper extraction are divided by Hunt * into three classes:

I. Those in which the copper in sulphuretted ores is rendered soluble in water, after roasting them, converting them into chlorides or sulphates.

II. Those in which free hydrochloric or sulphuric acid is

* Trans. Am. Inst. Min. Engineers, vol. x., p. 11.

used to dissolve the metal from oxides or roasted ores. These are usually costly processes, and are seldom practised.

III. A method by which a hot solution of ferrous chloride with common salt is used to convert copper oxides into chlorides. This is the Hunt and Douglas method.

The Hunt and Douglas process of extracting copper from its ores consists, as practised in North Carolina and in Chili, in the dissolving of the oxides in a hot solution of protochloride of iron and common salt, thus converting the protochloride into peroxide of iron, and the oxide of copper into protochloride and dichloride, the latter of which is soluble in strong brine. From this solution the copper is precipitated by the introduction of scrap iron. This method involves almost no consumption of chemicals other than common salt, which is added to supply unavoidable losses. The sulphurous ores are converted into oxides by crushing, grinding, and calcination in three-hearthed reverberatory furnaces. The iron consumed amounts to seventy per cent. of the copper reduced as cement copper. One furnace roasts two and a half to three tons of ore per day, using one-third cord of wood.

Special cases.—Carbonate ores sometimes supply excellent copper, although rarely, if ever, equal to that found native. They are now smelted in cupola furnaces, in which the parts exposed to highest temperature are surrounded and cooled by water-jackets. These furnaces are capable of smelting 50 tons per day. Oxides are similarly smelted, using about 1 ton of fuel (coke) for 6 or 7 tons of ore. The reduced copper is run into pigs or ingots of 250 to 300 pounds (115 to 160 kilogs., nearly) weight, and containing 2 or 2.5 per cent. slag.

Sulphuretted ores are smelted both in reverberatory furnaces and in cupolas. By the first method, the ores and slags, containing a mean of about 33 per cent. copper, are treated in charges of 4 tons each, and about four charges are worked in 24 hours. The matte is roasted and fused until a regulus is obtained containing 70 per cent. copper. This is slowly melted, the sulphur oxidized out of it, the slag skimmed and the charge oxidized sufficiently by the air-blast to form oxide of copper and sulphurous acid and to produce the reactions,

$$2\,CuO + CuS = 3Cu + SO_2$$
$$CuO + SO_2 = Cu + SO_3.$$

The gases thus carry some sulphuric acid. The metal should finally contain over 95, and even 98, per cent. copper. With labor at $2.25 and $1.50 per day and coal at $4.00 per ton, the cost of reduction is about $35 per ton of copper produced.

Cupolas and modifications of the broad-mouthed furnace of Rachette are also used for smelting the sulphuretted ores, and the cost is thus often reduced some 30 per cent. These furnaces are not as well adapted to treating a wide variety of ore as the reverberatory.* The latter is much better fitted than the former for smelting arsenical ores, and for use where wood is cheap, and charcoal, coal or coke expensive. The slag from the cupola is cleaner, the cost of repair may be made less, and no temporary loss of copper occurs as by its permeation of the bed of the reverberatory.

When the ore is very lean, or contains elements difficult of removal by smelting, or when the separation of silver or other valuable metals alloying with copper is necessary, wet methods of reduction are practised. The copper is either separated by solution or by separate precipitation. Such processes are adopted to save the metal otherwise lost in mine waters either below ground or flowing from ore-heaps.

Copper reduced by the dry method is liable to considerable injury by absorption of oxygen while in fusion. The extent of this injury is well shown by the behavior of bars made for test by the author † in the course of investigations of the properties of bronze alloys.

An analysis was made of the turnings of these bars for the purpose of learning whether the chemical composition would account for the presence of blow-holes and the lack of ductility.

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* "Mineral Resources of the United States." J. Douglas, Jr., p. 270.

† Report of U. S. Board, vol. i. ; 1878.

The result was the discovery of an extraordinary amount of suboxide of copper in bar No. 1. This was no doubt caused by repeated meltings.

The following are the analyses:

	NO. 1. Per cent.	NO. 30. Per cent.
Metallic iron	0.020	0.014
Metallic zinc	0.014	0.057
Metallic silver	0.035	0.014
Metallic arsenic	none	none
Metallic antimony	none	none
Metallic tin	none	....
Metallic bismuth	none	none
Metallic lead	trace	trace
Metallic copper	87.900	96.330
Suboxide of copper	12.086	3.580
Carbon	none	....
	100.055	99.995

No. 30 had been less exposed to the air than No. 1 and less frequently remelted.

34. **Metallic Copper,** although both malleable and ductile, excels in the first quality and finds more frequent employment in the form of sheet metal than in that of wire. These qualities are possessed in the highest degree by the pure metal and are greatly impaired by very slight admixture of foreign elements of metallic alloy. Its tenacity and hardness, although less than that of iron or steel, is greater than that of any other non-ferrous material; and its power of resisting oxidation, of taking a fine polish and of easy working, make it an extremely valuable material to the engineer.

Good copper should have a strength of at least 30,000 pounds per square inch (2,109 kg. per sq. cm.); and cold-working, by wire-drawing, for example, raises its tenacity sometimes to double that amount. If worked hot in the presence of oxygen, it is liable to serious injury by internal oxidation, and, in presence of carbon, by the formation of the carbide. It becomes hard and brittle when hammered or wire-drawn, and its ductility is restored by annealing, by *sudden* cooling—the opposite of the treatment required in annealing steel.

It can be forged, when pure, either hot or cold, more easily than iron. It loses strength with increasing temperature. Its oxide and carbonate are poisonous, and its surface is therefore tinned when it is used for culinary purposes or where liable to serious injury by corrosion.

Copper is very seldom cast, unalloyed, in consequence of the difficulty of obtaining sound, strong castings. When fluxed with phosphorus, it is, however, possible to make castings of good quality; and silicon, also, is one of the best known fluxes for all its alloys. "Phosphorus-copper" has a strength, according to Abel, of from 30,000 to 50,000 pounds per square inch (2,103 to 3,515 kgs. per sq. cm.), as the percentage of phosphorus added rises from one to three or four per cent. Arsenic, in small doses, hardens copper.

Riche* found that the density of copper, subjected alternately to mechanical action, then to tempering or annealing, displays inverse variations according as it is exposed to the air or sheltered from it during the re-heating; while in the first case the mechanical action increases the density, in the second, mechanical action diminishes it.

Professor Farmer has informed the author that he has succeeded in depositing copper, from cyanide solutions by electrolytic processes, harder than untempered steel.

35. **Copper of Commerce.**—The copper found in the market is of several kinds, each known commercially by a different name.

"Lake Copper" is that obtained in the neighborhood of Lake Superior, and is principally native copper. It is remarkably pure, and when well handled in melting and poling, it is considered unexcelled for purposes as, for example, conductors of electricity, in which every trace of foreign matter reduces appreciably, and often seriously, the value of the copper. The best Lake copper has ninety-three per cent. of the conductivity of chemically pure copper.

Australian, South American, and European coppers are

* *Comptes Rendus*, vol. 55, 1862; pp. 143–7.

usually not native coppers, nor are the coppers obtained from nearly every other part of the world. Japanese copper is a richly colored metal, which comes into the market in small ingots. All commercial coppers obtained from other than deposits of native copper are likely to be contaminated by the presence of arsenic, sulphur, oxygen, and metals. Electrolytic copper is very pure and constitutes about half the total production.

Copper, as sold in the market, contains from one-tenth to one per cent. of foreign matter; an excellent sample contained 99.9 per cent. copper. One-tenth of one per cent. of impurity, according to Egleston,* may reduce the conductivity of the metal ten per cent. The presence of one-half per cent. may make the metal worthless for many purposes. The following are analyses of three samples: †

AMERICAN COPPER.—EGLESTON.

	ORE KNOB.	L. SUPERIOR.	BALTIMORE.
Metallic copper	99.80	99.83	99.65
Oxygen	0.39	0.15	0.00
Sulphur	0.00	0.00	0.00
Silver	0.05	0.026	0.066
Lead	0.01	0.016	0.044
Arsenic	0.00	0.00	0.088
Antimony	0.00	0.00	0.035
	100.25	100.02	99.893
Silver in 2,000 pounds	14.6	7.03	19.75

A sample of Swiss copper, found by Berthier ‡ to possess extraordinary softness, ductility, and malleability, was composed of

Copper	99.12	Calcium	0.33
Potassium	0.38	Iron	0.17

and that author concludes that its valuable properties are

* Trans. Inst. Min. Engineers, vol. x., p. 63.

† Ibid., p. 54.

‡ "Essais par la Voie Sèche."

due to the presence of the alkaline metals. Mallet proposes * to introduce an alloy of sodium and tin in the manufacture of gun-bronze to secure freedom from oxide, using 0.05 per cent. sodium, or less.

Copper is too soft, and usually too weak, to be of as great value in the arts as iron, even were its price to admit of such use. It is principally employed in the form of sheets and wire. Copper in heavy sheets is sometimes used for the "fire-boxes" of locomotives, where iron would be rapidly corroded; it is extensively used in making large vessels for manufacturers of chemicals and pipes. Copper pipes of large size, such as are used on marine engines for steam and feed pipes, are made by rolling up sheet copper and brazing the edges together. Small pipe is sometimes drawn to size in dies; feed and "blow-off" pipes are usually thus made; this "solid-drawn" pipe is more costly, but much better, than brazed pipe."

The ductility, malleability, and the considerable strength of copper, permitting its being worked into rods, bars, wire, or sheets with equal facility, make it, next to iron, the most useful of the metals. Its quality is so greatly dependent upon its purity and freedom from oxidation or admixture with other metals, that it is very important to the engineer to see proper precaution observed in obtaining it for structural purposes.

Working by the hammer, in the rolls, or in the wire-mill, causes great increase in tenacity, while carelessness in melting and casting it may render it worthless for the purposes of the engineer, and even the strengthening processes cannot be carried far except with occasional annealing. It may be worked either cold or hot, and forged like iron, if not so highly or so long heated as to cause serious oxidation. It oxidizes quickly at high temperatures, and also when exposed to a damp atmosphere. Fusing it under a layer of salt, it is less liable to injury in the foundry.

Thin sheet copper is subject to a peculiar deterioration of strength, with time, which has been studied but little, and

* "Construction of Artillery," p. 97.

the cause of which is not fully ascertained. This degradation of quality is singularly irregular and erratic, and affects the product of the best mills, as well as low grade copper. It has been noticed particularly in thin metal, as cartridge sheets. This metal is sometimes of nearly pure copper, but often of alloy with zinc in considerable amount. Cartridge metal, passing the severest tests, was reported by Capt. Michaelis as failing in firing; later an improvement was observed. Dr. Egleston attributed failure in such cases to several causes, as impurities in the copper, oxidation, overheating, underheating, and over-compression in the rolling mill. Large quantities of gas are sometimes separated from the metal, often many times its own bulk. The stress and flow caused by the presence of this gas may be the most usual cause of loss of strength with time.

Copper is rarely worked in the lathe or by cutting tools; it is soft, yet tough and tenacious, and is easily distorted by the resistance offered to the tool, which it clogs and causes, especially if the latter is sharp and has an acute cutting angle, to chatter and dig into the work. Its peculiar qualities fit it well for working with the hammer, and it is often forged hot, and still oftener worked cold. Pieces are often cast and then hammered into the desired form, or beaten to the required degree of thinness. If, during the process, the metal becomes too hard and brittle, it is annealed by heating and suddenly cooling it.

Joints are made by soldering or brazing, or by riveting. Welding is practicable with a flux of one part sodium phosphide, two of boracic acid.

Copper vessels are usually brazed, and when used for culinary purposes, or when liable to be filled with alkalies or other substances which may dissolve the metal, are tinned. This operation consists in first thoroughly cleaning and brightening the surface by scraping or sand-papering, then washing with a solution of sal-ammoniac, or of zinc in hydrochloric acid, which leaves a clean metallic surface, free from oxide and greasy matter. Tin is then melted in the vessel and rubbed over the whole interior, the surplus finally poured off, and the polishing completed. Oily and ammoniacal matters, and according to Sir Humphrey Davy, weak solutions of salt, attack copper, as do nearly all acids.

36. **Sheet Copper** was formerly much used by engravers, but has been much less generally called for by that trade since other engraving processes have been perfected. Engraved rolls for calico-printing often have their surfaces made of the finest sheet copper, but are sometimes made of the cast metal. Embossing cylinders are made of copper or gun-metal. The patterns are produced either by engraving or by stamping.

Sheet copper is used to some extent, but less than formerly, in lining air-pump cylinders for steam engines and pumps used in mines, where the water is found to seriously corrode iron ; but here, as in sheathing ships, alloys with tin or zinc have displaced the unalloyed metal.

The sheet copper found in the market is classed as Brazier's Sheets and Sheathing Copper. The sizes of the sheets are :

SIZES AND WEIGHTS OF SHEET COPPER.

	BREADTH.	LENGTH.	WEIGHT.
Brazier's	2 feet.	4 feet.	5 to 25 lbs. per sheet.
	$2\frac{1}{2}$ "	5 "	9 to 150 " "
	3 "	5 "	16 to 300 " "
	4 "	6 "	16 to 300 " "
Sheathing	14 inches.	48 inches.	14 to 34 oz. per sq. ft.

The weight may be approximately computed by multiplying the cubic contents of the mass in inches by 0.3212 to obtain the weight in pounds.

The thickness of sheet copper is often measured by wire-gauge, and the diameter of copper wire is always so measured.

Copper is used to some extent in electro-plating, and is of common use with a slight alloy of hardening metal in coinage ; sheet copper is often tinned. Nearly all the copper used in the arts, however, is alloyed with zinc and tin to form the brasses and bronzes.

When used unalloyed, specifications should call for a tenacity of at least 25,000 pounds per square inch in castings, 35,000 in bars, and 60,000 in wire (5,075, 7,105, and 4,218 kgs. per sq. cm.).

Copper wire is used in enormous quantities in the construction of electric and magnetic apparatus. Its great conductivity, which is six times that of iron, makes it peculiarly valuable for this purpose. Its greater conductivity for heat, also excelling iron two and a half times, has given it value for heating surfaces of steam boilers. Copper "fire-boxes" are often used in locomotives, and copper utensils are of frequent use in minor departments of engineering, as in distillation, and in chemical and culinary operations. It is used to some extent in the sheathing of wooden vessels; but one of its alloys, a special sheathing metal, has now nearly taken its place. The "fastenings" of wooden ships are, in the best practice, always made of copper; it oxidizes very slowly, and its oxide does not injure the timber through which it is driven. Its use unalloyed is far less extensive, however, than when alloyed with other metals.

The steam and feed-water, and other pipes used on shipboard and on locomotives, are often made of copper, as are the staybolts of heating surfaces when the latter are made of this metal. Sheet copper is rolled, for fire-boxes and other purposes, up to 10 feet 10 inches (3.3 metres) long. These sheets must be free from cracks, blow-holes, or scale; and to secure a good surface, the sheets are inspected while going though the rolling mill, and any defects detected are carefully removed by the chisel, or by scraping, before the finishing pass is given. It is even necessary, frequently, to plane the ingots before rolling them.

Fire-box tube-sheets are hammer-hardened, in order that the "expander" used in setting the tubes may not distort the sheet. Hammer-hardened copper, when tested by tension, stretches irregularly, and the hammer-hardened plate may thus be distinguished from plate not so treated; the effect is also seen in the diminished elongation without much change of tenacity. Moderate hammering, according to Lebasteur, is quite as effective as more severe work.

Copper rods, or bars, are made with the same care, and the same precautions are adopted, as in making sheet copper. If reduced by the wire-drawing process, the reduction must be small at each pass, and the metal should be occasionally annealed, if the reduction is considerable. The maximum reduction in diameter should not exceed $\frac{1}{16}$th inch (0.16 centimetre). Rods intended for fire-box stays are often drilled through the axis of the stay, as a means of detecting fracture; these stays are now sometimes made by rolling up heavy sheet copper on a mandril and then drawing to size.

Copper tubes and pipe are sometimes made by repeatedly stamping disk-shaped ingots under the hydraulic press, and thus gradually changing their form to that desired. Very large quantities of copper are used in coinage.

The consumption of copper in the United States is not far from 40,000 tons per annum, and a very nearly equal amount is used in Great Britain (2.8 lbs. per capita).

Copper is, when cast, rendered sound and strong by the use of phosphorus as a flux. Abel, in 1860, found that the introduction of 2 to 4 per cent.* produces a remarkably uniform, sound, dense and tough metal, exceeding the strength of ordinary gun bronze by one-half, and attaining a tenacity of 50,000 pounds per square inch (4,218 kilogs. per sq. cm.)

Alloyed with tin to form bronze, and with zinc to make brass, copper has extensive use in all the constructive arts. It is used in alloying gold and silver for coinage, plate, and other similar purposes for which those metals are too soft. The copper usually amounts to about ten per cent. of the total weight.

COPPER TELEGRAPH WIRE, as stated by Glover & Co., has weight and conductivity, if pure, as follows:

* Construction of Artillery; Inst. Civil Engineers. 1860.

TABLE XVII.

RELATIVE DIMENSIONS, LENGTHS, RESISTANCES, AND WEIGHTS OF PURE COPPER WIRE.

B. W. G. No.	Diameter.		Area.		Weight and Length.				Length and Resistance.					Resistance and Weight.		B. W. G. No.
	Inch.	Millimetres.	Square Inch. 11 d² × .7854.	Square Millimetres.	Pounds per 1,000 ft.	Pounds per Mile. 1,760 yds.	Feet per Lb.	Mile per Lb.	Feet per Ohm.	1,000 ft. per Ohm.	Miles per Ohm.	Ohms per 1,000 ft.	Ohms per Mile.	Ohms per Lb.	Lbs. per Ohm.	
0000	.454	11.5313	.161883	104.435	623.924	3294.32	1.60276	.000303553	19966.5	19.9665	3.7815	.050084	.264443	.000080272	12457.5	0000
000	.425	10.795	.141862	91.52	546.76	2886.89	1.82895	.00034639	17497.15	17.49715	3.31385	.0571522	.301763	.000104529	9566.7	000
00	.380	9.6518	.113411	73.165	437.105	2307.92	2.28777	.0004333	13988.04	13.98804	2.64925	.071489	.377465	.000163553	6114.24	00
0	.34	8.6358	.0907922	58.573	349.928	1847.62	2.85773	.00054124	11198.17	11.19817	2.12086	.0893002	.471505	.000255196	3918.56	0
1	.300	7 620	.070686	45.602	272.435	1438.43	3.6796	.00069519	8718.30	8.71830	1.6512	.114701	.60562	.00042102	2375.18	1
2	.284	7.2134	.0633472	40.867	244.151	1289.11	4.0958	.00077573	7813.50	7.81350	1.47973	.12799	.67580	.00052422	1907.59	2
3	.259	6.5784	.0526854	33.989	203.058	1072.15	4.9247	.0009327	6498.14	6.49814	1.23071	.15389	.81254	.00075786	1319.50	3
4	.238	6.0451	.0444881	28.701	171.465	905.333	5.8321	.00110457	5487.107	5.487107	1.03923	.182245	962256	.0010629	940.844	4
5	.22	5.5879	.0380133	24.523	146.510	773.56	6.8255	.0012927	4688.51	4.68851	.887975	.213287	1.12616	.0014558	686.911	5
6	.203	5.1561	.0323655	20.88	124.742	658.638	8.0165	.0015183	3991.91	3.99191	.756045	.250506	1.32267	.0020082	497.96	6
7	.18	4.5719	.0254469	16.417	98.076	517.844	10.1962	.0019311	3138.59	3.13859	.59443	.318614	1.68228	.00324863	307.822	7
8	.165	4.1909	.0213825	13.794	82.411	435.135	12.1345	.0022981	2637.29	2.63729	.499486	.379177	2.00206	.00460101	217 343	8
9	.148	3.7591	.0172034	11.098	66.305	350.089	15.0818	.0028564	2121.84	2.12184	.401864	.471289	2.488405	.00710791	140.689	9
10	.134	3.4035	.0141026	9.098	54.354	286.99	18.398	.0034845	1739.40	1.73940	.329432	.574911	3.03553	.0105772	94.543	10

11	.12	3.0479	.0113097	7.296	43.590	230.152	22.9413	.004345	1394.93	1.39493	.264191	.716882	3.78514	.0164462	60.8042	11
12	.109	2.7701	.00933133	6.0199	35.964	189.893	27.805	.005266	1150.91	1.15091	.217976	.868875	4.58766	.0241593	41.392	12
13	.095	2.4129	.0070882	4.573	27.319	144.245	36.6047	.0069326	874.252	.874252	.165578	1.14383	6.03945	.0418692	23.8839	13
14	.083	2.1082	.00541062	3.4906	20.853	110.1061	47.954	.009082	667.338	.667338	.12639	1.49849	7.91203	.0718583	13.9163	14
15	.072	1.8288	.00407151	2.486	15.652	82.855	63.7267	.012069	502.175	.502175	.095109	1.99134	10.5142	.126788	7.8872	15
16	.065	1.6510	.00331831	2.1407	12.789	67.5276	78.1902	.014809	409.276	.409276	.077514	2.44334	12.9008	.191045	5.2344	16
17	.058	1.4732	.0026421	1.7045	10.1828	53.7675	98.203	.018589	325.871	.325871	.061718	3.0687	16.20274	.301355	3.31835	17
18	.049	1.2446	.00188574	1.2165	7.26796	38.3748	137.590	.0260587	232.585	.232585	.04405	4.2995	22.7014	.59157	1.6904	18
19	.042	1.0668	.00138544	.894	5.33972	28.1937	187.247	.035469	170.879	.170879	.032363	5.8521	30.8991	1.09596	.9122445	19
20	.035	.8890	.000962115	.6207	3.70815	19.579	279.676	.061075	149.3915	.1493915	.022475	8.42703	44.4947	2.27254	.44003	20
21	.032	.8128	.00080425	.5188	3.09972	16.3665	322.610	.061100	99.195	.099195	.018787	10.08116	53.2285	3.25229	.30748	21
22	.028	.7112	.000615753	.3972	2.37312	12.5301	421.384	.0798078	75.9461	.0759461	.014384	13.1672	69.5230	5.54848	.18023	22
23	.025	.635	.00049087	.3167	1.8919	9.9892	528.570	.100108	60.54377	.06054377	.011467	16.5170	87.2096	8.73038	.11454	23
24	.022	.5588	.000380133	.2452	1.4650	7.7357	682.55	.129271	46.8851	.0468851	.0088798	21.32874	112.616	14.5579	.068691	24
25	.020	.508	.00031416	.2027	1.21082	6.39315	825.883	.156417	38.748	.038748	.0073386	25.808	136.265	21.3142	.046917	25
26	.018	.4571	.000254469	.1642	.98077	5.17844	1019.61	.193108	31.3859	.0313859	.0059443	31.86144	168.229	32.4863	.030782	26
27	.016	.4064	.000201062	.1297	.77492	4.0916	1290.44	.24440	24.79873	.02479873	.0046967	40.3246	212.914	52.0367	.019217	27
28	.014	.3556	.000153938	.0993	.5933	3.13264	1685.48	.31922	18.98653	.01898653	.0035959	52.66892	278.092	88.7724	.011265	28
29	.013	.3302	.000132732	.0856	.511571	2.7011	1954.76	.370220	16.3710	.0163710	.0031006	61.0834	322.521	119.404	.008375	29
30	.012	.3048	.000113097	.0730	.4359	2.30152	2294.13	.434496	13.9493	.0139493	.0026419	71.68825	378.514	164.462	.0060804	30

PURE COPPER weighs 555 lbs. per cubic foot. The resistance of one mil-foot at 60° Fahr. is, according to Dr. Matthiessen, 10.32411 Ohms. Upon these data the above table has been calculated.

The *resistance* of copper varies with the temperature at about 0.38 per cent. per degree Centigrade, or 0.21 per cent. per degree Fahr.

STRANDED WIRES.—A *stranded conductor* of a given length is of *greater weight* and has a *less resistance* than an equal length of the same number of wires *unstranded.*

37. **Tin** (*Stannum;* Sn.) is less widely and less plentifully distributed than copper, but has probably been as long known and as generally used. In fact, the two metals have always been, as they are to-day, almost invariably used together; and their alloys, the bronzes, have been in general use since the earliest times. The ores of tin are found and worked extensively in Devonshire and Cornwall, Great Britain, and less extensively in Malacca, Banca, Germany, and Australia, in small quantities at Ashland, Alabama, and lately in the Black Hills of Dakota. Banca tin usually commands the highest price; it is known in the market as "Straits Tin."

Tin is found as "stream tin" (cassiterite) in many parts of the United States which are underlaid by the primitive rocks, and the ores are found in small quantities in California and other States west of the Mississippi, in Maine, and in Alabama. It is only worked at Ashland, and in a few other localities scattered over the United States. The tin used in the United States comes principally, via Great Britain, from Banca, Billiton, Cornwall, Australia, and South America. The amount is about 20,000 tons annually.

Tin sometimes occurs in the metallic state, but is generally found as an oxide.

38. **Ores, and Processes of Reduction.**—The common ore of tin, cassiterite, stannite, stannic oxide, $Sn O_2$, is a dioxide, and is often called tin-stone or stream-tin. The ore usually contains between 65 and 75 per cent. metal. It occurs in veins traversing the primitive rocks. Much care is demanded in dressing it, and in assorting it into the four qualities usually classed at the mine. The ore is stamped, washed, weathered a few days, calcined, again weathered and washed, and finally smelted in reverberatory furnaces. The tin thus obtained requires refining, which is done as in the working of copper, the melting and poling demanding and occupying five or six hours, and yielding a very pure metal. The blast-furnace is sometimes used instead of the reverberatory, and is said to yield a purer tin.

In detail, the processes of preparation are as follows:

The oxide comes to the metallurgist as "tin-stone," or oxide, either as "stream tin ore," called often "alluvial ore," or "mine tin ore." The former is usually comparatively clean. The latter is washed, to free it from the earthy matters accompanying it, by stirring it on a grating under a flowing stream; it is then assorted carefully, the stony and useless part picked out and thrown away, the remainder broken, if in large pieces, and reduced to a sufficiently small size to work well under the stamps.

The stamps consist of a series of heavy blocks of wood shod with cast iron, usually weighing 225 pounds (102 kilogrammes) or more, mounted on the lower ends of vertical shafts. They are lifted by cams revolving on a horizontal shaft, which engage lugs secured to the vertical rods. The motive power is either water or steam, and the stamps make fifteen to twenty-five blows per minute. The stamps fall into a trough into which the ore is fed, and as it is pulverized by the blows it is washed out at the side, through a finely perforated screen, by a constantly flowing stream of water.

From the stamps, the fine ore is carried by the current to a succession of settling tanks, in which it collects, while all other and lighter matter is swept away. The "slimes" thus retained are removed, are again washed in a flowing stream of water, and are then sent to the calcining furnaces. These are reverberatory furnaces, in which the sulphur and arsenic are driven out of the pyrites with which the ore is usually contaminated. The addition of common salt aids in this process, by the production of vaporous chlorides.

The ore is now washed once more to remove the sulphate of copper which exists in the mass, and often still again to free it from oxide of iron and other lighter mineral matters, leaving the "black tin" in proper shape for smelting.

The smelting process is conducted in reverberatory furnaces similar in general form and method of working to those used in iron working. The charge of ore, now containing about sixty per cent. tin, and weighing a ton or more, including about twenty per cent. its weight of ground coal and lime, introduced as a flux to remove the silica, is dampened with a small quantity of water and spread upon the hearth.

At a low, and long-continued heat, the oxide of tin gradually becomes deoxidized by the carbon present, and the metallic tin settles in the middle of the furnace, the hearth being slightly dished to receive and retain it. The ore is continually stirred as this goes on, to facilitate the settling of the tin; while the heat is finally considerably raised to produce a fluid slag. The slag is finally removed, and the tin is run off into a reservoir, from which, after the dross has risen to its surface and been skimmed off, the metal is cast in ingots. A portion of the slag is sufficiently rich in tin to be re-worked.

The ingots of tin, made as above, are refined by re-melting and separation from the dross, and then "boiling" in a large refining basin, kept at a moderate temperature, somewhat above that of fusion, by a process resembling in principle the "poling" of copper. The wood is secured in the bottom of the tank under the tin, and the steam and gases rising from it as it chars beneath the molten tin, cause the foreign materials to separate and rise to the surface.

This process being completed, the tin is again cast in ingots; the quality of the metal being determined, not only by the extent to which the purification has been carried, but on the part of the pool from which the ingot is cast. The upper part is purer than the lower, and yields "refined tin," while the lower portion is ordinary "block tin"; they should contain from 0.985 to 0.998 pure tin. The lowest part of the molten mass in the basin is reserved for further refining.

A small blast-furnace is sometimes used, as in Saxony, in reducing the ore; but it is a wasteful process. The fuel is charcoal, and the flux is either siliceous or calcareous, according as the ore contains an excess of basic or acid constituents.

39. **Commercial tin** is never pure. Chemically pure tin has a specific gravity of 7.28 to 7.4, according to the method of preparation, the purest being lightest. Its atomic weight is 116; color white, with a tinge of yellow; it possesses a peculiar odor; it oxidizes with difficulty, and when bent emits the crackling sound known as the "cry of tin." It has little tenacity, considerable ductility, and greater malleability.

The coefficient of expansion is 0.000023; its melting point is 443° Fahr. (232° Cent.); specific heat, 0.0562; latent heat of fusion, 14.25. It boils at a white heat; its conductivity is low.

Tin oxidizes very slowly in the air at ordinary temperatures, but burns quite freely at a white heat and with a white flame. Exposed to severe cold it becomes crystalline and friable. Its principal uses are in the making of alloys with copper, zinc, lead, etc., and in the manufacture of "tin-plate."

The yellow oxide is used for polishing metals, such as steel cutlery and glass. The white oxide is used in making a white opaque glass generally known as "enamel."

This metal is readily rolled into very thin sheets, known as tin-foil, and drawn into tubes and into fine wire. It resembles zinc in its change from great ductility at the boiling point of water, to equal brittleness at about 400° F. (204° C.). It then melts a few degrees above the latter temperature, as already stated.

The following is a complete analysis, made at the request of the Author, of Queensland tin:

ANALYSIS OF "QUEENSLAND TIN."

	Per cent.		Per cent.
Lead	0.165	Antimony	none.
Iron	0.035	Bismuth	"
Manganese	0.006	Nickel	"
Arsenic	trace.	Cobalt	"
Copper	none.	Tungsten	"
Zinc	"	Molybdenum	"

Kerl * gives a set of analyses, thus:

KIND.	BANCA.		BRITISH.		PERUVIAN.		SAXON.	BOHEMIAN.	
*Elements....	1	2	1	2	1	2		1	2
Tin	99.961	99.9	99.96	98.64	93.50	95.66	99.9	99.59	98.18
Iron	0.019	0.2	......	......	0.07	0.07	......	......	.....
Lead	0.014	......	......	0.20	2.76	1.93	......	......	.....
Copper	0.006	......	0.24	0.16	......	......	......	0.406	1.60
Antimony	......	......	......	......	3.76	2.34	......	......	.....
Bismuth	......	......	......	......	......	......	0.1	......	.....

* Metalhuttenkunde, 1873.

Grain tin is made by heating ingots to a temperature at which they become brittle and breaking them up by dropping them on the floor.

Manufactured tin is found in the market in nearly every form in which iron and copper are sold.

Tin-foil is made by rolling into plates and sheets, then heating, doubling, and again rolling, and repeating the latter processes until it is sufficiently thin for use as desired. It is sometimes rolled down in a compound sheet composed partly of lead; and it is often alloyed with lead to make thin sheets and other forms. Tin-plate is made, as described in the preceding volume, by tinning sheet-iron, and consists principally of the latter metal. Copper, lead, and zinc are sometimes tinned. Brass pins are tinned by dipping in a solution of the chloride or of the oxide; the other metals are sometimes similarly tinned.

Unmanufactured tin comes into the market as "block tin," as "grain" tin, and in small bars or "sticks." Block tin is cast in ingots or blocks in moulds of marble; grain tin is made by heating these ingots until very brittle, and then breaking them up on stone blocks; it is sometimes granulated by melting and pouring into water.

The production of tin has been enormously increased during late years by the increased demand for tin-plate, which is due to the growth of the "canning industries" and the roofing business. The consumption now exceeds a quarter of a million tons per year.

Sheet tin, or tin-foil, is often no more than one-thousandth of an inch (0.00254 cm.) in thickness. The foil is used for wrapping tobacco and other materials which are to be protected from the action of the atmosphere. Thicker sheets are used in "silvering" mirrors by amalgamation with mercury, and for making amalgam and for other purposes connected with the generation and use of electricity. Pure tin is used in making some tin vessels, as dyers' kettles. Its cleanliness and excellent qualities make it valuable for tinning culinary utensils. The tubes are used sometimes alone, and often as a lining for lead pipe, in the supply of water to houses. The wire is very ductile and moderately tenacious, and has the perfect inelasticity exhibited by tin in all its forms.

Tin is very extensively used alloyed with lead, in pewter and Britannia metal, and sometimes with a little copper as a hardening or "temper."

The evidence lately discovered of the existence of an extensive region, bearing tin, in Dakota, according to the report of Professor Blake,* and of other deposits in Alabama, lead to the expectation of a large future development of this industry in the United States.

Of the whole product of the world, over 15,000 tons per annum are used in Great Britain, probably nearly 20,000 in the United States. Cornwall supplies above 10,000 tons per annum, Banca is producing large quantities, and Australia is rapidly approaching that district in its production. The use of tin for "tin-plates"—sheet iron tinned on both sides—is a very great proportion of the total. Good "tin-plate" is plated with the best tin, while the cheaper, or "terne," plates are plated with cheap alloy. Good tin-plate is distinguished by the thickness, evenness, and brightness of the coating of tin, the absence of dark spots produced by imperfections in the coating and of roughness due to the incomplete covering of the rough iron surface. "Pin-holes" in the coating often indicate a low grade of iron in the plated sheet. The iron should be good "charcoal iron," but is often "coke iron." The cheaper grades are as suitable for many purposes as the more expensive.

40. **Zinc** in the metallic state was not familiar to the ancients, although they were accustomed to use its ores in the manufacture of brass. The alloy was used in coins occasionally; the Greek and Roman coinage was, however, principally bronze. Zinc was probably discovered, five hundred years ago, by Albertus Magnus, and by him called *marchasita aurea;* its modern name was first given by Paracelsus in the middle of the sixteenth century. It became a regular article of manufacture about 1720, in Germany, and in England

* *Engineering and Mining Journal*, 1883.

fifteen or twenty years later; the ore generally reduced was calamine, and the process was one of distillation. The metal had already been smelted in the East Indies. It has been regularly manufactured in the United States since about 1850, first at Bethlehem, N. J., and later in a number of other localities. The city of St. Louis, alone, supplies the market with fifteen tons per day. The whole product for the United States was, in 1900, about 125,000 tons (or tonnes, nearly).

Zinc ores were known to the ancients, and were used in the manufacture of brass long before the art of reducing them was discovered. The alloy was made by smelting together the ores of copper and zinc. The metal became known about 1600, but was little noticed until after Hobson and Sylvester discovered, in 1805, that it becomes ductile and malleable at about 300° F. (144° C.), when it was brought into the market in competition with lead. It has since been extensively used for sheathings, roofing, culinary, and other vessels, architectural ornaments, etc. The oxide is extensively used as a substitute for white lead.

41. **Ores of Zinc** occur abundantly in the United States, the best being obtained in New Jersey, Pennsylvania, and Virginia, and in a line of deposits running through West Virginia and the Middle States, across to Illinois, Missouri, and Kansas, and north into Wisconsin. Large quantities are mined in Missouri and other parts of the country. They are mined extensively in Europe. Calamine and blende are the ores principally used in the production of the zinc of commerce.

These ores are the carbonate known as calamine, the silicate, or siliceous calamine, the sulphide, or blende, and the oxide, or red ore.

The latter is given its color by the oxides of manganese and iron which are present with the zinc. It is the common ore of New Jersey. Calamine is also found in the United States, near the red ore. It is a common ore in the North of England and in Scotland, in Belgium, Silesia, Spain, and Sardinia. It is an impure carbonate, having a peculiar columnar structure, a dirty red color, and moderate cohesion.

It often contains lead, iron, manganese, and cadmium and rarer metals.

When raised from the mine, the ores are carefully picked over, and the gangue and lean ores removed as completely as possible. They are next broken to small fragments or powder under stamps, and washed very thoroughly.

They are calcined and smelted, the calcination rendering them porous and more easily reducible by driving out moisture and carbonic acid. The process is generally conducted in reverberatory furnaces, but sometimes in kilns.

In smelting, the ore is mixed with half its weight of any cheap form of carbon, the two materials being well ground and mixed, and is reduced at a high temperature in retorts or muffles, usually three feet long and eighteen inches high, a half-dozen being heated in a single furnace. The reduced metal passes off in the state of vapor, condenses as it issues through a properly formed channel, and flows into the moulds placed to receive it. The process is therefore one of distillation.

Two processes are in use—the Belgian and the Silesian. In the former the distillation is carried on in cylindrical retorts, four or five diameters in length, put up in "benches," which consist of forty or fifty, or even more, set in several rows, one above another, within a furnace stack, with one end depressed and accessible from the front. Two or four furnaces are often built in one structure, and their products of combustion are led to a single chimney. The upper rows of retorts are charged with about sixteen pounds (7.26 kilogrammes), and the lower with fifty per cent. more ore, the charge being first moistened to prevent the formation of dust. The furnaces and retorts are heated separately, and after three or four days' heating the former, the latter are introduced. The open end of the retort is closed by a fire-clay plug to which an iron funnel-shaped cap is fitted to conduct the distilled zinc away, while acting also as a condenser. Every two hours these are removed and cleared out, the zinc collected in them thrown into a ladle, and the unreduced oxide found with it is re-worked later. The retorts are re-charged every twelve hours, and the furnaces are only stopped for repairs about once in every two months. The zinc is poured from the ladle, when filled, into ingot moulds.

In the Silesian process, the distillation is carried on in ovens or muffles, which are better calculated to bear high temperatures, and in which, therefore, the work can be more perfectly done.

The distilled zinc runs down an iron tube, which is the condenser, into a small reservoir at the mouth of the oven. Thirty-two are set in a furnace. They are re-charged once a day. Re-melting is carried on in clay-lined iron crucibles or kettles. The fuel consumed in these processes is from about six times the weight of ore in the best examples of Belgian work, to twelve or fifteen in the Silesian furnaces.

Zinc ores are often found to contain lead, and their treatment by usual processes is somewhat difficult. Thus Chenhall * gives:

COMPOSITION OF ZINC ORES.

	CONSTANTINE.	CAVALO.	BLUESTONE.	AMERICAN.
Zinc	10.64	13.40	29.28	27.20
Lead	4.81	17.14	12.90	12.00
Copper	1.35	0.44	0.65	0.20
Silver and Gold	0.04	0.06	0.03	....
Sulphur	26.85	15.37	22.14	....
Iron	19.93	4.98	7.16	....
Alumina	2.33	1.02	....	....
Magnesia	....	0.22	....	....
Barium sulphate	....	35.04	....	..
Silica	26.48	11.19	26.84	....
Arsenic	0.65	0.13	0.15	....
Lime	0.60	....	0.84	....
Sulphuric Acid	3.53	....	....	....
Antimony	0.02	....	....	....
Oxygen and loss	2.77	1.01	1.01	....
	100.00	100.00	100.00	....

These ores are treated by the Parnell process of dissolving in sulphuric acid, and decomposing the sulphate by heating

* Proc. British Institute Civil Engineers; 1882–3; Part iv.

it with the sulphide. The loss is reported to be, for lead ores, which are similarly treated, three per cent.

Commercial zinc thus prepared usually contains some lead, and may contain a considerable amount. Where needed pure, it should be very carefully selected by analysis.

42. **Metallic Zinc** is a bluish white metal known to the trade as "*spelter.*"

Its atomic weight is 65. It is rather brittle, and can be rolled satisfactorily only when heated somewhat above the boiling point of water. When pure, it can be worked, with care, into bars or sheets at ordinary temperatures. After passing the boiling-point, it again gradually loses its ductility and malleability, and can be powdered readily at a temperature somewhat below the red heat.

The rolling of this metal was at first accomplished with very great difficulty, from the fact that its malleability is confined to very narrow limits of temperature. For this reason it is always an operation only entrusted to experienced hands. The most suitable temperature is about 120° Cent. (248° Fahr.), and this must be maintained throughout the process. Below this point the metal opposes too great a resistance, and must be re-heated; above this point it becomes brittle; at 200° Cent. (390 Fahr.), it can be brayed in a mortar.

Zinc should be re-melted before being rolled into sheets. The heat of fusion varies between 400° Cent. and 500° Cent. (750° Fahr. and 930° Fahr.). Re-melting is generally performed in a reverberatory furnace to cleanse the zinc of impurities. The thickness of the ingots must vary with the final dimensions required; this renders re-melting indispensable.

The re-melted plates are first roughed down or rolled between heavy rolls, and after being cut down to a fixed weight, are taken to the finishing train, where the rolling is completed. There are thus two distinct operations—the roughing down and the finishing. Between the two, the sheets are re-heated in annealing boxes placed upon the melting furnace. Each operation gives rise to a production of scrap, which is more or less large in amount according to the quality of the metal and thickness of the sheet. This scrap, and all defective sheets, are re-melted with the ingots from the foundry.

The fact that zinc, heated to a temperature exceeding the boiling point of water, becomes malleable, was discovered about the year 1805, and rolled sheet zinc then soon made its appearance in the market, and was used to some extent as a roofing material.

Zinc is used extensively in the form of sheets for roofing, sheathing of iron ships, domestic utensils, etc., etc. Very large quantities are used by the engineer in the brass alloys and in the surface-protection of sheet-iron. It unites readily with the other useful metals to form alloys, which are usually characteristically different from their constituents. The principal of these alloys are the brasses, or alloys with copper. The metal is also often mixed in small proportions with the bronzes, or copper-tin alloys, to form the copper-tin-zinc ternary alloys often used in machine construction. Of the world's product of this metal, amounting to above 200,000 tons, the United States produces twenty per cent. Belgium and Germany make two-thirds.

Zinc sheets of standard dimensions have the following weights:

THICKNESS AND WEIGHT PER SQUARE FOOT.

Inch.	Inch.	Inch.
.0311 = 10 oz.	.0534 = 14 oz.	.0686 = 18 oz.
.0457 = 12 oz.	.0611 = 16 oz.	.0761 = 20 oz.

Cast zinc, as well as rolled, is often used in the manufacture of ornamental work; it takes the impression of the mould as sharply as good foundry iron, and is especially liked for small work.

A prize offered in 1826 by the Society for Advancement of Industry in Prussia, led to the discovery, by Krieger, of Berlin, that hollow ware can be cast in zinc, and, by Geiss, that it would make good architectural ornaments. An extensive consumption of the metal for these purposes at once arose, and the applications of zinc in these directions are becoming rapidly more general. It is largely used in decoration, as a substitute for bronze, and to a considerable extent in the construction of large statuary; in this case, however, the mass is usually built up of smaller parts soldered together. Berlin has been the head-quarters of this industry.

Zinc castings made at a high temperature are brittle and crystalline; when cast at near the melting point, they are comparatively malleable. It is hardened by working, and must be occasionally annealed.

The value for sheathing and for work exposed to the weather, arises from the permanence and impenetrability of the coating which forms over its surface—a basic carbonate.

Zinc is the most strongly electro-positive of the metals of commerce, and is almost exclusively used as the perishable element in voltaic batteries.

It has a specific gravity of 6.9 to 7.2, melts at 770° F. (410° Cent.), and boils at 1900° F. (1040° Cent.); its vapor burns readily with a bluish-white flame, forming the white oxide.

The salts and the higher oxide of zinc are extensively used in the arts, especially in making paints and dyes. The chloride is used in large quantities as a preservative of timber and as a disinfectant.

Rolled zinc is made very much as sheet lead or sheet copper is made; but its temperature must be kept at a little above the boiling point of water, to secure the necessary malleability, and it must also be free from alloy. It is freed from its most usual constituent, lead, by re-melting the spelter, as received from the furnace, on the hearth of a reverberatory furnace which has a gradual slope terminated by a basin, into which the melted metal flows, and in which the zinc and lead separate, the lead settling to the bottom, while the zinc lies on the top. The zinc is ladled out and cast into ingots for the mill.

These ingots are warmed to the proper temperature, and then rolled into sheets, and sometimes into bars, between rolls kept heated by the passage through them of steam of moderate pressure.

Galvanized iron is sheet iron covered with a coating of zinc by immersion in molten zinc.

Zinc is produced in the United States to the amount, annually, of about 120,000 tons (1899), and the production is rapidly increasing. At least one-half comes from Illinois, one-third from Missouri, and nearly as much from Kansas. New Jersey supplies zinc of excellent quality, and furnishes all that is exported, sending abroad considerable ore. The gas-furnace of Siemens is now adapted to smelting zinc, and is coming into general use in consequence of its cheapness of operation and manageability. The known deposits of zinc are being rapidly worked out.

The importations of foreign zinc into the United States are more than equalled by the export of special grades of American zinc to Europe, where the metal is much sought on account of its high value for the manufacture of military rifle cartridge cases.

The amount of coal used for one pound of zinc is the following at the different works, the Eastern works using anthracite principally, and the Western works using bituminous coal:

	FUEL.	REDUCTION.	TOTAL.
Passaic	4.5	1.3	5.8
Bergen Point	5.5	1.9	7.4
Lehigh	4.5	1.7	6.2
Carondelet	4.4	1.2	5.6

The yield of zinc is stated to be

Lehigh, for calamine	73.5	per cent.
Lehigh, for blende	70.0	"
Passaic, for calamine	80.0	"
Martindale, for blende and silicates	73.0	"
Carondelet, for silicates	76.80	"

Of the whole quantity consumed in the United States in 1899, about ten per cent. is used in galvanizing wire.

43. **Lead** (*Plumbum;* Pb.) is a bluish-white, lustrous, inelastic metal, so soft that it may be easily scratched with the finger-nail. It has too little tenacity to be readily drawn into fine wire, although some lead wire is found in the market. It is very malleable, and is very extensively used in the forms of sheet-lead and lead-pipe. It is very heavy (S. G. 11.4), and is easily fusible, melting at 620° F. (327° C.); it absorbs, in fusing, 5.4 metric thermal units per kilogramme (9.8 B. T. U.). Its specific heat is 0.03 at low temperature, and 0.04 near the melting point. The coefficient of expansion is given by Calvert and Johnson at 0.00003. It is a very bad conductor of both heat and electricity. At high temperatures it becomes slightly volatile; in this respect and in changing in character from ductile to brittle as the melting point is approached, it resembles zinc somewhat.

Oxidation occurs but slowly in dry air, and the oxide forms a protecting coating over the metal. When exposed to moist air containing carbonic or acetic acid, however, oxidation progresses rapidly. Lead is readily dissolved in water containing carbonic acid or salts of nitric acid; the solution is poisonous, as all the salts of lead are cumulatively poisonous.

Lead oxides are of great value in the arts. "Red lead," or minium (Pb_4O_5), is used, mixed with drying oils, as a pigment, and by the engineer as a cement, in the latter case often mixed with "white lead," a basic carbonate [$2PbCO_3Pb(OH)_2$], which admixture gives greater hardening and cementing power; this quality is often still further improved by the addition to the cement of red and white lead, in oil, in equal parts, of several times its weight of borings of iron with a little sal-ammoniac and sulphur. Red lead is much used in the manufacture of flint glass.

Lead compounds are easily identified by the formation of the yellow oxide in the reducing flame of the blow-pipe. Lead salts in solution give a black precipitate when exposed to the action of sulphuretted hydrogen.

Lead was known, but was of little importance in the earliest historic times. It is supposed to have been discovered later than either copper or tin. It was the custom, apparently, among the Hebrews and their contemporaries, to engrave records of importance, and which were desired to be made permanent, upon tablets of lead with an iron stylus. The Phœnicians used the metal in weighting anchors, and sold it to the Greeks and the Egyptians. It was used by the Babylonians, according to Herodotus, in securing iron cramps in masonry, probably in the same manner as is usual in modern engineering.

44. **The Ores of Lead** are galena or the sulphide, and the carbonate. Nearly all the lead of commerce is obtained from galena, which consists of eighty-seven per cent. lead, nearly, when pure, and 13 per cent. sulphur; it nearly always contains silver, sometimes in quite large amounts, varying from a fraction of one per cent. up to fifty per cent.; arsenic, copper, iron, and zinc. The ore is very often worked for its silver. Galena is worked in Saxony and Bohemia, in England, Spain, and the United States; it is usually found in the palæozoic rocks. The ores worked in the United States generally contain comparatively little silver, and are quite pure. They are found principally in the valley of the Mississippi. Enormous deposits exist in Missouri, Iowa, Illinois, and Wisconsin, in crevices and pockets in those lower Silurian rocks which have lately been distinctively known as the galena limestone. These deposits have been worked only from about 1820, although the existence of the ores had been then known more than a century. The ores of lead occur all through the Alleghanian districts of the eastern United States, but none are profitably worked.

Lead ores are now often smelted in furnaces of the Rachette type, *i.e.*, having a rectangular form and widening section from bottom to top. These permit the use of a low pressure of blast, and comparatively unlimited magnitude of charge. The fuel is usually charcoal or coke, or both, the flux is iron and limestone, or sometimes silica, and the ore is broken to the size of the fist or of an egg. The ore is often first roasted. The total fuel used amounts to from fifteen to twenty-five per cent. of weight of charge.

45. **The Smelting of Galena** is performed in a reverberatory furnace, first roasting it, usually adding a little lime, until it is largely converted into lead sulphate. An increase of temperature of furnace with an oxidizing flame drives off the sulphur in the form of sulphurous acid, and the reduced metal is tapped off. Some of the lead is volatilized, and is condensed in the flues or in a vacuum chamber, constructed for the purpose, in which it meets with a shower of water.

Antimony and tin, when present in objectionable proportions, are oxidized by exposing the molten lead, in shallow pans, to the action of the air. Silver is removed, often, by the Pattinson process of concentration, by melting, agitation, and slow cooling, with repeated separation of the crystallizing metal which contains little silver, from the more infusible portion which is richer in the precious metal. The final product is subjected to the action of the air at high temperature, which oxidizes the lead and leaves the silver in the metallic state.

The lead-smelting process is very largely, like the process of reducing copper, one of desulphurization. The preliminary roasting of galena converts a part into oxide of lead, the metalloid passing off in sulphurous acid, while another portion becomes a sulphate. The whole mass is then melted, the sulphur all passing off in sulphurous acid, and the metallic lead is left behind. This is done on the basin-shaped hearth of a reverberatory furnace, which is about six feet (1.8 metres) wide and 8 feet (2.44 metres) long, and is lined with slags melted down in place. The tap-hole for the slag is above that for metal. The process of smelting is conducted in four operations or "fires."

The lead tapped off at the first melting of argentiferous ores is richest in silver. As soon as it is out of the furnace a second charge is thrown in and roasted; the dross from the preceding charge is added.

Some lead is reduced and is tapped off after an hour or more, and the remaining ore is, in the course of about two hours, converted into oxide and sulphate.

The temperature of the furnace has been, up to this period, kept below the red heat, in order that the ore may not melt down and the desired change thus be checked. The heat is now increased to a full red, and the reaction of the oxide and sulphates present upon the sulphide, leads to the reduction of the lead, which runs off freely. This process occupies about an hour, and the temperature of the furnace has been alternately raised and depressed to facilitate the separation of the metal; a little lime being added, also, to flux the ore.

The temperature is now again raised for another hour; more lime is added, and further reduction occurs. Finally, the furnace is heated to its maximum temperature, and held at this heat for three-quarters of an hour or more, when the lead is tapped off, the slags hardened with lime, and reduction is complete. The whole process has occupied five hours or more. The fuel consumed amounts to something more than one-half the weight of the ore smelted.

The slag is still rich in lead, and is again worked separately.

The molten lead tapped off is often refined, as is done in purifying tin, by the use of sticks of wood in the basin. It contains a considerable amount, often, of silver, copper, antimony, and iron, amounting sometimes to several per cent. This is partly removed by the process of "softening," which consists in running it into a reverberatory furnace, having for its hearth a shallow basin, and there oxidizing out the impurities by exposing it to the oxygen-laden gases passing over it. The process of smelting has of late been modified, and is now very generally conducted in blast-furnaces, instead of in reverberatory furnaces.

When rich in silver, Pattinson's process is adopted. This consists in melting in a series of basins, in which the metals gradually separate. Lead crystallizes at a lower temperature than the alloy, and the molten metal being allowed to cool slowly, crystals of comparatively pure lead are formed, which are separated from the remaining mass which is richer in silver, and are transferred from one melting pot in a series to another; the lead richer in silver being gradually separated until that to be sent to market contains little to pay for further working. The melting pots are set side by side, and the purer lead is transferred from pot to pot in one direction, while that containing silver is similarly transferred in the reverse direction, until the pots at the extremes of the series contain, the one nearly pure and marketable lead, while the other contains so much silver that it can profitably be worked to recover it. This method is going out of use.

46. Commercial Lead.—The lead is run into "pigs" about 3 feet (0.9 metre) long, usually weighing about 150 pounds (70 kilogs.). Spanish "pigs" weigh 112 pounds (50 kilogs.). A "fodder" is 8 pigs.

Pig-lead is rolled into sheets 6½ to 7½ feet (2 to 2¼ metres) wide, 30 to 35 feet (9 to 11 metres) long, and sent to market in rolls. The weight runs very nearly six pounds per square foot for each 0.1 inch thickness (120 kilograms per square metre per centimetre in thickness). Sheet-lead is extensively used for tanks, sheathing, etc., and sometimes, although less than formerly, for roofing. Lead-pipe is made as below by forcing lead through an orifice, the size of the pipe to be made, over a former which gives it the required internal diameter.

Lead shot is made by dropping the molten metal from the top of a shot-tower of such height that the globules of the leaden rain thus produced may cool and become solid before striking the water in a tank at the bottom, placed there to receive it.

Lead pipe is now made by a peculiar process called "squirting"; it was formerly made by a process of "drawing" through dies. In the modern process, the lead is melted in crucible, or iron pots, and then carried to a compressing chamber fitted with a plunger which is driven by hydraulic pressure. The lead is allowed to solidify and cool to about 400° F. (204° C.). The ram is then forced down upon it, and, at a pressure of a ton and a half or more per square inch, the lead flows freely from an orifice in the bottom of the chamber, and around an iron core attached to the plunger, thus taking the size desired, and issues in the form of a pipe of a length determined by the relative capacity of the chamber and section of pipe.

Bar lead and lead wire and rods are made in the same manner, but dispensing with the core on the plunger. The compressing chamber is sometimes attached to the hydraulic press plunger, and rises against a fixed plunger in which is the orifice of issue, while the core is fixed in the compressing chamber. This arrangement is more convenient and causes less frictional resistance. Tin-lined pipe is often made.

The alloys of lead will be referred to later. The oxides and salts have great value in the arts.

White lead, the carbonate of lead, is made by exposing sheet-lead to carbonic acid and moisture. The lead is coiled up in pots, piled in heaps and covered with spent tan-bark and horse-dung. A little acetic acid, in each pot, attacks the metal, forming the acetate, which is then altered into carbonate by the carbonic acid generated in the hot-bed. It it used extensively in making paints.

Red lead is produced by heating the protoxide in the presence of oxygen and thus converting it into the peroxide.

Litharge is made by similarly acting upon the metallic lead and thus forming the protoxide. It is used as flux, as a constituent of cement and in the manufacture of red lead and of glass.

The salts of lead are much used in medicine and to a considerable extent in dyeing. They are all poisonous.

Lead is now produced in the United States at the rate (1899) of about 220,000 tons annually, and the production is increasing at the rate of ten per cent. or more a year. But little is imported. Of that produced in the United States, Utah yields about 20 per cent., Nevada, 6 to 8 per cent., Colorado, over one-third, principally from Leadville, and Missouri and Kansas 15 per cent.

Great Britain produces very nearly as much as the United States, reducing Spanish and other imported ores, which are principally argentiferous. Spain exported nearly as much more, and Germany quite as much.

47. **Antimony** (*Stibium; Sb.*), is a grayish white, crystalline and lustrous metal, moderately hard, extremely brittle, of inferior tenacity and has a peculiar taste and odor. It

melts at a low red heat, 840° F. (450° C.), and may be distilled at a white heat in an atmosphere free from oxygen. It does not oxidize in dry air at ordinary temperatures, but takes up oxygen slowly in cool, moist air, and rapidly when hot. It expands while solidifying, like iron. Its specific gravity is 6.7.

The most common ore is the sulphuret, which is found abundantly in Borneo and in considerable deposits in England, France, and Hungary, and also in California. It is reduced by roasting to expel the sulphur. The salts of antimony are poisonous.

The metal is a bad conductor of heat and electricity, and is used, with bismuth, is making thermo-electric piles. Its principal use is in the manufacture of alloys, as britannia metal, type metal, pewter, specula, etc. It expands when solidifying from fusion. It is rarely used alone.

Antimony is found in abundance in the Rocky Mountain section of North America, and especially in California and Nevada. The ore is usually a crude sulphuret, containing, often, some bismuth and a little silver. It is smelted at several points and sold in the eastern markets for use in making type metal, britannia ware, and babbitt metal.

Gray antimony was used by the ancients for coloring the hair and eyebrows.

48. **Bismuth** (*Bi.;* atomic weight, 208) is a brittle, pinkish white, heavy, useful metal, having some resemblance to antimony. It has a specific gravity of 9.8 to 9.9. It expands on solidifying, at a temperature of 500° F. (260° C.). Its coefficient of expansion is 0.00134; specific heat, 0.0305. It crystallizes with remarkable facility. It may be distilled at a high temperature. It is very diamagnetic. Its principal use is in making alloys. It injures brass seriously.

The metal is obtained either by reducing the sulphide or, oftener, by purifying native bismuth.

Its oxides and salts are used in medicine, and in the arts to a moderate extent, only, almost invariably alloyed with other metals.

Commercial bismuth contains many impurities, which are removed by fusion with nitre. Chemically pure bismuth is obtained by precipitation, by dilution of its solution in nitric acid. The bismuth of commerce comes principally from Germany and Bohemia, and some from Peru. Deposits of oxides and sulphides have been found in Utah.* The quantity mined is not great and the demand is small, not more than ten or fifteen tons being used in this country annually. It has about one-eighth or one-tenth the value of silver.

49. **Nickel** (*Ni.;* atomic weight, 58.8) is a bluish, nearly silver white metal, having high lustre, considerable ductility and malleability, and closely related, chemically, to iron and cobalt, which metals are often associated with it, in nature. It has about the hardness of iron, but is heavier, having a specific gravity of 8.3 to 8.9, has about equal fusibility, but is far less subject to oxidation and corrosion. Its oxide is white and defaces the polished metal comparatively little, and is easily removed. Nickel can be either cast or forged; but it is generally used in making alloys or in plating more oxidizable metals. It is magnetic, although much less so than iron.

The Ores of Nickel are the arsenide, which is by far the most common, and is known to the miners as kupfernickel, the sulphide, the sulphate, and the silicate. Nickel ores are found in France, Sweden, Cornwall, Spain, Germany, New Caledonia, and in Oregon and other localities in the United States, Canada now supplying the greatest quantity. The ores are reduced by fluxing with chalk and fluor-spar, if arseniated, or by roasting and then reducing with charcoal and sulphur to the state of sulphide, and then by double decomposition with carbonate of soda, obtaining the carbonate, which is finally reduced with charcoal. The metal was discovered and the ore reduced as early as 1751 by Cronstadt. Large quantities come from New Caledonia.

The nickel ores of Oregon have the following composition as given by Hood, as determined by analyses of ores sent to San Francisco:

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* *Polytechnic Review,* April, 1876.

	A.	B.	GARNIERITE.	NOUMEITE.
Silica	48.21	40.35	47.23	47.90
Iron and alumina oxide	1.38	1.33	1.66	3.00
Nickel oxide	23.88	29.66	24.01	24.00
Magnesia	19.90	21.70	21.66	12.51
Water	6.63	7.00	5.25	12.73

A. Amorphous.—Hardness, 2.5; specific gravity, 2.45; color, pale apple green, becoming lighter by exposure. Adheres to tongue; not unctuous. Does not fall to pieces in water.

B. Amorphous.—Hardness, 2.0–2.5; specific gravity, 2.20; color, dark apple green, becoming lighter by exposure. Adheres to tongue; unctuous. Falls to pieces in water.

Garnierite. Amorphous. — Hardness, 2.0–2.5; specific gravity, 2.27; color, apple green. Adheres to tongue; not unctuous. Falls to pieces in water.

Noumeite. Amorphous.—Hardness, 2.5; specific gravity, 2.58; color, dark apple green. Does not adhere to tongue; unctuous. Does not fall to pieces in water.

According to Mr. Nursey, most of the nickel made in the United States is produced by what is known as the Thomson soda process. Matte of first fusion is freed from iron by subsequent roasting and smelting. It is then smelted in a cupola furnace with sodic sulphate and coke. The product of this fusion when drawn off separates, whilst fluid, by gravity, into two portions, a lighter and a heavier, which are separable when cold. The lighter part, known as "tops," contains nearly all the soda, copper, and iron, whilst the heavier portion, called "bottoms," contains nearly all the nickel. As the separation of nickel and copper is not quite complete the bottoms are treated over again, substantially in the way we have described, until nickel sulphide of satisfactory purity is obtained. Metallic copper is ultimately produced from the tops, the very small quantity of cobalt present going with the nickel and there remaining. The nickel sulphide when dead roasted, becomes nickel oxide, which is considered to be sufficiently good for use in the manufacture of nickel steel. To produce shot nickel, nickel oxide is reduced, melted, and poured into water. In this form the metal assumes a good appearance, but it is not approved of for delicate uses. By reducing, melting, and moulding the oxide, rough slabs are formed, which, treated as anodes, yield electrolytic nickel of high quality.

The French company, Le Nickel, melts the nickel silicate of New Caledonia with gypsum, thus producing matte consisting of nickel sulphide and iron sulphide. By successive roasting and smelting, the iron is entirely removed as slag, and a final dead roasting produces nickel oxide of the requisite purity to yield, by reduction, good merchantable metallic nickel. Some part of this nickel oxide is sold as oxide to steel makers and others.

The Manhes converter is the invention of Mr. Peter Manhes. Taking the matte just referred to, he concentrates it by blowing air through it, when melted, in a basic lined converter, thus removing all the iron. After clearing off the slag he desulphurizes the metal by continued fusion in the converter with lime and lime chloride. The pure nickel goes to the bottom of the converter and is teemed into moulds for the market.

50. Uses of Nickel.—*Nickel plating* by the electric current was practised experimentally by Jacobi and Becquerel in 1862, but it was commercially practised by Isaac Adams, of Boston, some years later. The plating fluid is a solution of the double chloride or the sulphate of nickel and ammonium. The current is usually obtained from the magneto-electric machine. This has become, during late years, a very important industry, and nickel plating is adopted by all manufacturers of small articles of metal subject to corrosion and tarnishing.

The malleability of nickel allows of its being chased as are silver and gold, and with the result of greater lustre, while the qualities of brilliancy, hardness, and durability, whether used solidly or in electro-plating, make it very suitable for table service.

The sheet-nickel of commerce is as thin as 0.01 inch

(0.025 cm.), and the wire is nearly as fine. It can be welded, with care, and can be forged like iron.

Nickel coinage was commenced, about 1850, by Switzerland, and in the United States in 1857. This application, and nickel plating by electrolytic action, absorb enormous quantities. The working of this metal has been most extensively carried on in the United States by Mr. J. Wharton, at Camden, N. J., from sulphuretted ores mined at Lancaster Gap, Penn. Sheets have been produced 6 feet (1.8 m.) long and 2 feet (6.1 m.) wide.

Dr. Fleitmann's discovery, that a small dose of manganese added to the molten charge, when ready to pour into the moulds, renders the nickel sound, strong, malleable, and ductile, has greatly cheapened, as well as improved, the product. Fleitmann has welded together iron and nickel, and steel and nickel. Nickel-steel, Fe. 75, Ni. 25, is non-corrodible.

Nickel is principally used in the arts in the manufacture of hollow ware which is to be plated with silver, as practised by Gorham, and for vessels of nickeled iron; the latter are less liable to injury than when the nickel is deposited by electrolysis. It has come to be extensively employed in alloy with steel for armor-plate, giving enormous shock-resisting power.

Commercial nickel often contains iron. Canadian (Quebec) ores contained,* in the garnet, calcite, 50.40; chromite, 6.87; chrome garnet, 49.73, and in pyroxene, silicon and alumina, 50.60; iron oxide, 8.73; magnesium and calcium oxides, 35.90; water, 5.83. The reduced ore gave: iron, 71.84; nickel, 22.70. The slag contained no nickel.

Commercial nickel contains, usually, measurable amounts of carbon, silicon, iron and often cobalt.

The nickel plates now largely used as anodes for nickel plating are prepared by fusing commercial nickel, generally with addition of charcoal, and casting in suitable form. The subjoined analyses by Mr. W. E. Gard,† of such plates, show that silica may be reduced and retained as silicon, and that a considerable amount of carbon may be present:

* "Nickel Ores"; W. E. Eustis. Trans. Am. Inst. Min., Eng.

† *Am. Journal of Science and Art*, 1878.

	NO. I.		NO. II.		NO. III.	
	a.	*b.*	*a.*	*b.*	*a.*	*b.*
Carbon	.530	.549	1.104	1.080	1.900	1.830
Silicon	.303	.294	.130	.125	.255	.268
Iron	.464	.463	.108	.110	.301	.318
Cobalt	.446	.438	trace	....	trace	....
Sulphur	.049	.057	.266	.340	.104	.096
[Nickel]	98.208	98.199	98.392	98.345	97.440	97.488
Total	100.000	100.000	100.000	100.000	100.000	100.000

No. I. was American nickel, manufactured and cast by Jos. Wharton, at Camden, N. J. A careful examination by means of Marsh's apparatus showed not the least trace of arsenic or antimony. No. II. was a sample taken from a cast nickel anode used by a nickel-plating establishment in New Haven. No. III. a sample taken from the same anode after it had been used in the plating bath until upward of half its weight had been removed. Solvent action had extended quite through the plate, leaving as usual a porous flexible mass retaining its original form. A comparison of Nos. II. and III. shows that under galvanic action the carbon, silicon, and iron of the anode dissolved relatively slower than nickel, while the reverse happens with sulphur.

51. **Aluminum**; or, **Aluminium** (*Al.;* atomic weight, 27.5), is a white silver-like metal, very malleable and ductile, a good conductor of both heat and electricity, uniting with oxygen only with great difficulty, and therefore little liable to corrosion either by exposure to air or to the action of the oxygen acids. It dissolves freely in hydrochloric acid and in solutions of the alkalis. It is remarkable for its lightness; its specific gravity being 2.6 to 2.7. The salts of this metal are not expensive, and are used in large quantities in the arts; the sulphate, alum, is the most useful, and finds its most important applications in dyeing and calico printing. The alloys of aluminium are very valuable. Its remarkable lightness, combined with its strength, make it useful for

alloys. Equal volumes have equal strength when steel has about 80,000 pounds tenacity. Specific heat (Richards), 0.227.

This metal was discovered by Wöhler, in the year 1827, and by him obtained in considerable quantity, twenty years later, by reduction with sodium. Deville obtained it in ingots on a commercial scale, and the metal rapidly became familiar to chemists. Rose, in 1855, found that it could be obtained from cryolite, in which it exists as a fluoride, by reduction with sodium.

Aluminium is made by Hall's process of solution of alumina (bauxite) in a bath of molten cryolite (a double fluoride of sodium and aluminium) and of electrolysis by a heavy current of low voltage (2.8 to 4). This remarkable and important invention transferred the metal from the class of rare to that of useful metals and reduced its cost to less than copper and brass, bulk for bulk. [See Appendix.]

Next to silica, the oxide of aluminium (alumina) forms, in combination, the most abundant constituent of the crust of the earth, in the form of hydrated silicate of alumina, clay. Common alum is sulphate of alumina combined with another sulphate, as potash, soda, etc. It is much used as a mordant in dyeing and calico printing, also in tanning.

Aluminium is of great value in mechanical dentistry, as, in addition to its lightness and strength, it is not affected by the presence of sulphur in the food. Dr. Fowler obtained patents for its combination with vulcanite as applied to dentistry and other uses. It resists sulphur in the process of vulcanization so perfectly as to make it an efficient and economical substitute for platinum or gold.

The metal, aluminium, is distinguished from other white metals by its peculiar gray-white color, differing from both zinc and tin, and especially its remarkably low density, possessing as it does, but one-third the weight of copper, one-fourth that of silver, and one-eighth that of gold. It has a pleasant metallic ring when struck, and confers a beautiful tone when introduced into bell-metal. Deville made a bell of but 44 pounds (20 kilogs.) weight, which was, however, one and a half feet in diameter (½ metre), and exhibited an exquisite timbre; it was presented to the Royal Society in 1868.

It is sufficiently malleable and ductile to permit its being rolled into thin sheets and drawn into fine wire. Its melting point is at, or near, 1,300° F. (700° C. nearly), between the fusing point of silver and zinc, and it does not evaporate at any temperature yet observed. The metal may be worked cold, like copper or soft brass, and may be coined perfectly and easily. Oxidation occurs very slowly and it retains a polish as well as silver. It has often been proposed for use in coin, for which purpose it is well adapted by its beauty, lightness, sonority, and non-oxidizing quality. Laboratory weights have been made of the metal, and have remained standard for many years. Its solubility in the solutions of the alkalis is, as with copper and silver, such as to prevent its use for some purposes. It is very extensively used in making fine articles of luxury, and is proposed for use for philosophical and engineering apparatus, and for utensils. Some 3,000 tons per year are now (1899) so used. [See Appendix.]

Alloys of aluminium with other metals, with the exception of copper and zinc, are not in much use. There are several manufactories of the metal producing considerable quantities of product. Its cost is five per cent. of that of silver; that of the bronze is five per cent. of that of the metal and somewhere about that of copper-tin bronze. *See* page 305.

52. **Mercury** (*Hydrargyrum;* Hg.), often called *quicksilver*, is used by the engineer for a number of important purposes. It is a dense fluid metal, having an atomic weight, 200, a specific gravity of 13.6, a specific heat of 0.032 to 0.0333 as it passes from the solid to the liquid state, a coefficient of expansion, according to Regnault, of from 0.00018 to 0.000197 as its temperature rises from the freezing point of water, 0°, to 350 Cent. (32° to 662° F.) Its latent heat of fusion is 2.82 metric units per unit of weight (5.08 British). It boils at about 350° C. (662° F.), forming a colorless, transparent, poisonous vapor, and evaporates at all temperatures. The density of its vapor, according to Dumas, is 6.976. It unites freely, at ordinary temperatures, with several other metals

forming "amalgams." Iron and platinum are not among these metals. Mercury is therefore preserved in iron bottles.

The Ores of Mercury are *cinnabar*, "vermilion," which is the sulphide, and *calomel*, the chloride; the former is the usual source of the mercury of commerce. The metal is sometimes found native, in small quantities; it is frequently alloyed slightly with silver. The ores of mercury are principally mined in California; but large quantities are produced also in Spain, Austria, and China.

Mercury, or "Quicksilver," is only produced in the United States, in California, where it is obtained from the red sulphide (cinnabar). The quantity produced is not far from 60,000 flasks of 76½ pounds each, per annum, and one-fourth as much more is imported. Its principal use is in the manufacture of vermilion (sulphide of mercury), and amalgamating mirrors.

Cinnabar is dark brown in color, earthy in texture, and very heavy, its specific gravity being 8.2; abrasion produces a red powder and a red streak on the mass. The ore is reduced by distillation and usually with considerable loss of vapor. The ore is broken up into pieces somewhat larger than an egg, and roasted in a deep furnace, of circular form, closed at the top and connected by flues with a set of condensing chambers in which the mercury is condensed by contact with iron plates, over which cooling streams of water are kept flowing. The charges weigh 700 or 800 pounds (318 to 363 kilogrammes), and are worked off in about three-quarters of an hour; the fuel used per charge is 25 or 30 pounds (11.3 or 13.6 kilogs.) of charcoal. In some cases, as in India, a reverberatory furnace is used in reducing the cinnabar, when the ore is lean. In still other cases, lean ores are distilled in small iron retorts, holding about 70 lbs. (32 kilogs.), with lime, and the vapors are condensed in stone bottles half filled with water, or, the retorts are larger and contain as much ore as the furnace above described. Condensation is effected in a "hydraulic main," kept cool by immersion in a trough of water.

Mercury, as distilled, usually contains bismuth, lead, and zinc, and is often re-distilled in the iron bottles in which it is purchased from the smelter, or purified by washing with dilute nitric acid. A subsequent washing with water and drying with filter-paper and then warming it, leaves it in good condition. It is also purified by shaking with powdered sugar or with charcoal, the impurities being thus oxidized out by contact with air.

This metal is used in many kinds of philosophical apparatus, in the pressure gauges used for standardizing steam gauges, in the barometer, in "silvering" mirrors, and in a few alloys.

Mercury was the last metal discovered by the ancients, and is supposed to have been known four or five centuries before the Christian era. Red cinnabar, its sulphide, was, however, used as a cosmetic several hundred years earlier, and was imported into Greece and Italy, in enormous quantities, from the Spanish mines of Almaden. The Peruvians made similar use of it at the time of the discovery of their country by Pizarro.

53. **Platinum** (*Pt.*) is a metal possessing qualities of the highest value in the arts; but its considerable cost forbids its common use. It is so named from the Spanish *platina*, the diminutive of *plata*, silver, because of its white, silvery color. It is found in the mountainous portions of South America, Central America, Mexico and California, in the West Indies, and in the Ural Mountains, in the metallic state, but mingled with ore of iron, copper, and the rarer metals, and usually alloyed with a small quantity of iridium. Its atomic weight is 197.4.

The metal is purified by solution in a mixture of nitric and hydrochloric acids, precipitation by potassium chloride of the double chloride of potassium and platinum, re-solution by nitro-hydrochloric acid and reprecipitation by sal-ammoniac, sometimes, after repeated solution, as the double chloride of ammonium and platinum. The volatile element is driven off by heating, and the "spongy platinum" remaining is welded into a solid mass, after cleansing by trituration and washing.

Commercial Platinum always contains osmium and usually silicium and iridium. Fusion in the oxy-hydrogen flame with proper fluxing removes these metals by oxidation and the promotion of slag. Deville and Debray fuse the ore with galena in a small reverberatory furnace, and, fluxing with glass and litharge, obtain an alloy of lead and platinum nearly free from other metals. This is expected to remove the lead, and the platinum so obtained is refined on the lime-covered hearth and thus obtained in a very pure state.

Various other ways are sometimes practised. The best method of compacting the metal is by fusion, which can be accomplished by the oxy-hydrogen flame in a little furnace made by forming a cavity between blocks of lime.

Platinum is nearly as ductile as gold and silver, and is only exceeded in malleability by those metals and copper. It is white like silver and has nearly as high a lustre. It is softer than silver and about as hard as copper; but it is rapidly hardened by the addition of traces of iridium or of rhodium. Its specific heat is 0.03243 at common temperatures, according to Regnault. The coefficient of expansion is 0.0000068 per degree, Cent., according to Calvert and Johnson, 0.0000085 per Bordaz, 0.000001 according to other authorities, varying according to purity and physical condition. Platinum can only be fused by the oxy-hydrogen flame or the voltaic arc. It is the heaviest of the metals used in the arts, having a specific gravity of 21.15 to 21.5. This metal is not oxidizable in the air or by any acid, although a mixture of nitric and muriatic acids will slowly dissolve it. At high temperatures, alkalis will produce corrosion by contact with it, as will potassium sulphate, and sulphur, phosphorus and arsenic. Chlorine attacks it slightly, iodine and bromine not at all. Chloric acids dissolve it.

Platinum is principally used in the manufacture of vessels required to resist heat or the action of acids, as crucibles, evaporating basins, stills or retorts used in the concentration of sulphuric acid, etc. Carbon and silica corrode it, and the metals, generally, freely alloy with it; its applications are thus somewhat restricted.

Platinum was discovered by the Spaniards, in the sixteenth century, in the gold mines worked at the time, on the Isthmus of Darien; it only became valuable in the arts two centuries later, after Sickengen had, in 1772, found that it could be welded at a single white heat; it then came into demand, its hardness, strength, freedom from liability to oxidation, and especially its infusibility, giving it a value nearly equal to that of gold.

54. **Magnesium,** (*Mg.;* atomic weight, 24) is a silver white, lustrous metal, ductile and malleable, very light (s. g., 1.75), readily combustible, easily cut and worked, and resembling alumina in many respects. It melts and volatilizes like zinc, and at about the same temperature. In the form of powder or thin wire or ribbon, it takes fire like a shaving of wood and burns rapidly, with an intense bluish white light very rich in actinic rays.

It abounds in dolomitic limestone in the form of silicate and carbonate of magnesia, in *carnellite*, a double chloride of magnesium and potassium, from which it is reduced by sodium, using fluor spar as a flux, purifying it by distillation.

Magnesium has been manufactured by two establishments, the American Magnesium Company, Boston, United States, and the Magnesium Metal Company, Manchester, Great Britain. The English manufactory produced by far the most. The former furnished large quantities for the English army during the campaign in Abyssinia, the metal being employed extensively for signals.

Magnesium can readily be ignited at the flame of a candle. Combustion is frequently interrupted by the dropping off of the burning portion, so that it becomes necessary to feed the unburnt portion into the flame continually. The wire burns to the best advantage if inclined at an angle of about 45°.

An uninterrupted and very brilliant combustion is produced by lamps especially constructed for this purpose. Such a lamp* is made by the American Magnesium Company. The strips of magnesium are rolled up on cylinders in the upper part of the apparatus. These strips are unrolled by clockwork

* From designs patented by R. H. Thurston, 1865. New Marine Signal Light: Journal Franklin Institute, 1866.

in the lower part of the apparatus, and are carried between two small rollers, the uniform motion of which feeds them regularly into the lamp, where they are ignited. The ashes are cut off at intervals by means of eccentric cutters, and collect in the bottom of the apparatus. A small chimney is added, which is very important, as producing a draught of air directly through the flame. A portion of the products of combustion is thus carried away, and the flame becomes very intense, while it is less so without a draught. This lamp has been found very efficient, especially for marine signals. At trials made at sea, on two vessels stationed eight miles apart, the signals could be readily distinguished; it is said to be visible 28 miles.

Larkin has constructed and patented a lamp in which the magnesium is not employed as wire, or in strips, but as a powder. By this means the clock-work, or other mechanical device, has been dispensed with. The metallic powder is contained in a reservoir, which has a small opening in the bottom. The magnesium powder flows through this like the sand in the sand-clock. It is intimately mixed with a certain quantity of fine sand, in a manner diluted; first, in order to be able to make the opening sufficiently large; furthermore, to produce a continuous flow of the material. The mixture falls into a metallic tube, through which illuminating gas is led from the upper end. The mixture is ignited at the lower end. The flame is very brilliant, and the remaining sand falls into a vessel placed below, while the smoke passes away through a chimney. A lamp of this character was adopted in several forms of signal apparatus devised for the Army and the Navy Signal Corps, by the Author, in the years 1866–70. [See Appendix: Magnesium as Constructive Material.]

55. **Arsenic** (*As.;* atomic weight, 75) is found native, but is usually obtained from the sulphite or from the alloy with iron known as arsenical iron. It is also found alloyed with other metals. It is reduced from arsenical pyrites, or from arsenical iron, by roasting in retorts, the arsenic passing off by sublimation and condensing outside as in the zinc manufacture. The arsenic of commerce is made principally from German

and Spanish ores. The oxide is easily reduced by heating with carbon.

This metal is a gray, lustrous solid, of steely fracture and color, having a density of 5.6 to 5.95, crystallizing in rhombohedra, volatilizing at a red heat, with a garlic-like odor, and oxidizing easily at a high temperature, but not readily at a low temperature. It has no value in the arts of construction and engineering except in alloys.

56. **Iridium** (*Ir.;* atomic weight, 197) is the heaviest of useful metals. It was discovered in the year 1803 by Tennant, who analyzed the metallic residue which remains when platinum ores are dissolved. Tennant proved that the platinum residues contained two new metals, to one of which he gave the name of iridium, on account of the varying color of its salts, and to the other the name osmium, because of the peculiar odor which its volatile oxide possesses. Iridium is found in the platinum ores in considerable quantity in the form of the alloys of platiniridium and osmiridium. The first of these occurs in grains and small cubes with rounded edges; the second, usually, in flat, irregular grains, and sometimes in hexagonal prisms. Iridium, in the cold state, resists the action of acids and alkalies. It parts with its oxygen at a high heat, and, although it possesses a number of valuable qualities, has been used, until recently, only for the points of gold pens. Its limited use was caused by the difficulty of obtaining it in metallic form. It is found in Russia, Brazil, California and several other countries, and is usually accompanied by gold or platinum. Since its discovery, numerous chemists and metallurgists have unsuccessfully endeavored to reduce the ore and obtain iridium in the metallic form. Chemists have succeeded in producing some small pieces of iridium the size of a pea by means of the oxyhydrogen blowpipe flame, the metal obtained, however, being porous and valueless. In 1855, George W. Sheppard, of Cincinnati, succeeded in producing a similar result with the aid of a powerful galvanic battery. Later, John Holland, of that city, began experimenting in the same direction, and after several years of trial succeeded in reducing the iridium ore to a solid

metal in common furnaces. He used phosphorus as a flux, by means of which, it was said, the metal could be made to fuse as easily as cast iron.

This new method of fusing iridosmine was discovered in 1881; it consists in heating the ore to whiteness and adding phosphorus. The mass becomes at once fused, and the phosphide thus obtained is reduced by heating with lime. The metal is exceedingly hard, has a brilliant metallic lustre and is not attacked by acids; when pure, its density is 18.7.*

The ore used as above, and the metal, have been examined by Clarke and Joslin.† The ore has a specific gravity of 19.182, the metal 13.77. The composition of the latter was

Iridium	80.82
Osmium	6.95
Phosphorus	7.09
Ruthenium, Rhodium	7.20
	102.06

showing the fused metal to be a phosphide, of the formula, Ir_2P.

Phosphorus was found to re-act similarly with platinum.

57. **Manganese** (*Mn.;* atomic weight, 55) is usually found as a peroxide, although occurring in many other compounds. Its oxide is reduced by carbon at a white heat, usually by heating the peroxide in powder with oil. The metal is also obtained by heating the chloride or fluoride with sodium. It is gray in color, resembling light gray cast iron, usually weak and brittle, heavy (s. g., 7 to 8) and slightly magnetic. It is produced electrolytically like aluminium.

It has a strong affinity for oxygen, and it is this which makes it valuable in the arts. In one of its forms it is quite different, however. As reduced from the chloride by sodium it is hard and does not easily oxidize.

Manganese is always used as an alloy. Its most usual form is seen in "*spiegeleisen*," an alloy with iron used in the

* Proc. Ohio Mechanics' Institute, 1882.

† *Am. Chemical Journal*, vol. v. No. 4, 1883.

Bessemer and other processes of steel-making, which is made by direct reduction from manganiferous ores by the ordinary small charcoal blast-furnace. It is cast either into pigs or into flat plates. When very rich in manganese and comparitively low in carbon, it is called "*ferro* manganese." Spiegeleisen contains from 3 or 4 to 8 or 10 per cent. manganese, while ferro-manganese contains 20 to 80 per cent.

58. **The Rare Metals** are of no value to the engineer in his everyday work; they are enormously costly, and possess, as a rule, none of the qualities which are essential to their use in construction. They are here only referred to, to complete the list.

Gold and silver are too well known to demand description. They are both dense, but soft, metals, difficult of oxidation, little subject to corrosion, and therefore sometimes very useful in plating other metals not readily attacked by acids, alloying with copper and some other metals readily, and forming compounds which, like these metals themselves, are of little or no value to the engineer.

Cadmium is a white, malleable and ductile metal resembling tin. Its sulphide, known as cadmium yellow, is bright in color and has qualities of great value to artists. The metal is of little use. Dentists make with it alloys and amalgams.

Calcium is yellow, ductile and malleable, and softer than gold. At a red heat it burns with a dazzling white light.

Erbium is very rare; it resembles aluminium in its properties and compounds.

Glucinum resembles aluminium, though lighter and untarnishable. It excels iron in strength, and copper in conductivity.

Lithium is a metal resembling silver in color. It admits of being drawn into wire, but has little tenacity. It is remarkable for its lightness and the readiness with which it combines with oxygen.

Molybdenum is a silvery white, brittle and infusible metal. It never occurs native, and neither it nor its compounds are of practical use.

Osmium is remarkable for its high specific gravity and infusibility.

Palladium resembles platinum. An alloy of 20 per cent. with 80 per cent. gold is perfectly white, very hard and does not tarnish by exposure.

Rhodium is white, very hard and infusible. Its specific gravity is about 11.

Ruthenium resembles iridium. It is rare and of little value.

Strontium is yellowish, ductile and malleable; it burns in the air with a crimson flame.

Thallium is very soft and malleable.

Thorium is an extremely rare metal, remarkable for taking fire below red heat, and burning with great brilliancy. Neither the metal nor its compounds are of practical use; its oxide has the high specific gravity of 9.4.

Titanium is a rare metal, usually obtained in crystalline form, and also as a heavy iron-gray powder. The crystals are copper-colored and of extreme hardness.

Tungsten is a hard, iron-gray metal, very difficult of fusion. An alloy of ten per cent. of this metal and 90 per cent. of steel is of extreme hardness. Both the metal and its compounds have proved of value alloyed in steel and bronze. Chromium has similar uses.

Uranium is very heavy and hard, but moderately malleable, resembling nickel and iron; it is unaltered at ordinary temperatures by air or water.

Rubidium and caesium so closely resemble platinum that no ordinary test will distinguish them.

Indium is very soft, malleable and fusible; it marks paper like lead.

Barium, cerium, columbium (or niobium), didymium, lanthanium, tantalum, terbium, yttrium, and zirconium, are all rare metals and not very well known.

59. **The Commercial Metals** are never chemically pure. Lake Superior copper and the best lead and tin are practically so, but all other metals have such a variety of quality and composition, as sold in our markets, that the purchaser and consumer can only rely upon careful analyses to determine their value for any proposed use. This precaution is

especially advisable when the engineer selects metals or alloys for use in construction.

Thus copper has been found to contain as much as 30 per cent. lead and 8 or 9 per cent. of nickel, iron, arsenic, and other metals; lead often contains several per cent. of antimony, arsenic, zinc, and other elements; iron may contain besides the sulphur and phosphorus which frequently seriously injure it, a considerable amount of manganese, chrome, nickel and cobalt, and even copper; platinum often contains appreciable quantities of the other rare metals, as paladium, rhodium, usually iridium and osmium, and sometimes iron and copper; zinc is very frequently rendered useless for the engineer's purposes by the presence of lead.

The Prices of Metals are so constantly varying that no list can be given of great accuracy. The cost of reduction, the relations of supply and demand, and the accidental fluctuations of the market combine to determine the exact figures. The following table, mainly from Bolton,* may be taken as representing approximate values.

PRICES OF METALS.

METAL.	STATE.	VALUE IN GOLD PER LB. AVOIRDUPOISE.	PRICE IN GOLD, 1900.	AUTHORITY.
Vanadium	Cryst. fused	$4,792.40	$ 480	S.
Rubidium	Wire	3,261.60	2,400	S.
Calcium	Electrolytic	2,446 20	1,920	S.
Tantalum	Pure	2,446.20	1,684	S.
Cerium	Fused globule	2,446.20	1,920	S.
Lithium	Globules	2,228.76	960	S.
Lithium	Wire	2,935.44	1,440	S.
Erbium	Fused.	1,671.57	1,920	S.
Didymium	"	1,630.08	2,880	S.
Strontium	Electrolytic	1,576.44	1,920	S.
Indium	Pure	1,522.08	720	T.
Ruthenium	....	1,304.64	1,500	T.
Columbium	Fused	1,250.28	450	S.
Rhodium	....	1,032.84	1,000	T.
Barium	Electrolytic	924.12	500	S.
Thallium	....	738.39	950	T.
Osmium	....	652.32	12	T.
Palladium	....	498.30	600	T.

* *Engineering and Mining Journal*, Aug. 21, 1875.

PRICES OF METALS.—*Continued.*

METAL.	STATE.	VALUE IN GOLD PER LB. AVOIRDUPOISE.	PRICE IN GOLD, 1900.	AUTHORITY.
Iridium	....	$466.59	$480	T.
Uranium	....	434.88	240	T.
Gold	....	299.72	2[illegible]9	....
Titanium	Fused	239.80	360	....
Tellurium	"	196.20	150	....
Chromium	"	196.20	175	....
Platinum	"	122.31	250	....
Manganese	"	108.72	100	T.
Molybdenum	....	54.34	50	T.
Magnesium	Wire and tape	45.30	1.05	T.
Potassium	Globules	22.65	8	T.
Silver	....	18.60	15	....
Aluminum *	Bar	16.30	.30	S.
Cobalt	Cubes	12.68	5	S.
Nickel	"	3.80	.35	T.
Cadmium	....	3.26	3	T.
Sodium	....	3.26	1	T.
Bismuth	Crude	1.95	1	S.
Mercury	....	1.00	1	....
Antimony	....	.36	.20	T.
Tin	....	.25	.25	....
Copper *	....	.22	.18	....
Arsenic	....	.15	.05	....
Zinc	....	.10	.06	....
Lead	....	.06	.05	....
Iron	....	.01½	.01	....

The prices of many may be considered also as "fancy prices," and a whole pound of some of the metals named could hardly be obtained at even these figures. In compiling the table, the prices of the rarer metals are obtained from Trommsdorff's and Schuchardt's price lists; the avoirdupois pound is taken as equal to 453 grammes, and the mark as equal to 24 cents gold.

It is evident that the prices of the metals bear no relation to the rarity of the bodies whence they may be derived; for calcium, the third in the list. is one of the most abundant elements.

* The price of copper fell in 1885–86 to 10 cents per pound, rising in 1887 somewhat; aluminium (1896) has dropped to 50 cents or less; magnesium to $5; nickel to 25 cents a pound; silver to 50 cents an ounce; platinum, $6; while lead and zinc cost 3 and 4 cents a pound.

CHAPTER III.

PROPERTIES OF THE ALLOYS.*

60. Properties of Alloys.—The Author, before entering upon the researches directed by the Committee on Metallic Alloys of the United States Board, and before making a series of experiments on the characteristics of alloys, as a proper introduction to the work instituted a somewhat exhaustive examination of the records of earlier experiments in this direction.

The result of this investigation has been to reveal a vast amount of information on the chemical and physical properties of the alloys; but such information is widely scattered, and authorities do not always agree. Some experiments have been made upon alloys made from the impure commercial metals, others from metals rendered chemically pure for the purpose. Again, the apparatus used has not always been of the same degree of accuracy, and this has produced another cause of disagreement. These differences, however, are usually slight.

It is evident that alloys, being composed of metallic bodies, will possess all the physical and chemical characteristics of metals; they have the metallic lustre, are more or less ductile, malleable, elastic, and sonorous, and conduct heat and electricity with remarkable facility. In retaining these properties, however, the compound is so modified in some of its qualities, that it often does not resemble either of its constituents, and might, consequently, be regarded as a new metal, having characteristics peculiar to itself. This is especially the case with those which are used in the arts. It would

* Prepared originally, in large part, and with the assistance of Mr. Wm. Kent, M.E., for the Committee on Metallic Alloys of the United States Board, appointed to test, iron, steel, and other metals. See Report, Vol I., 1878.

almost seem that there is no department of the arts requiring the use of metals for which an alloy may not be prepared possessing all the requisite qualities, when these are not found in the original metals.* The physical properties of an alloy are often quite different from those of its constituent metals. Thus copper and tin mixed in certain proportions, form a sonorous bell-metal, possessing properties in which both metals are deficient; in another proportion they form speculum metal, which is as brittle as glass, while both of the constituent metals are ductile. It is impossible to predict from the character of two metals what will be the character of an alloy formed from given proportions of each. In most cases, however, it will be found that the hardness, tenacity, and fusibility will be greater than the mean of the same properties in the constituents, and sometimes greater than in either; while the ductility is usually less, and the specific gravity is sometimes greater and sometimes less.† The color is not always dependent upon the colors of the constituent metals, as is shown by the brilliant white of speculum metal, which contains 67 per cent. of copper.

Very slight modifications of proportions often cause very great changes in properties. M. Bischoff ‡ states that he can detect the deteriorating effect of one part tin upon ten million parts of pure zinc, and the writer has found half of a per cent. of lead to reduce the strength of good bronze nearly one-half and to affect its ductility to an almost equal extent.

It is not a matter of indifference in what order the metals are melted in making an alloy. Thus, if we combine 90 parts of tin and 10 of copper, and to this alloy add 10 of antimony; and if we combine 10 parts of antimony with 10 of copper, and add to that alloy 90 parts of tin, we shall have two alloys chemically the same, but in other respects—fusibility, tenacity, etc.—they totally differ. In the alloys of lead and antimony, also, if the heat be raised in combining the two metals much above their fusing points, the alloy becomes harsh and brittle.

* Muspratt's Chemistry, vol. 1, p. 533.

† Ure's Dictionary, vol. 1, pp. 46–50.

‡ British Assoc. Reports, 2, 1870, pp. 209, 210.

Some metallic alloys are much more easily oxidizable than the separate metals. An alloy of tin and lead heated to redness takes fire and continues to burn for some time.*

In regard to certain physical properties, Matthiessen† remarks that the metals may be divided into two classes:

Class A.—Those metals which impart to their alloys their physical properties in the proportion in which they themselves exist in the alloy.

Class B.—Those metals which do not impart to their alloys their physical properties in the proportion in which they themselves exist in the alloy.

The metals belonging to class A are lead, tin, zinc, and cadmium; and those belonging to class B, in all probability, all the rest.

The *physical properties* of alloys may be divided into three classes:

I. Those which in all cases are imparted to the alloy approximately in the ratio in which they are possessed by the component metals.

II. Those which in all cases are not imparted to the alloy in the ratio in which they are possessed by the component metals.

III. Those which in some cases are and in others are not imparted to the alloy in the ratio in which they are possessed by the component metals.

As types of the first class, specific gravity, specific heat, and expansion due to heat may be taken; as types of the second class, the fusing points and crystalline form; and as types of the third class, the conducting power for heat and electricity, sound, elasticity, and tenacity.

61. The Chemical Nature of Alloys.—The chemical nature of alloys has long remained a disputed point among scientists. The question, "Are alloys definite chemical compounds, solutions, or mechanical mixtures?" is not easily answered. Several authors give their views and describe their methods of making experiments to settle this question, but there still

* Ure's Dictionary, vol. 1, p. 49.

† Jour. Chem. Soc., vol. 5, 1867, pp. 201–220.

remains a wide difference of opinion in regard to it. Most writers now agree, however, in considering some alloys as chemical compounds and others as mixtures, but they differ as to whether any particular alloy is the one or the other. Thus Calvert and Johnson * consider the tin-copper alloys definite compounds, while Matthiessen† claims that they are "solidified solutions of one metal in the allotropic modification of the other." Muspratt ‡ says:

Many alloys consist of simple elements in definite or equivalent proportions, while others are produced from compound bodies, and often the components do not exist in the ratio of their chemical equivalents. Metals, in forming alloys, do not, however, combine indiscriminately with one another; the union is governed by the greater affinities which some of them manifest for each other; just as, in the chemistry of bases and acids, a predisposing attraction determines a preference. This in some measure proves that the alloys are not mechanical mixtures, but definite chemical compounds. It is remarkable that the native gold found in auriferous sands and rocks is alloyed with silver in the ratio of one equivalent of the latter to four, five, six, eight, ten, etc., equivalents of the former, but the combinations never afford results indicative of the metal being united in fractional parts of an equivalent.

Muspratt further says that another proof of the chemical combination subsisting is, that the compound melts at a lower temperature than the mean of its ingredients; but Matthiessen § argues that this is no proof.

Watts ‖ remarks that most metals are probably to some extent capable of existing in combination with each other in definite proportions; but it is difficult to obtain these compounds in a separate condition, since they dissolve in all proportions in the melted metals, and do not generally differ so widely in their melting or solidifying points from the metals

* Phil. Trans., 1858, p. 363. † British Assoc. Rep., 1863, p. 47.

‡ Muspratt's Chemistry, vol. 1, p. 534.

§ British Assoc. Rep. 1853, p. 42; also, Jour. Chem. Soc., vol. 5, 1867, p. 207.

‖ Watts' Dictionary, vol. iii. p. 942.

they may be mixed with as to be separated by crystallization in a definite condition.

The chemical force capable of being exerted between different metals may, as a rule, be expected to be very feeble, and the consequent state of combination would therefore be very easily disturbed by the influence of other forces. But in all cases of combination between metals, the alteration of physical properties, which is the distinctive feature of chemical combination, does not take place to any great extent. The most unquestionable compounds of metals are still metallic in their general physical characters, and there is no such transmutation of the individuality of their constituents as takes place in the combination of a metal with oxygen, or sulphur, or chlorine, etc. The alteration of characters in alloys is generally limited to the color, degree of hardness, tenacity, etc.

Messrs. Calvert and Johnson, about the year 1860, made a long series of experiments on alloys and amalgams made with pure metals, with the hope of throwing some light upon the subject, and of solving the question "Are alloys mixtures or compounds?" They believe that they have succeeded in ascertaining: First, the influence which each additional equivalent quantity of a metal exerts on another; secondly, the alloys which are compounds and those which are simple mixtures; for compounds have special and characteristic properties, while mixtures participate in the properties of the bodies composing them. They hold that the bronze alloys are definite compounds; for each alloy has a special value of conductivity of heat, and also its own specific gravity, and its own rate of expansion or contraction; while, on the contrary, the alloys of tin and zinc are mixtures; for they conduct heat, have a specific gravity and expand according to theory, or according to the proportions of tin and zinc which compose each alloy. Calvert and Johnson's conclusions are chiefly based upon their experiments on the heat conductivity of the alloys. Later experiments, made by Matthiessen,* on the conducting power of electricity, led him

* British Assoc. Reports, 1863, pp. 37-48.

to different conclusions. He experimented upon upwards of 250 alloys, all made of purified metals. The results of his investigations are published in a paper, "On the Chemical Nature of Alloys," from which is transcribed the following classification of the solid alloys, composed of two metals, according to their chemical nature.

1. *Solidified solutions of one metal in another:*

The lead-tin, cadmium-tin, zinc-tin, lead-cadmium, and zinc-cadmium alloys.

2. *Solidified solutions of one metal in the allotropic modification of another:*

The lead-bismuth, tin-bismuth, tin-copper, zinc-copper, lead-silver, and tin-silver alloys.

3. *Solidified solutions of allotropic modifications of the metals in each other:*

The bismuth-gold, bismuth-silver, palladium-silver, platinum-silver, gold-copper, and gold-silver alloys.

4. *Chemical combinations:*

The alloys whose composition is represented by Sn_5Au, Sn_2Au, and Au_2Sn.

5. *Solidified solutions of chemical combinations in one another:*

The alloys whose composition lies between Sn_5Au and Sn_2Au, and Sn_2Au and Au_2Sn.

6. *Mechanical mixtures of solidified solutions of one metal in another:*

The alloys of lead and zinc, when the mixture contains more than 1.2 per cent. lead or 1.6 per cent. zinc.

7. *Mechanical mixtures of solidified solutions of one metal in the allotropic modification of the other:*

The alloys of zinc and bismuth, when the mixture contains more than 14 per cent. zinc or 2.4 per cent. bismuth.

8. *Mechanical mixtures of solidified solutions of the allotropic modifications of the two metals in one another:*

Most of the silver-copper alloys.

Matthiessen, however, does not claim that the above classification is not liable to exception. He was obliged to assume that some of the metals undergo a change, or are converted into an allotropic modification in the presence of another metal, in order to explain some of the phenomena which he observed, but he admits that until the allotropic modifications have been isolated, the assumption must remain an hypothesis.

To conclude, we can only say that the question is still unsettled. From the marked peculiarities of properties observed in a few of the alloys, we are led to pronounce them chemical compounds. Some others, we must admit, are simple mixtures, or rather, solidified solutions. But in regard to the large majority we are still in doubt. Further experiments may throw more light on the subject, but it is probable that with the larger number of alloys it will be found impossible to discover their exact chemical nature.

62. Specific Gravity.—The specific gravity of an alloy is rarely the mean between the densities of each of its constituents. It is sometimes greater and sometimes less, indicating, in the former case an approximation, and in the latter a separation of the particles from each other in the process of alloying. This subject has been studied by several writers, and their published results agree quite closely in regard to some of the alloys, but differ in regard to others. These differences may be accounted for by the differences in the apparatus used by the experimenters, by the fact that some determinations have been corrected for temperature and pressure of the atmosphere, while others were not; but principally from the fact that several of the alloys are liable to be very deficient in homogeneity, and that the density of the same alloy will vary according to the conditions under which it is formed, as being cast too cold or too hot, cast in iron or in sand moulds, etc. A bar cast in a vertical position is apt to have a greater specific gravity at the bottom of the bar than at the top. Repeated fusion of an alloy also causes changes in its density.

It is common among authorities who publish determinations of specific gravities of the alloys, to give the calculated as well as the observed specific gravity. The calculated specific gravity is that which the alloy would have if there were neither expansion nor condensation of the metals during the act of combination. The specific gravities should be calculated from the volumes and not from the weights. Dr. Ure* gives the rule as follows: Multiply the sum of the weights into the products of the two specific gravity numbers for a numerator, and multiply each specific gravity number into the weight of the other body and add the products for a denominator. The quotient obtained by dividing the said numerator by the denominator is the truly computed mean specific gravity of the alloy. Expressed in algebraic language the above rule is—

$$M = \frac{(W + w)\, Pp}{P w + p\, W},$$

where M is the mean specific gravity of the alloy, W and w the weights, and P and p the specific gravities of the constituent metals.

Clarke's compilation of the "Constants of Nature," published by the Smithsonian Institution, contains a full table of specific gravities of the alloys, with the names of about twenty-five authorities. Of these, the principal are Mallet, Calvert and Johnson, Matthiessen, and Riche.

The following table of the alloys whose density is greater or less than the mean of their constituents, is given by several writers:

TABLE XVIII.

ALLOYS OF ABNORMAL DENSITY.

Alloys, the density of which is greater than the mean of their constituents.	Alloys, the density of which is less than the mean of their constituents.
Gold and zinc.	Gold and silver.
Gold and tin.	Gold and iron.
Gold and bismuth.	Gold and lead.
Gold and antimony.	Gold and copper.
Gold and cobalt.	Gold and iridium.
Silver and zinc.	Gold and nickel.
Silver and tin.	Silver and copper.
Silver and bismuth.	Iron and bismuth.

* Ure's Dictionary, 6th ed. 1872, vol. 1, p. 92.

TABLE XVIII.—*Continued.*

Alloys, the density of which is greater than the mean of their constituents.	Alloys, the density of which is less than the mean of their constituents.
Silver and antimony.	Iron and antimony.
Copper and zinc.	Iron and lead.
Copper and tin.	Tin and lead.
Copper and palladium.	Tin and lead.
Copper and bismuth.	Tin and palladium.
Lead and antimony.	Nickel and arsenic.
Platinum and molybdenum.	Zinc and antimony.
Palladium and bismuth.	

Calvert and Johnson agree with Matthiessen in giving the density of the alloys of lead and antimony as less than the mean of the constituents, and Matthiessen shows the alloys of lead and gold to have a greater density than the mean of their constituents. Some alloys of tin and gold and of bismuth and silver are shown by Matthiessen to have a greater, and some a less, density than the mean of their constituents, and the same is true of the alloys of some other metals.

63. **Fusibility.**—A remarkable property of many of the alloys is their great fusibility. In nearly all cases the fusing point of an alloy is lower than the mean of its constituent metals, and in some instances, as in the so-called fusible alloys, it is lower than that of either. The cause of this fact has not been definitely ascertained. Some regard it as a proof that the alloy is a distinct chemical compound, but most authorities differ from this view. Matthiessen * supposes that chemical combinations may exist in the fused mass, which suffer decomposition on cooling or solidifying. He says that the low fusing points admit of explanation by assuming that chemical attraction between the two metals comes into play as soon as the temperature rises, and the moment the smallest portions melt, then the actual chemical compound is formed which fuses at the lowest temperature, and then acts as a solvent for the particles next to it, and so promotes the combination of the metals where this can take place.

* British Assoc. Reports, 1863, p. 42.

In another place * Matthiessen remarks that all mixtures have a lower fusing point than the mean of the substances forming the mixture ; for instance, salt-water solidifies below zero, and a mixture of the chlorides of sodium and potassium fuse at a lower point than the mean of the fusing points of the components.

Some alloys have been observed to fuse at one point and solidify at a lower one ; for example, the tin-lead alloys, which all solidify at 181° C., but the fusing point of which varies with the different proportions of the component metals from 181° C. to 292° C.

Concerning these alloys, Pillichody † remarks as follows:

When the points of solidification are observed by immersing the thermometer in the melted alloy, it usually exhibits, during the passage of the mass from the liquid to the solid state, two stationary points. This effect is due to the separation of one or other of the component metals, while an alloy of constant composition still remains liquid. This alloy corresponds to the composition $Sn_3 Pb$. An alloy richer in lead would first deposit lead, and an alloy containing a larger proportion of tin would first deposit tin—the alloy $Sn_3 Pb$ remaining liquid for a longer or shorter time, and ultimately solidifying at 181° C. This temperature, therefore, corresponds to the lowest melting point that can be exhibited by an alloy of tin and lead, a larger proportion of either metal causing the melting point to rise.

With the exception of the alloys of tin and lead, and the fusible alloys, the fusing points of but few of the alloys have been determined. An accurate pyrometer for temperatures above red heat is needed for this purpose. The "Constants of Nature," while it has the specific gravities of several hundred alloys, gives the melting points of only six, exclusive of the fusible alloys and those of lead and tin. Mallet ‡ gives the relative fusibility of the several alloys of copper and tin and copper and zinc, and shows that their fusibility increases regularly as the proportion of copper in the alloy diminishes.

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* *Jour. Chem. Soc.*, vol. 5, 1867, p. 207.
† Ibid., vol. 15, 1862, p. 30.
‡ *Phil. Mag.*, vol. 21, 1842, pp. 66–68.

Some alloys in passing from the liquid to the solid state do not change at once, but remain for some time in a pasty condition. Their temperature of solidification, therefore, cannot be distinctly recognized. This is the case with an alloy of the composition Bi_2PbSn_2, which is fusible in boiling water, but which remains in a pasty condition through an interval of several degrees of temperature, so that it can be handled like a plaster.

M. Person * made experiments upon the alloys $Bi_3Pb_2Sn_2$ (D'Arcet's alloy, fusible at 96° C.), Bi_2PbSn_2 (fusible in boiling water), and $BiPbSn_2$ (fusible at 145° C.), and formed the conclusion that it is possible to assign in advance the heat necessary to fuse an alloy, if that required to fuse each of its component metals is known. He gives the formula $(160 + t) \vartheta = l$, in which t is the temperature at which fusion is effected; for example, 332° C. for lead if melted alone, but only 96° C. if melted in D'Arcet's fusible alloy; l is the expenditure of heat necessary to produce the fusion, that is, a certain number of *calories* (1 *calorie* = 3.96 British thermal units) variable with t; ϑ is the difference of the specific heats of the liquid and solid. If t and l are known, ϑ can be found. In the case of tin, $t = 235$, $l = 14.3$, from which $\vartheta = 0.0362$. Having this value of ϑ, it is easy to calculate the heat necessary to melt tin at any temperature whatever, for instance at 96° C., for which we find 9.3 *cal.* Making the same calculation for bismuth and for lead we find 7.382 and 2.7 *cal.* It only remains to take these numbers in the proportion in which each metal exists in the alloy, which gives a little less than 6.3 *calories*, which differs from the number found by experiment (6 *cals.*) only 0.3 *cal.*

Nothing appears to have been written upon this branch of the subject since M. Person's paper was published, but it is probable that if the investigation was pursued further our knowledge of the causes of the remarkable fusibility of the alloys would be much increased.

M. Riche † has determined the melting points of certain

* *Comptes Rendus*, vol. 25, 1847, pp. 444–446.

† *Ann. de Chim.*, vol. 30, 1873, p. 351.

alloys of tin and copper, by means of Becquerel's thermo-electric pyrometer. He obtained concordant results with the alloys $SnCu_3$ and $SnCu_4$, but with all other alloys the results differed widely among themselves.

W. C. Roberts,* chemist to the British mint, has published a series of determinations of the melting points of several alloys of silver and copper. The temperature was estimated by finding the amount of heat contained in a wrought-iron cylinder of known weight which was dropped into the melted alloy while in the furnace, and removed as soon as the mass showed signs of solidifying. The specific heats of the iron and of the alloy were the data used in the calculation. The alloy, composed of 630.29 parts of silver and 369.71 parts copper, corresponding to the formula AgCu, showed the lowest fusing point, or 846.8° C.; that of pure copper being 1330° C., and that of pure silver 1040° C.

64. **Liquation.**—Many of the alloys exhibit the phenomena of liquation, or separation of the mass of melted metal in the act of solidification into two or more alloys of different composition. The resulting alloy, or mixture of alloys, is consequently deficient in homogeneity. The causes of this separation are as yet but imperfectly understood. Some observations seem to show that an alloy of constant composition and of a comparatively high fusing point solidifies first in crystals disseminated throughout the mass, while the remainder of the melted metal remains fluid for a longer time, and finally solidifies around and among these crystals. This fact would tend to prove that the first alloy solidified was a distinct chemical compound, but it has been shown that crystals of exactly the same appearance have been formed from two metals in a wide range of proportions.

The different circumstances under which the separated alloys may be formed, such as the heat of the metal when poured into the mould, and the fact of slow or of rapid cooling, are known to have some influence upon the amount of liquation, or the difference of composition of different parts of the same casting, but this influence is not exerted upon all alloys

* Proc. Roy. Soc., vol. 23, 1875, pp. 481–495.

in the same direction, some alloys being affected in one way and some in another by the same manner of treatment. The bronze alloys, such as gun-metal, are said to have the liquation diminished by rapid cooling. When the mass is cooled slowly, bronze castings often show in the interior what are called spots of tin, but which are really spots of a white alloy of copper and tin, containing a larger percentage of tin than the average of the whole casting. When slowly cooled, also, the bottom of the casting is often found to contain a larger percentage of copper than the top. When cooled rapidly, however, as shown in the experiments of General Uchatius* in casting cannon in chilled moulds, the liquation is reduced to a minimum, and the resulting alloy is more homogeneous.

Levol † made some experiments on the liquation of the alloys of silver and copper, and concluded that the only homogeneous alloy of these two metals was the one whose composition is 718.97 parts of silver and 281.07 parts of copper, corresponding to the formula Ag_3Cu_2, and that all the others are liable to more or less liquation. It has lately been shown, however, by Mr. W. C. Roberts, ‡ chemist to the British mint, that this alloy is only homogeneous when cooled rapidly. If the cooling is slowly effected, its homogeneity is disturbed, the external portions being slightly richer in silver than the centre.

Mr. Roberts made several determinations of the liquation of other alloys of silver and copper, and found that the arrangement of an alloy is to a great extent dependent on the rate at which it is cooled, and that several alloys of silver and copper are, under suitable conditions, as homogeneous as Levol's alloy. The alloy of 925 parts silver and 75 parts copper was found to be nearly homogeneous when cooled very slowly, the composition of the corners and centre of a cube 45 millimetres on a side showing a maximum difference of only 1.4 parts in 1,000, while the same when cooled rapidly showed a difference of 12.8 parts in 1,000.

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* Ordnance Notes No. xl, Washington, D. C., 1875.

† *Ann. de Chim.*, vol. 36, 1852, pp. 193–224.

‡ Proc. Roy. Soc., vol. 23, 1875, pp. 481–495.

Col. J. T. Smith * relates, in reference to some experiments made by him on the alloy of silver and copper containing 91⅔ per cent. of silver, that the separation of the constituent parts of the alloy was not so much due to the rapidity or slowness with which the heat of the fluid metal was abstracted, as to the inequality affecting its removal from the different parts of the melted mass in the act of consolidation. Thus, if a crucible full of the melted alloy were lifted out of the furnace and placed on the floor to cool, the surface of the melted metal within it being well covered with a thick layer of hot ashes, the lower parts of the mass after it had become solid would be found to contain less silver in proportion than the upper surface.

If, on the other hand, the crucible were left to cool while imbedded in the furnace, the upper surface being exposed to the air, then the lower parts would, after solidification, be found finer than the upper surface.

Riche † has made several experiments on the liquation of the alloys of copper and tin. He remarks that to manifest the property of liquation, it is necessary to agitate the crucible containing the melted alloy, at the moment of solidification, in order to separate the small crystals already formed. The results obtained on the last product, remaining liquid in a mass weighing 1,000 to 1,200 grammes, showed a remarkable liquation of all the alloys of copper and tin except those corresponding to the formulæ $SnCu_3$ and $SnCu_4$

Several other alloys exhibit like phenomena to an even greater extent than those above mentioned. Matthiessen and Von Bose experimented upon alloys of lead and zinc and bismuth and zinc, melting the metals together in various proportions, and found that one end of a bar would have an excess of one metal and the other end an excess of the other. Alloys of copper and lead containing an excess of lead show a liquation in a remarkable degree, the excess of lead partly oozing out from the mass on cooling.

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* Proc. Roy. Soc., vol. 23, 1875, pp. 433–435.

† *Comptes Rendus*, vol. 67, 1868, pp. 1138–1140, and vol. 30, 1873, pp. 351–419.

65. Specific Heat.—The published determinations of the specific heat of the alloys are not numerous. This results, not from any difficulty of making the observations, but probably because they have not been considered of such practical importance as those of other properties, and partly, also, because M. Regnault's * determinations, made in 1841, and his deductions therefrom, are accepted as final.

M. Regnault determined the specific heat of two classes of alloys; first, those which at 100° C. are considerably removed from their fusing points; and, secondly, those which fuse at or near 100° C. The specific heats of the first series were so remarkably near to that calculated from the specific heats of the component metals that he announced the following law:

"*The specific heat of the alloys, at temperatures considerably removed from their fusing point, is exactly the mean of the specific heats of the metals which compose them.*"

The mean specific heat of the component metals is that obtained by multiplying the specific heat of each metal by the percentage amount of the metal contained in the alloy and dividing the sum of the products for each alloy by 100.

A curious fact discovered in regard to these alloys is also that the product of the specific heat of each alloy by its atomic weight is sensibly constant, varying in the whole series only from 40.76 to 42.05.

The second series of alloys, or those which fuse at a temperature at or near 100° C., show a wide divergence from the above law, the specific heats of all of these being much higher than that calculated from their constituents. The product of the specific heats by the atomic weights varied also from 45.83 to 72.97.

Matthiessen † describes a simple arrangement of the differential thermometer for the purpose of showing that the specific heat of an alloy is the same as the mean of those of its components.

66. Expansion by Heat.—The expansion of the alloys by

* *Ann. de Chim.*, vol. 1, 1841, pp. 129–207.

† *Jour. Chem. Soc.*, vol. 5, 1867, p. 205.

heat has been examined by Messrs. Calvert and Lowe,* with a view to learn whether their expansion followed the law of the proportions of their components. Four series of alloys were examined, namely, those of zinc and tin, lead and antimony, zinc and copper, and copper and tin. In each case the expansion was less than that deduced by calculation from their equivalents.

In alloys of copper with tin, it was found that where only a small quantity of tin entered into the composition of a bar, the expansion fell considerably below that of pure copper, although the tin added has a much higher rate of expansion than copper.

From experiments made by Messrs. Calvert and Lowe upon the expansion of chemically pure metals, they conclude that a very small proportion of impurity has a marked influence upon the expansion. Their results differed largely from those of other experimenters who used only the commercial metals; but when they, too, used commercial metals, the results agree.

The alloys upon which they experimented were also formed from pure metals, and on account of the difficulty of procuring these in sufficient quantity, the bars experimented on were very small, being only 60 millimetres, or less than 2½ inches long. The apparatus used, however, as described at length in the *Chemical News*, was so sensitive, that an expansion of $\frac{1}{50000}$ of an inch could readily be observed.

If experiments were made upon alloys formed from the ordinary commercial metals, it would probably be found that their rate of expansion would differ considerably from that of alloys formed from pure metals.

The molecular condition of a metal was observed to have an important influence on the rate of expansion. The same will no doubt be found true in the case of alloys.

Matthiessen † states that the expansion due to heat of the metals takes part in that of their alloys approximately in the ratio of their relative volumes. He gives a table of the

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* *Chem. News*, vol. 3, 1861, p. 315.

† *Jour. Chem. Soc.*, vol. 5, 1867, p. 206.

expansion of several alloys which tends to confirm his statement.

67. **Conductivity for Heat.**—The power of the alloys to conduct heat has been examined with great care by several experimenters. The published results are not always concordant, but the differences may be partially accounted for by the various kinds of apparatus used, and the great influence which small impurities and changes in molecular condition and crystalline form exert upon conductivity.

The conducting power for heat in an alloy is found in some cases to be the mean of the conducting power of the component metals, and in others to apparently have no relation whatever to such mean. As examples of the first case may be cited the alloys of tin and zinc and tin and lead; and of the second, the alloys of gold and silver and gold and copper. From this circumstance it has been expected that the heat-conducting power could be used as a means of determining whether an alloy is a chemical compound or a simple mixture. As before stated, however, the authorities differ widely on this point.

Messrs. Weidemann and Franz,* in 1853, made some experiments on the conducting power of the metals and of a few of the alloys, using a thermo-electroscope as an apparatus.

In 1858, Calvert and Johnson † made an extensive research on alloys formed from pure metals, using an apparatus of their own invention, by which the relative conducting power was shown by the rise in temperature in a given time of a given volume of water secured in a box at one end of the bar, while the other end of the bar was heated to 90° C. They claim that the method which they employed gave such consistent results, that they were able to determine the influence exercised on the conducting power of the metals by the addition of 1 or 2 per cent. of another metal, and also to appreciate the difference of conductivity of two alloys made of the same metals and only differing by a few per cent. in the relative

* *Pogg. Annalen*, vol. 89, 1853, pp. 497–531.

† Phil. Trans., 1858, pp. 349–368.

proportions of the metals composing them. They found also that the conducting power of metals was different when they were rolled out into bars or cast, and that it was modified by molecular arrangement or position of the axes of crystallization, as was shown by the different conducting power of metals cast horizontally and vertically. Some curious results were observed in regard to alloys of gold and silver. Silver being the best conductor, its conductivity is rated as 1,000, and that of gold the next, is 981; but gold alloyed with 1 per cent. of silver has a relative conductivity of only 840.

The conduction of heat by alloys, according to Calvert and Johnson, may be considered under three general heads:

1. *Alloys which conduct heat in ratio with the relative equivalents of the metals composing them.*

2. *Alloys in which there is an excess of equivalents of the worse conducting metal over the number of equivalents of the better conductor,* such as alloys composed of 1 Cu and 2 Sn, 1 Cu, and 3 Sn, etc., and which present the curious and unexpected rule that *they conduct heat as if they did not contain a particle of the better conductor,* the conducting power of such alloys being the same as if the bar was entirely composed of the worse conducting metal. A not less remarkable fact is that the alloys of a series, such as those of 2 equivalents of bismuth and 1 of lead, 3 Bi and 1 Pb, 4 Bi and 1 Pb, all conduct heat alike, the various increasing quantities of lead exercising no influence on the conductivity.

The results obtained with this class of alloys are most important to engineers; for it will be seen in the case of alloys of brass and bronze that no increase is gained in the conductivity of an alloy by increasing the quantity of a good conductor; nay, in many cases it would be a decided loss, unless a sufficient quantity of the better conducting metal be employed to bring the alloy under the third head.

3. *Alloys composed of the same metals as the last class, but in which the number of equivalents of the better conducting metal is greater than the number of equivalents of the worse conductor;* for example, alloys composed of 1 Sn 2 Cu, 1 Sn 3 Cu, etc. In this case each alloy has its own arbitrary con-

ducting power; the conductivity of such an alloy gradually increases and tends toward the conducting power of the better conductor.

In a later experiment upon the conductivity of mercury and the amalgams, Calvert and Johnson* discovered that they had committed an error in their first experiments in determining the conductivity of mercury, by disregarding the fact that convection of the liquid increased the apparent conductivity. In the first experiments they found the apparent relative conductivity to be 677, silver being 1,000; but in the later experiments they determined the real relative conductivity to be only 54, or less than that of any other metal. In regard to the fluid amalgams, they found in all cases that their conductivity was nearly the same as that of pure mercury.

Weidemann,† in 1859, published a paper in which he calls in question the accuracy of the results found by Calvert and Johnson, and criticises the apparatus used by them and the small size of the bars upon which they experimented. He also gives the results of some experiments which he has made upon the conductivity of a few alloys.

Matthiessen ‡ describes a simple apparatus for showing the different conductivities of alloys. He also states that the conductivity for heat furnishes no evidence of whether an alloy is a chemical compound or a mixture.

68. Conductivity for Electricity.— The conductivity for electricity, like the conductivity for heat, is one of the properties which, in some alloys, is the mean of that of the component metals, and in others seems to have no relation whatever to such mean.

There have been a large number of experiments made upon the electric conductivity of the alloys, but in this, as in the examination of other properties, with widely varying results. In the first place, the determinations of the conducting powers of the metals themselves are far from agree-

* Phil. Trans., 1859, pp. 831–835.

† *Pogg. Annalen*, vol. 108, 1859, pp. 393–406.

‡ *Jour. Chem. Soc.*, vol. 5, 1867, p. 213.

ing; as, for instance, the conductivity of copper, according to different experimenters, is given at numbers ranging from 66 to 100, pure silver being 100.

Again, Matthiessen * has shown that small traces of the metals, and especially of the metalloids, reduce the conductivity of copper to a great extent. He states also, that there is no alloy of copper which conducts electricity better than pure copper, and that the fact of the wires experimented upon being annealed or hard drawn causes a marked difference in the values obtained, annealed wire being a better conductor than hard drawn; and, further, that temperature has likewise a marked influence, the metals losing in conducting power as the temperature increases.

In 1833, Professor Forbes † published the statement that the order of conducting powers of the metals for heat and for electricity is the same. He states, as a general conclusion, "that the arrangement of metallic conductors of heat does not differ more from that of those of electricity than either arrangement does alone under the hands of different observers."

Twenty years later, Weidemann and Franz ‡ arrived at the same conclusion in regard to brass and German silver, and Weidemann,§ in 1859, concluded the same in regard to alloys in general. Weidemann and Franz remarked that whatever the quality may be upon which calorific conduction depends, the close agreement of the figures renders it exceedingly probable that the same quality influences in a similar manner the transmission of electricity; for the divergence of the numbers expressing the conductivity for heat from those expressing the conductivity for electricity are not greater than the divergences of the latter alone, exhibited by the results of different observers.

The most extensive series of investigations upon the electric conductivity of alloys has been made by Matthiessen.

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* Phil. Trans., 1860, pp. 85–92.

† *Phil. Mag.*, vol. 4, 1834, p. 27.

‡ *Pogg. Annalen*, vol. 89, 1853, pp. 497–531.

§ Ibid., vol. 108, 1859, pp. 393–407.

His results are published in the following papers: "On the Electric Conducting Power of the Metals;"* "On the Electric Conducting Power of Alloys;"† "On the Influence of Temperature on the Electric Conducting Power of Alloys;"‡ "On the Thermo-Electric Series;"§ "On the Effect of the Presence of the Metals and Metalloids upon the Electric Conducting Power of Pure Copper;"‖ "On the Chemical Nature of Alloys."¶

It was chiefly from these researches that Matthiessen arrived at the conclusions in regard to the question whether alloys are chemical compounds or mixtures, which have already been given under the head of the chemical nature of alloys.

Matthiessen's examination of the conductivity of copper, made in 1860, greatly stimulated the refinement of the metal used in telegraphy and led to a gradual improvement, from a conductivity of less than 50 per cent. up to above 98 per cent., that of pure copper in the latest work. Good wire has highest conductivity when soft, but the strength of soft copper is often much less than one-half that of hard drawn wire. Use has no apparent effect on conductors of this metal, but it is at times subject to a peculiar change resulting in brittleness and loss of conductivity; this is especially liable to occur in electro-magnets.

In regard to the conducting power for electricity of the alloys, Matthiessen divides the metals into two classes:

Class A.—Those metals which, when alloyed with one another, conduct electricity in the ratio of their relative volumes.

Class B.—Those metals which, when alloyed with one of the metals belonging to class A, or with one another, do *not* conduct electricity in the ratio of their relative

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* Phil. Trans., 1858, pp. 383–387.

† Phil. Trans., 1860, pp. 161–176.

‡ Phil. Trans., 1864. pp. 167–200.

§ Phil. Trans., 1858, pp. 369–381.

‖ Phil. Trans., 1860, pp. 85–92.

¶ British Assoc. Reports, 1863, pp. 37–48.

volumes, but always in a lower degree than the mean of their volumes.

To Class A belong lead, tin, zinc, and cadmium. To class B belong bismuth, mercury, antimony, platinum, palladium, iron, aluminium, gold, copper, silver, and in all probability most of the other metals.

69. **Crystallization.**—The crystallization of alloys exhibits some curious phenomena. It was formerly supposed that if a distinct crystal of an alloy were found, it would have a definite chemical composition, and would show that the alloy was not a mixture, but a veritable chemical compound.

In 1854, however, Prof. J. P. Cooke * published a paper on two crystalline compounds of zinc and antimony, which exhibited such properties as justified him in considering them definite chemical compounds. To distinguish them, he gave them the names of Stibiotrizincyle, with the formula $SbZn_3$, and Stibiobizincyle, with the formula $SbZn_2$. In the paper named, the crystalline form and other properties are fully described.

A short time afterward it was found that well-defined crystals, like those described as $SbZn_3$, were obtained from the alloys containing between 43 and 60 per cent. of zinc; and even in alloys of a higher zinc percentage crystals of the same form were still seen, although they were no longer well defined. In the alloys containing between 20 and 33 per cent. of zinc, well-defined crystals, like those described as $SbZn_2$, were formed; and finally, there separated from the alloys containing between 33 and 42 per cent. of zinc, thin metallic plates, which evidently belonged to the same crystalline form. †

The same fact has been observed by Matthiessen and Von Bose ‡ in regard to the alloys of gold and tin, namely, that well-defined crystals are not limited to one definite proportion of the constituents of an alloy, but are common to all gold-tin alloys containing from 43 to 27.4 per cent. of gold.

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* *Am. Jour. Art and Sci.*, vol. 18, 1854, pp. 229-237.

† Ibid., vol. 20, 1855, pp. 222-238.

‡ Proc. Roy. Soc., 1860-'62, pp. 433-436.

They also found in the case of these alloys that the crystals and the mother liquor were never of the same composition, the percentage of gold in the mother liquor being much below that in the crystals.

From experiments by F. H. Storer,* it appears that the alloys of copper and zinc yield crystals, sometimes exhibiting distinct octahedral faces, sometimes in confused aggregates of crystals, but all of octahedral character, and bearing a striking resemblance to the crystals of pure copper obtained by fusion. None of the crystals were found to contain a larger proportion of either metal than the remainder of the molten liquid from which they had separated. Storer concludes that all the alloys of copper and zinc crystallize in the regular system, and that they are not definite atomic compounds, but merely isomorphous mixtures of the two metals.

Calvert and Johnson† have also noticed the crystallization of the alloys of copper and zinc, and state that it is probable that Cu_2Zn and Cu_3Zn are definite compounds, as they are perfectly crystallized, and have also a special heat-conducting power of their own. They state that the most splendid of all the brass alloys is the alloy CuZn, which is of a beautiful gold color, and crystallizes in prisms often 3 centimetres long.

Slow cooling of an alloy is apt to favor the separate crystallization of one or more of its components, and thus render it brittle. Sometimes in casting an alloy in large masses, there will be a partial separation of the constituents, and crystals of different composition will be found at the top and bottom of the mass, those at the bottom usually containing the larger percentage of the metal which has the greater specific gravity. This phenomenon has already been noted under the head of liquation.

70. Oxidation and Action of Acids.—But few experiments have been made to determine the rate of oxidation or corrosion of the alloys by atmospheric influences or by the action of acids. It is generally found that the action of the atmosphere is less on alloys than on their component metals. An

* "Memoirs of the American Academy," vol. 8, 1863, pp. 27–56.

† Phil. Trans., 1858, p. 367.

instance of this is the ancient bronze statues and coins, some of the latter of which have their characters still legible, although they have been exposed to the effects of air and moisture for upward of twenty centuries.

The action of the atmosphere on an alloy heated to a high temperature is sometimes quite energetic, as is shown in the alloy of three parts lead and one of tin, which, when heated to redness, burns briskly to a red oxide. When two metals, as copper and tin, are combined, which oxidize at different temperatures, they may be separated by continued fusion with exposure to the air. Cupellation of the precious metals is a like phenomenon.

Mushet* found that unrefined copper resisted the action of muriatic acid better than pure copper. This he thought was due to the presence of tin in the unrefined copper, as he found that an alloy of copper containing about 3 per cent. of tin resisted the action of acid to still greater extent. The latter he recommends for the purpose of ship-sheathing.

Calvert and Johnson† have made several experiments to determine the action of nitric, hydrochloric, and sulphuric acids upon alloys of copper and zinc and copper and tin. Some of the results thus obtained were entirely unexpected. Nitric acid of 1.14 specific gravity was found to dissolve the two metals in an alloy of zinc and copper in the exact proportion in which they exist in the alloy employed, while an acid of 1.08 specific gravity dissolved nearly the whole of the zinc and only a small quantity of the copper. Hydrochloric acid of 1.05 specific gravity was found to be completely inactive on all alloys of copper and zinc containing an excess of copper, and especially on the alloy containing equivalent proportions of each metal. Zinc was found to have an extraordinary preventive influence on the action of strong sulphuric acid on copper.

The alloys of copper and tin were all found to resist the action of nitric acid more than pure copper, but the preven-

* *Phil. Mag.*, vol. 6, 1835, pp. 444–447.

† Ibid., vol. 10, 1855, pp. 250, 251; also, *Jour. Chem. Soc.*, vol. 19, 1866, pp. 434–454.

tive influence of tin presents the peculiarity that the action of the acid increases as the proportion of tin increases ; thus the alloy $CuSn_5$ is attacked ten times more than the alloy Cu Sn. The alloys $SnCu_2$ and $SnCu_3$ were attacked by strong sulphuric acid with more violence than any other of the bronzes.

Three alloys, viz., $Cu_{18}ZnSn$, $Cu_{10}ZnSn$, and Cu_4Zn_2, were found to be only slightly attacked by strong nitric or hydrochloric acids, and not at all by sulphuric acid. The resistance to the action of nitric acid is remarkable, as its action on each of the component metals is very violent.

A. Bauer* has also published, in the *Berichte der deutschen chemischen Gesellschaft*, the result of some experiments on the action of hot sulphuric acid on several alloys of lead. These experiments show that the addition of a little antimony or copper renders the alloy more able to resist sulphuric acid, while bismuth has a decidedly injurious effect.

71. **Hardness and other Mechanical Properties.**—The mechanical properties of the alloys, such as hardness, malleability, ductility, resistance to strains of tension, compression, and torsion, elasticity, resilience, etc., are of the utmost importance to the engineer, but, at the same time, it is most difficult to find reliable information regarding them. But few experimenters of authority have investigated the subject, and their researches, although valuable as far as they go, are too limited in extent to allow of a complete classification and comparison. A few alloys which are of special service in the arts have been well studied by those who have had occasion to use them, with a view to learn their mechanical properties, not as a matter of scientific interest, but as an actual necessity. This has been the case especially with the various gun-metals, upon which many experiments have been made under authority of the different governments, so that among all the alloys our knowledge of the gun-metals is the most extensive and accurate. In like manner the properties of journal and anti-friction metals have been investigated by those who are concerned in their manufacture and use.

* *Scientific American*, vol. 33, 1875, p. 135.

With these, and a few other exceptions, however, our information on the mechanical properties of the alloys is very meagre. It has been the endeavor of the Author, as far as possible, to supply this manifest want by a series of experiments on a large number of alloys, testing them to determine their mechanical properties.

The hardness of some of the alloys has been investigated by Calvert and Johnson.* They used an apparatus for determining the hardness, which consists, chiefly, of a conical steel point of a certain size, which is pushed into the material whose hardness is to be determined a given distance by means of weights applied at the end of a lever. The relative hardness is shown by the weight required for the different materials.

A somewhat similar apparatus was used by Major Wade † in determining the hardness of gun-metal, but he used a diamond-shaped point and a fixed weight, determining the relative hardness by the distance which the point was pushed into the metal. General Uchatius,‡ in experiments for the Austrian Government, used an indenting tool, which was forced into the metal to be tested by a weight of 4.4 pounds falling through a height of 9¾ inches. The shorter the cut made by the indenting tool, the greater the hardness.

Mallet § in 1842, in his experiments on the alloys of copper and tin and copper and zinc, determined their tensile strength, and also the order of their ductility, malleability, and hardness. In his work on the "Construction of Artillery," ‖ published in 1856, the same author discusses the physical and mechanical properties of gun-metal, showing the effects of sudden and of rapid cooling, and the deteriorating effect of small proportions of a third metal, such as iron, zinc, lead, or antimony.

In regard to the extent of our knowledge upon these sub-

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* *Phil. Mag.*, vol. 17, 1859, pp. 114–121.

† "Report of Experiments on Metals for Cannon," Phila., 1856.

‡ Ordnance Notes No. XL., Washington, D. C., 1875.

§ *Phil. Mag.*, vol. 21, 1842, pp. 66–68.

‖ Mallet, "Construction of Artillery," London, 1856, pp. 80–101.

jects," he remarks: "Gun-metal, probably the very earliest used material for cannon, is that which has received the least improvement or systematization of our knowledge as to its use, up to the present time; the archæologist finds the rude weapons of Scandinavian, Celtic, Egyptian, Greek, and Roman warfare formed of nearly the same alloys of copper and tin, and in about the same proportions, as the cannon of to-day."

The circumstances of chief difficulty and importance in the manipulation of gun-metal, as affecting the production of cannon, are:

1st. The chemical constitution of the alloy, as influencing the balance of its hardness, rigidity, or ductility, and tenacity.

2d. Its chemical constitution, and what other conditions influence the segregation of the cooling mass of the gun, when cast, into two or more alloys of different and often variable composition.

3d. The effects of rapid and of slow cooling, and of the temperature at which the metal is fused and poured.

4th. The effects due to repeated fusions, and to foreign constituents, in minute proportions, entering into the alloy.

The circumstances of manipulation, as above named, have already been shown to have a vast influence upon nearly all the properties of the alloys, and their study is of the greatest importance, not only in reference to gun-metals, but to all alloys which may be used as materials of construction.

In connection with the subject of gun-metal, the experiments lately made by General Uchatius * for the Austrian Government are of interest. He found that the tenacity, elasticity, and hardness of bronze were increased to an extraordinary degree by driving a series of conical steel mandrels or plugs, gradually increasing in size, into the bore of the gun. The metal in the interior of the gun was thus stretched or strained much beyond its elastic limit, and was thereby given a new molecular condition, which enables it better to resist both the expansive force of the exploded powder, and the abrading effects of the shot.

The results of the experiments of General Uchatius have

* Ordnance Notes No. XL., Washington, D. C., 1875.

been communicated to the Ordnance Department of the United States by Col. T. T. S. Laidley, U. S. A., who calls attention to the fact that experiments were made upon bronze, with a view to improve its quality for guns, by Mr. S. B. Dean, of Boston, in 1868–69, at which time he used the identical mode of improving the bronze adopted by General Uchatius some four years later. Patents for the improvement were secured in May, 1869, not only in this country, but also in England, France, and Austria. The want of funds rendered it necessary for Mr. Dean's experiments to be discontinued. This matter will be considered at greater length in a later division of this volume.

CHAPTER IV.

THE BRONZES AND OTHER COPPER-TIN ALLOYS.

72. **The Alloys of Copper,** with smaller quantities of the more common metals, are the most valuable and the most common, and the most extensively used of all compounds or mixtures known to the engineer and the metallurgist. Those which are produced by the union of copper and tin are generally classed as the "Bronzes." When copper is alloyed with zinc, the composition is known as "Brass." These terms are not exclusively so applied, however, and the term brass is not infrequently used to cover the whole series of alloys composed, wholly or in part, of alloys of copper and tin, copper and zinc, or combinations of brass and of bronze with each other or with less quantities of other metals. *Bronzes* are here supposed to contain principally *copper and tin.* These alloys are produced by the union, either chemically or by solution, when molten, of two or more metals. Nearly all metals can unite with nearly all other metals in this manner, and the number of possible combinations is infinite; nevertheless, but few alloys are found to be very generally used in the arts. It is considered probable that the metals may combine chemically in definite proportions, but the compounds thus produced usually dissolve in all proportions in either of the constituents, and it is rarely possible to separate the chemically united portions. In some cases the affinity is very slight, as between lead and zinc, either of which will take up but about one and a half per cent. of the other. The alloys are usually the more stable as their constituents are the more dissimilar, and, when this difference is chemically great, the compound becomes brittle. Occasionally, an alloy is formed which gives evidence of the occurrence of chemical union, by the production of heat; this is seen in some copper-zinc alloys.

Copper alloys are formed with nearly all metals with great facility, and with no other precaution than that of either preventing access of oxygen to the molten mass, or of thoroughly fluxing the alloy, to take up such as may have combined with it. Many of these alloys were once considered chemical compounds; but the view which seems most generally accepted, at the present time, is that they are almost invariably either mere mixtures, or that a species of solution of the one metal in the other takes place.

The most minute trace of foreign element often produces an observable, or even an important, alteration of the properties of copper. This is especially true of its conductivity for electricity, which is reduced greatly by an exceedingly minute proportion of iron or lead.

73. **History.**—The alloys of these metals were used extensively by the ancients for coins, weapons, tools and ornaments, and the composition of their bronzes, as shown by recent analyses, indicates that they were as skilful in brass-founding as the modern workman.

Thus, Phillips gives the following as the results of his own examinations and as showing the proportions of the constituents employed in the manufacture of brass, at times both preceding and closely following the Christian era:

	DATE.	COPPER.	ZINC.	TIN.	LEAD.	IRON.
Large brass of the Cassia family..	B.C. 20	82.26	17.31	....	....	.35
" " Nero " ..	A.D. 60	81.07	17.81	1.05	....	....
" " Titus " ..	" 79	83.04	15.84	....	....	.50
" " Hadrian " ..	" 120	85.67	10.85	1.14	1.73	.74
" " Faustina " ..	" 165	79.14	6.27	4.97	9.18	.23

Thus, copper and zinc were the essential constituents of the alloys examined; but then lead was sometimes present in considerable quantities, together with tin and iron. Although zinc occurs in such considerable quantities in these alloys, it was not known in the metallic state until about the thirteenth century, when it was described by Albert of Bollstadt.

Many analyses of ancient articles of bronze have been made, and our knowledge of this very old alloy is considerably greater than that of the alloys of zinc. The proportion of the constituent metals was varied according to the purpose to which the alloy was to be applied, as will be seen from the following analyses, the hardness being modified according to the proportion of tin present. The alloys containing the largest amount of tin were used for mirrors, while those of medium hardness were used for sword-blades and other cutting instruments:

	COPPER.	TIN.	LEAD.	IRON.	COBALT.	ANALYST.
1. Chisel, from ancient Egyptian quarry.	94.00	5.90	....	.10	....	Wilkenson.
2. Bowl, from Nimroud.	89.57	10.43	....	....	....	Dr. Percy.
3. Bronze overlaying iron	88.37	11.33	....	....	....	"
4. Sword-blade, Chertsey, Thames	89.69	9.58	....	.33	....	J. A. Phillips.
5. Axe-head	88.05	11.12	.78	....	....	Prof. Wilson.
6. Celt	81.19	18.31	.78	....	....	"
7. Roman As, B.C. 500	69.69	7.16	21.82	.47	.57	J. A. Phillips.
8. Julius Cæsar	79.13	8.00	12.81	....	....	"

The third specimen was analyzed by Dr. Percy, who describes it as a small casting in the shape of the foreleg of a bull, forming the foot of a stand, consisting of a ring of iron supported upon three bronze feet. A longitudinal section disclosed a central core of *iron*, around which the bronze had been cast.

Some writers, to account for the immense masses of hard stone wrought by the Egyptians and ancient Americans, suppose that they possessed means of hardening bronze to a degree equal to that of our steel; this requires confirmation, since no remains of bronze of such a hard variety have ever been discovered.

The bronze weapons discovered by Dr. Schliemann among the ruins excavated by him at or near the site of ancient Troy* were often of nearly the composition of modern gun-bronze; they contained copper 90 to 96, tin 8.6 to 4. The date,

* "Troy and its Remains;" London and New York, 1875; p. 361.

archæologically, is at the beginning of the "bronze age," and immediately at the close of the "stone age." Sir John Lubbock finds the bronze implements and ornaments of the bronze age as remarkable for their beauty and variety as for their utility.* They consisted of axes, arrow-heads, knives, swords, lances, sickles, ear-rings, bracelets, rings, etc., etc.

The bronze used by the prehistoric nations contained no lead; that of the Romans and post-Romans was rarely of pure copper and tin, but were usually more or less alloyed with lead. Silver, zinc, and lead was not known in the bronze age. The prehistoric bronzes were cast, sometimes in metal or in stone, and sometimes in sand, moulds. A more common method was by wax models, or "patterns," which were used to make the desired cavity in an earthen or sand mould, the wax being melted out afterward.

According to Charnay,† the Aztecs discovered a means of tempering copper, and of giving to it a considerable degree of hardness, by alloying it with tin. Copper hatchets were known among them; since Bernal Diaz states in the narrative of his first expedition to Tobasco, that the Spaniards bartered glass-ware for a quantity of hatchets of copper, which at first they supposed to be gold. Copper abounded in Venezuela, and we still find there in great numbers trinkets of copper mixed with gold, or of pure copper, representing crocodiles, lizards, frogs and the like.

In cutting down trees, they employed copper axes like our own, except that, instead of having a socket for the haft, the latter was split, and the head of the axe secured in the cleft.

The hatchet described seems to have been a piece of native copper wrought and fashioned with a stone hammer. The Aztecs made good bronze chisels, as described by Señor Mendoza, director of the National Museum of Mexico. He describes certain specimens of bronze chisels belonging to the collection in that museum. When freed from oxide the bronze presents the following characteristics: In color it resembles gold; its density is 8.875; it is malle-

* "Prehistoric Times;" London and New York, 1872.

† *N. A. Review*, 1875; Ruins of Central America.

able, but unlike pure copper, is hard, and breaks under strong tension or torsion; the fracture presents a fine granulation like that of steel; in hardness, it is inferior to iron, but it is sufficiently hard to serve the purpose for which it was intended. One of these chisels was found to consist of copper 97–87 per cent., tin 2–13 per cent., with traces of gold and zinc.

The bronzes were used by the ancients in the manufacture of weapons and of tools. The use of phosphorus increases the purity and adds strength and hardness to these alloys, and the remarkable hardness of ancient bronze weapons is found by Dr. Reyer to be due, in part at least, to the presence of phosphorus, probably introduced with the flux used in melting. The proportion of tin varied up to 20 per cent.

74. **The Alloys of Copper and Tin** have many uses in the arts. The two metals will unite to form a homogeneous alloy in a wide range of proportions. As tin is added to pure copper, the color of the alloy gradually changes, becoming decidedly yellow at 10 per cent. tin and turning to gray as the proportion approaches 30 per cent. In the researches conducted by the Author, it was found that good alloys may contain as much as 20 per cent. tin. When the color changes from golden yellow to gray and white, the strength as suddenly diminishes; and alloys containing 25 per cent. tin are valueless to the engineer; nevertheless, this alloy and those containing up to 30 per cent. show compressive resistances increasing to a maximum. The tensile and compressive resistances have no known relation; the torsional resistance is more closely related to tenacity.

A small loss of each constituent occurs in melting, the loss often being highest with the metal present in the lowest proportion; this loss rarely exceeds one per cent., except when the fusion has taken place slowly with exposure to the air, when considerable copper-oxide is liable to form. The specific gravities of these alloys do not differ much from 8.95.

Under 17.5 per cent. tin, the elastic limit lies between 50 and 60 per cent. of the ultimate strength; beyond this limit the proportion rises, and at 25 per cent. tin the elastic limit and breaking point coincide. Passing 40 per cent. tin, this change is reversed and the elastic limit, although indefinite, is lowered until pure tin is reached and a minimum at about 30 per cent.

The modulus of elasticity of all the bronzes lies between ten and twelve millions.

Riche states that tempering produces on steel, forged or annealed, an inverse effect to that which it produces on bronzes rich in tin; it diminishes its density instead of increasing it, from which it may be seen that tempering diminishes the density of annealed steel and makes it hard, while tempering increases the density of annealed bronze and makes it soft.

There is always an increase in density, whether the bronzes rich in tin be tempered, or slowly cooled, after compression.

These experiments confirm most clearly the fact affirmed by D'Arcet, that tempering softens the bronzes, rich in tin, for we can flatten in the press the tempered bronzes, while it is impossible to do this with steel.

It is evident from his experiments that tempering augments considerably the density of bronze rich in tin, and that annealing evidently diminishes the density of tempered bronze. Still the effect of slow cooling by no means destroys the effect of tempering, for the density continues to increase till it becomes remarkable.

While all mechanical action increases the density of the annealed bronze, it very slightly, but still sensibly, diminishes the density of annealed steel, and, on the whole, tempering and shock increase the density of annealed bronze, while they diminish the density of annealed steel.

But the variations are very decided for bronze and very slight for steel.

Bronze of 96 and 97 parts copper may be employed to great advantage, and with no serious inconvenience, in the manufacture of medals. Its hardness, much less than that of the alloy of M. de Puymaurin, does not much exceed that of copper; it possesses a certain sonority and casts well, rolls evenly, and its color is more artistic than that of copper.

The action of the press and of heat modify its density but little.

75. **Properties.**—Copper and tin alloy in all proportions, and the most useful compounds known to the engineer are the "bronzes," as these alloys are called. They include gun-metal, bell-metal and speculum alloys. The following is Mallet's list of these alloys and table of their properties.*

TABLE XIX.

PROPERTIES OF COPPER-TIN ALLOYS.

At. wt.: Cu. = 31.6; Sn = 58.9.

AT. COMP.	COPPER.	S. G.	COLOR.	FRACT.	TENACITY.	MALL.	HARD.	FUS.
Cu Sn	per ct.				Tons per sq. in.			
1 : 0	100.	8.607	red-yellow	....	24.6	1	10	16
a 10 : 1	84.29	8.561	"	fine grain	16.1	2	8	15
b 9 : 1	82.81	8.462	yellow-red	"	15.2	3	5	14
c 8 : 1	81.10	8.459	"	"	17.7	4	4	13
d 7 : 1	78.97	8.723	pale red	vitreous	13.6	5	3	12
e 6 : 1	76.29	8.750	"	"	9.7	brittle	2	11
f 5 : 1	72.80	8.575	ash gray	conchoid.	4.9	"	1	10
g 4 : 1	68.21	8.400	dark gray	"	0.7	friable	6	9
h 3 : 1	61.69	8.539	white gray	"	0.5	"	7	8
i 2 : 1	51.75	8.416	white	lam. grain	1.7	brittle	9	7
j 1 : 1	34.92	8.056	"	vitreous	1.4	"	11	6
k 1 : 2	21.15	7.387	"	lam. grain	3.9	"	12	5
l 1 : 3	15.17	7.447	"	"	3.1	8 tough	13	4
m 1 : 4	11.82	7.472	"	"	3.1	6 "	14	3
n 1 : 5	9.63	7.442	"	earthy	2.5	7	15	2
o 0 : 1	0.	7.291	"	....	2.7	......	16	1

a, *b*, *c* are gun-metals; *d*, hard brass for pins; *e*, *f*, *g*, *h*, *i*, bell-metal; *j*, *k*, for small bells; *l*, *m*, *n*, *o*, are speculum alloys.

The addition of a small quantity of tin to copper causes it to become brittle under the hammer, according to Karsten, and the ductility is restored only by heating to a red heat and suddenly cooling. Mushet finds that the alloy, copper 97, tin 2, makes good sheathing, as it is not readily dissolved in hydrochloric acid. The best gun-metal is from copper 90, tin 10, to copper 91, tin 9; if richer in copper, it is especially liable to liquation, which action is detrimental to all these alloys. Bell-metal, copper 80, tin 20, to copper 84, tin 16, is sonorous and makes good castings, but is hard, difficult to

* *Dingler's Journal*, lxxxv., p. 378; Watts's Dict. ii., p. 43.

work and quite brittle. Suddenly cooling it from a high temperature reduces its brittleness, while slow cooling restores its hardness and brittleness. It is malleable at low red heat and can be forged by careful management.

Speculum-metal, copper 75, tin 25, is harder, whiter, more brittle and more troublesome to work than bell-metal.

Old flexible bronzes contain about ¾ ounce of tin to the pound of copper, or copper 95, tin 5, as stated by Ure. Ancient tools and weapons, as shown elsewhere, contain from 8 to 15 per cent. tin; medals from 8 to 12 per cent., with often 2 per cent. zinc to give a better color. Mirrors contained from 20 to 30 per cent. tin. The metals mix in all proportions, and the alloys are, to a certain extent, independent of their chemical proportionality. The occurrence of hard, brittle, elastic alloys between the extremes of a series having soft tin and ductile copper at either end, both of which metals are inelastic, is probably a proof that these alloys are sometimes chemical compounds. They are probably, usually, compounds in which are dissolved an excess of one or the others of the components.

76. **The Principal Bronzes** are those used in coinage, in ordnance, in statuary, in bells, and musical instruments, and in mirrors and the specula of telescopes. These alloys oxidize less rapidly than copper, are all harder, and often stronger and denser.

Coin bronze, as made by the Greeks and Romans, contained from copper 96, tin 4, to copper 98, tin 2, and Chaudet has shown that the first of these alloys can be used for fine work, obtaining medals of this composition of very perfect polish while sufficiently hard to wear well. Puymaurin succeeded well with alloys of copper 93.5, tin 6.5, to copper 90, tin 10; and Dumas found the range of good alloys for this purpose quite large, varying from 96 copper, 4 tin, to 86 copper, 14 tin, but the best falling near the middle of this range.

Gun bronze has various compositions in different countries. The most common proportion would seem to be copper 90, tin 10, or copper 89, tin 11. Well made, it is solid, yellowish, denser than the mean of its constituents, and much harder.

stronger, and more fusible than commercial copper; it is somewhat malleable when hot, much less so when cold.

It is subject to some liquation, and should therefore be quickly chilled in the mould; it loses some tin when permitted to stand at a temperature of 400° to 500° Fahr. (200° to 260° C.). This liquation gives rise to light-colored spots throughout the metal. This bronze does not readily oxidize at ordinary temperatures, but is quickly attacked when hot; it usually becomes greenish when exposed to the weather, by the formation of the hydrated carbonate; thus "patina" is observed on all unpolished old bronze guns or old statues.

Statuary bronze is usually of nearly the same composition as gun-bronze. It should be rapidly melted, poured at high temperature, and quickly cooled to prevent liquation.

Bell-metal is richer in tin than the preceding, and varies in composition somewhat with the size of bell. The proportion, 77 copper, 23 tin, is said to be a good one for large bells; it shrinks 0.015 in the mould while solidifying. The range of good practice is found to be from 18 to 30 per cent. tin, 82 to 70 per cent. copper; the largest proportions of tin are used for the smallest bells, and an excess is added to meet the liability to oxidation and liquation; copper 78–82, tin 22–18, is a very usual composition. When made of scrap metal, as is not uncommon, serious loss of quality is liable to occur by the introduction of lead and other metals deficient in sonorousness. When properly made, this alloy is dense and homogeneous, fine-grained, malleable if quickly cooled in the mould, rather more fusible than gun-bronze, but otherwise quite similar; excelling, however, in hardness, elasticity and sonority.

These bronzes become quite malleable when tempered by sudden cooling, and this treatment is resorted to when they are to be subjected to prolonged working or to a succession of processes. Chinese gongs are made of copper 78 to 80, tin 22 to 20, and are beaten into shape with the hammer, the metal being softened at frequent intervals by heating to a low red heat and plunging into cold water. The tone desired is obtained by hammering the instrument until the proper degree of hardness is obtained. Tempering not only increases the ductility and malleability of these alloys, but also, it is claimed, their strength, while decreasing their hardness and density, when they are made into thin sheets; thick plates are less affected; annealing by slow cooling produces an opposite effect.

Speculum-metal contains, often, as much as 33 per cent. tin; it is steely, almost silvery white, extremely hard and brittle, and capable of taking a very perfect polish. The most suitable proportion of tin varies slightly with the character of the copper, some kinds requiring more and some less to give the degree of whiteness and the perfection of polish required. An excess of tin injures the color and reduces the lustre of the mirror.

The finest speculum metal is perfectly white, without a shade of yellow, sound, uniform, and tough enough to bear the grinding and polishing without danger of disintegration. The specula made by Mudge were twice fused, and contained from 32 parts copper and 16 tin to 32 copper and 14.5 tin. A little tin is lost in fusion. According to David Ross, the best proportions are: copper, 126.4; tin, 58.9, *i.e.*, atomic proportions. He adds the molten tin to the fused copper at the lowest safe temperature, stirring carefully, and securing a uniform alloy by remelting, as is often done in making ordnance bronze.

Bronze for bearings and pieces subject to severe friction, as in machinery, is made of many proportions. Gun-bronze is one of the best; the Author has known of one case in which the bronze was made of ingot copper 90, ingot tin 10, and used in the main crank-shaft journal of a steam vessel for ten years without appreciable wear, although the area was not unusually large for the load and the velocity of rubbing was high, as is usual in screw engines. The proportions given in several cases will be found elsewhere; they vary in practice from 88 to 96 per cent. copper, as more or less hardness is required. Bronze for steam engine packing rings is sometimes made of 92 to 94 copper, 7 to 9 parts tin, 1 part zinc.

77. Old Bronze.—According to Riche,* the analysis of

* Appendix to U. S. Report on Tests of Iron and Steel, vol. i, p. 556.

antique medals shows that, though the ancients sometimes used copper for this purpose, they ordinarily employed bronze in which the proportion of tin varied between wide limits (from 1 to 25 per cent.). The manufacture of medals with a bronze rich in tin is not practised at the present day, on account of its hardness, and because considerable relief is necessary, while this was very slight in the medals of antiquity. Bronze has been wholly given up and copper substituted for it; but copper also presents some serious inconveniences. It rusts badly, does not ring when struck; its red tint is not artistic, and this is concealed by an artificial bronzing which adheres poorly, and which causes different medals to vary in tone.

In 1828, M. de Puymaurin made a large number of experiments, and continued them until 1832, after which an alloy of 94 copper, 4 tin, and 2 zinc was adopted in France, of which, from time to time, medals were manufactured until 1847, at which time it was entirely given up on account of the hardness of the metal leading to a deterioration of the coin. Riche advises a bronze containing 96 or 97 per cent. copper, and 4 or 3 per cent. tin, as less hard, more sonorous, capable of making good castings, and of working well in the rolls, under the hammer, or in the dies; it has also a good color.

78. **Oriental Bronzes.**—Analyses of Japanese bronzes, made by M. E. J. Maumené,* give the following:

	NO. 1.	NO. 2.	NO. 3.	NO. 4.
Copper	86.38	80.91	88.70	92.07
Tin	1.94	7.55	2.58	1.04
Antimony	1.61	0.44	0.10	1.04
Lead	5.68	5.33	3.54	1.04
Zinc	3.36	3.08	3.71	2.65
Iron	0.67	1.43	1.07	3.64
Manganese	0.67	trace	1.07	3.64
Silicic acid	0.10	0.16	0.09	0.04
Sulphur	0.10	0.31	0.09	0.04
Waste	0.26	0.79	0.21	0.56
	100.00	100.00	100.00	100.00

* *Comptes Rendus*, 1875.

These alloys are all of a granulated texture, blistered on the interior surface, sound on the exterior surface (which can be readily polished with a file). Their color is sensibly violet when antimony is abundant, red when iron is present. All the specimens were cast thin, from 0.195 to 0.468 inch, and the mould was well filled. It appears by analysis that these alloys were not made with pure metals, but with minerals. We should, says Maumené, consider these bronzes as resulting from the use of copper pyrites, and antimonial galena mixed with blende; and the calcination was not always complete, as the presence of sulphur in specimen No. 2 proves.

Antique alloys, Greek, Roman, old French, etc., present similar indications.

79. **Density of Bronzes.**—The increase of density above the mean of the densities of the two constituents, probably either due to the affinity of the metals, or freedom from air-cells, is exhibited by the following table, prepared by Briche:

ALLOY.	S. G. ACTUAL.	CALCULATED.	DIFF.
Copper 100; tin 4	8.79	8.74	0.05
" " " 6	8.78	8.71	0.07
" " " 8	8.76	8.68	0.08
" " " 10	8.76	8.66	0.10
" " " 12	8.80	8.63	0.17
" " " 14	8.81	8.61	0.20
" " " 16	8.87	8.60	0.27
" " " 33	8.83	8.43	0.40
" " " 100	8.79	8.05	0.74

The condensation of the alloy, due to the affinity of its constituents, or to greater homogeneousness, increases as the proportion of tin increases throughout the range above studied.

80. **Ordnance Bronze.**—According to the U. S. Ordnance Manual, bronze used for ordnance consists of 90 parts of copper and 10 of tin, allowing a variation of one part of tin, more or less. It is more fusible than copper, much less so than tin, more sonorous, harder, and less susceptible of oxidation, and much less ductile, than either of its components. When the mixture is well made, the metal is homogeneous;

the fracture is of a uniform yellow color, with an even grain. The specific gravity of bronze is about 8.7, being greater than the mean of the specific gravities of copper and tin.

Copper proposed to be used in ordnance bronze should be condemned for the manufacture of guns, if it contains sulphur in an appreciable quantity; more than one-thousandth of arsenic and antimony united; more than about three-thousandths of lead, iron, or oxygen; if it contain more than about five-thousandths of foreign substances altogether; or if, near these limits, it give bad results when subjected to the mechanical tests of hammering, rolling, and wire-drawing.

It is also stated that tin offered should be rejected if, when run into elongated drops, it have not a smooth and reflecting surface, without any considerable sign of rough spots; if, when analyzed, it contain more than about one-thousandth of arsenic and antimony united; more than about three-thousandths of lead or iron; or more than four-thousandths of foreign substances.

All *bronze* ought to be rejected which contains sulphur in an appreciable amount; which contains more than about one-thousandth of arsenic and antimony united; more than about three-thousandths of lead, iron, or zinc; or, in all, more than about five-thousandths of foreign substances.

Notice should be taken of the appearance of the fracture of specimens; it sometimes gives indications sufficient to authorize the rejection of certain bronzes full of sulphur or oxides.

Gun-metal, when broken, should present a fine, close-grained fracture, of a uniform, beautiful golden color; it should be ductile, although finely granular and possibly crystalline. Bronze guns often exhibit, when burst, a decidedly crystalline surface, the axes of the crystals lying radially to the bore.

According to the practice of the Navy Department, the bronze used for rifled howitzers is composed of Lake Superior copper 9 parts, tin 1 part. This is used when the casting is made in a sand mould. When a chill mould is used, which is the method now adopted for such castings, the proportion is changed to 10 to 1.

The copper is melted in a reverberatory furnace, and three hours after the fires are started, when the copper is in perfect fusion, the tin is stirred in; half-an-hour after, the bronze is run off into the moulds. The casting cools naturally, and is taken out of the mould about twenty-four hours after the metal is run in. The chill mould is warmed sufficiently to drive out the moisture.

81. **Phosphor-Bronze and Manganese Bronzes** are alloys which are now so well known and have become so important in the arts as to demand special notice.

Phosphor bronze has been known many years. It consists simply of any alloy of bronze or brass or any ternary alloy of copper, tin and zinc which has been given exceptional purity and excellence by skilful fluxing with phosphorus. It is also supposed that the presence of phosphorus is useful in giving the tin a crystalline character which enables it to alloy itself more completely and strongly with the copper. Phosphor-bronze will bear remelting with less injury than will common bronze. The phosphor bronzes greatly excel the unphosphuretted alloy in every valuable commercial quality, and they are very extensively used for every purpose for which such alloys are fitted.

The following are Kirkaldy's figures for tenacity and ductility of phosphor-bronze wire of No. 16 Birmingham gauge:

PHOSPHOR-BRONZE WIRE, NO. 16, B. W. G.

MATERIALS.	LOAD AT FRACTURE.				Elongation, Length 5 in.	No. twists before breaking.	
	Unannealed.		Annealed.				
	Per sq. mm.	Per sq. in.	Per sq. mm.	Per sq. in.	Per cent.	Unannealed.	Annealed.
Phosphor-bronze of several proportions.	72.3 kil.	46 T.	34.7 kil.	22 T.	37.5	6.7	80
	85.1	54	33.6	21.3	34.1	22.3	52
	85.2	54.1	37.5	23.8	42.4	13.0	124
	97.7	62.1	42.8	27.2	44.9	17.3	53
	112.2	71.2	41.7	26.5	46.6	13.3	66
	106.3	67.6	45.4	28.9	42.8	15.0	60

CAST PHOSPHOR-BRONZE.

REDUCT. OF SECTION.	ELASTIC LIMIT.		ULTIMATE RESISTANCE.	
Per cent.	Per. sq. mm.	Per sq. in.	Per sq. mm.	Per sq. in.
8.4	16.05 kil.	10.6 T.	37.0	23.5 T.
1.5	17.38	11.05	32.5	20.6
33.4	11.6	7.2	31.3	19.9

The phosphorus is sometimes added to the alloy in the form of copper-phosphide, which is made by reducing acid phosphate with charcoal. This is added to the extent of from one and a half to three and a half per cent. Dry phosphorus may be added in the crucible if preferred to phosphor-tin or copper-phosphide.

Phosphor-bronze was early known to chemists, but its valuable qualities as a material to be used in construction were first made known by MM. Montefiori, Levi, and Kunzel, who discovered the alloy in the year 1871. According to Dick,* who introduced the alloy into the United States, the chemical action of phosphorus on the metals composing the alloy is two-fold : it reduces any oxides dissolved therein, and it forms with the purified metals a homogeneous and regular alloy, the hardness and the toughness of which are completely under control.

We summarize, from the same source, the special uses of phosphor-bronze : 1. It is very tough, and thus fitted for piston rings and valve covers. 2. It is very tough and hard, and therefore used for machine castings, pinions, cog-wheels, propeller screws, hydraulic press and pump barrels, piston rods, screw bolts for steam cylinders, and hardware. 3. Very hard bronze is adopted for bearings of heated rolls, valves, etc. 4. Harder and stronger alloys than ordinary bell metal are employed for bells, steam-whistles, etc. 5. Acquiring great toughness, elasticity, and strength under the hammer, it is

* Journal Franklin Institute, 1878.

used for hammered piston-rods and bolts. 6. As bearing metal it is said to be better than the best gun-metal, very much less liable to heat than gun-metal, and when heated, it does not cut the journal.

Ordnance has been made of this modification of gun-bronze by European nations, and has been found to excel in strength, toughness, and endurance. Small arms have also been made of it, and, in ship-work, the screws and sometimes rods in small vessels. When sheathing of this metal is used, it is found to possess exceptional power of resisting corrosion.

82. **Uses of Phosphor-Bronze.**—The comparatively high cost of phosphor-bronze has checked its introduction, notwithstanding its undeniable excellence. It is said to be stable, not losing much phosphorus by remelting, the temperature of the fusion of the alloy being kept low, ranging from 752° to 932° Fahr. (400° to 500° C.).

Phosphor-tin is now sold in the market for use in making this bronze ; it is known by its number, as No. 0, No. 1.

All alloys made with copper and phosphor-tin may be forged cold, provided the percentage of tin does not much exceed 12 per cent., and by this treatment they increase considerably in hardness. An alloy of 94 or 95 per cent. of copper, and 6 or 5 per cent. of phosphor-tin, may attain the hardness of ordnance steel, while the toughness of the bronze remains high. When expense does not permit the use of phosphor-bronze instead of ordinary bronze, the quality of the latter may be very materially improved by re-placing one-tenth of the percentage of tin by phosphor-tin, which carries enough phosphorus into the bronze to deoxidize the metals in the alloy, and the small increase in cost is counterbalanced by soundness of castings and improved working.

It is best to avoid the use of zinc in making phosphor-bronze with phosphor-tin. Take, for heavy main-shaft journals, 85 per cent. of copper and 15 per cent. of phosphor-tin, and for coupling and crank-rod journals, 90 per cent. of copper and 10 per cent. of phosphor-tin ; these alloys have great hardness and high tensile strength and toughness.

As a substitute for ordinary bronze take:

30 parts of good brass { 35 parts of zinc, 65 parts of copper,
16 parts of copper,
4 parts of phosphor-tin, No. 0.

Gearing, tuyères for blast-furnaces, and wire ropes of this alloy have been successfully used, the latter on the hoists of deep mines in Europe; they have the advantages of great strength and freedom from corrosion.

Phosphide of copper may be used in the manufacture of phosphor-bronze. It may be prepared by adding phosphorus to copper sulphide solution and boiling, adding sulphur as the sulphide is precipitated. The precipitate is carefully dried, melted, and cast into ingots. When of good quality and in proper condition, it is quite black.

Phosphide of tin is oftener employed. When the precipitated tin obtained by the addition of zinc to a solution of chloride of tin ($SnCl_2$) is heated with phosphorus in the proportions of about nine atoms of tin to one of phosphorus, the phosphide (Sn_9P) is produced. This compound resembles cast zinc, is crystalline, melts at about 370° C. (700° F.) and can be easily introduced into the crucible in the process of manufacture of bronze.

"Phosphor-bronze" is, therefore, any copper-tin alloy or bronze which has been fluxed, in the process of making the alloy, by the addition of a measurable quantity of phosphorus. The metalloid may be added either pure or combined, and either to the alloy itself or to one of its constituents, usually to the tin—often as phosphate of copper, before mixing. A small quantity of phosphorus, chemically uniting with copper, hardens and strengthens it. Added in the process of manufacture, in larger amount, it prevents the formation of copper, or other metal, oxide, and thus produces an alloy of such purity as to give greatly increased strength, and ductility as well, and also greater homogeneousness.

In using phosphate of copper, Messrs. Ruoltz and de Fontenay mix the sirupy acid phosphate with 0.20 charcoal and melt in plumbago crucibles, and use this material in the following proportions,* the phosphate containing 9 per cent. phosphorus:

In preparing phosphor-bronze it seems immaterial whether phosphor-copper or phosphor-tin is used, though the former is more likely to find an extended use, as it is applicable, not only for phosphor-bronze, but for other copper alloys containing no tin, as yellow brass, German silver, etc., and for pure copper. It also possesses the advantage of being able to take up the greatest quantity of phosphorus, and consequently to offer the efficient reagent in the most compact form.

In making phosphor-bronze or copper alloys of all sorts, the copper should first be melted in the usual way, with a cover of charcoal put over it as quickly as possible. After the required quantities of tin, zinc, etc., have been added, or in case of gun metal or brass scrap, after the latter has been completely melted, the small exactly weighed quantity of phosphor-copper is added while the metal is continually stirred. For stirring, a graphite bar, a strip cut from an old plumbago crucible, or a bar of retort carbon should be used. The stirring has to be done carefully, and the metal then freed of the coal and scoriæ floating on the top; it should be poured before the surface begins to be covered with a skin. The latter point and the careful stirring cannot be too urgently recommended. Phosphor-metals should always be covered with charcoal when remelted. A further addition of an extremely small quantity of phosphor-copper is necessary only in case the metal should not assume a bright mirror face. Phosphor-tin is better than phosphor-copper.

For preparing phosphor-bronze or remelting old gun metal and turnings, the addition of 1¼ lb. to 1¾ lb. of phosphor-copper of 15 per cent. phosphorus is generally sufficient for a hundred-weight of metal. In making or remelting brass, an addition of ½ to ¾ part only is required per hundred. A larger percentage increases the hardness, but may lead to brittleness. The phosphor-copper of 15 per cent. phosphorus itself is so brittle that the small ingots of about 2 lb.

* Lebasteur, p. 321.

(1 kg.) weight in which it is usually sold, can be broken in the hand by a light blow with a hammer into such pieces as are required.

Sheathing metal made of phosphor-bronze is found to resist the action of sea-water remarkably well. In experiments made at Blankenbergh, lasting six months, comparing the best English copper and phosphor-bronze, the following results were arrived at: *

THICKNESS OF THE SHEETS = 0.236 in. = 0.6 cm.	WEIGHT BEFORE IMMERSION.	WEIGHT AFTER IMMERSION.	LOSS OF WEIGHT.	
			Actual.	Per cent.
Sheet of copper............	74.4	72.2	2.2	3.015
Do.	88.9	86.2	2.7	3.100
Sheet of phosphor-bronze....	69.5	68.75	0.75	1.123
Do. Do.	114.3	112.97	1.33	1.195

The loss in weight, therefore, due to the oxidizing action of sea-water during the six months' trial, averaged for the English copper 3.058 per cent., while that of the phosphor-bronze was but 1.158 per cent.

According to Delalot,† true phosphor-bronze is not an alloy; it is a combination of copper with phosphorus; it is simply a phosphide of copper in definite proportions. The metal unites with the metalloid either cold or hot; for some applications of phosphor-bronze the cold method suffices. Phosphor-bronze made by the hot process does not allow the introduction of simple bodies other than the metal and the metalloid. Copper exempt from arsenic, antimony, iron, or zinc, is required; it must be commercially pure. The manufacturer may choose from three kinds of phosphorus, ordinary, amorphous, and all the earthy biphosphates. Amorphous phosphorus is the most expensive, but the best. The secret of making good phosphor-bronze lies in the working of the

* M. J. Maure, *Engineering*, Sect. 12; 1873.

† Moniteur Industrielle Belge; 1878.

furnace and in practice. The following are the best combinations in definite proportions. The minimum and maximum percentages of phosphorus in phosphor-bronze are 2 and 4. Five sorts of phosphor-bronze, however, are considered to answer all requirements.

0. Ordinary phosphor-bronze of 2 per cent. of phosphorus.
1. Good " " " 2½ " "

These two numbers are superior to ordinary bronze and steel in all cases.

2. Superior phosphor-bronze of 3 per cent. of phosphorus.
3. Extra " " " 3½ " "
4. Maximum " " " 4 " "

These three, according to Delalot, are superior to any other bronzes. Above No. 4, phosphor-bronze is useless; below 0, it is inferior to common bronze and steel. The price of phosphor-bronze unworked, for all numbers, should not exceed that of copper by over ten per cent. Nos. 3 and 4 are comparatively unoxidizable.

It is stated by Dumas that the characteristics of these alloys change with the addition of phosphorus. The color, when the proportion of phosphorus exceeds ½ per cent. becomes warmer, and like that of gold largely alloyed with copper. The grain and fracture approximate to those of steel. The elasticity is considerably increased, the tenacity also becomes in some cases more than doubled; the density is also increased, and to such a degree that some phosphor-bronzes are with difficulty touched by the file. The metal, when cast, has great fluidity, and fills the mould perfectly, exhibiting the smallest details. By varying the doses of phosphorus and tin, the particular characteristic of the alloy which is most desired can be varied at pleasure.

83. Tabular Exhibit of Properties of the Copper-Tin Alloys.*—The following table is a list of about 140 different alloys of copper and tin, giving some of their mechanical and physical properties.

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* Prepared originally for the U. S. Board; Committee on Alloys' Report, vol. i., 1878, p. 389.

TABLE XX.

PROPERTIES OF ALLOYS OF COPPER AND TIN.

Number.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility. (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity, silver = 100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
1		100	0			8.791*a* 8.874*b*	Copper red	Fibrous	27,800		30.8						U. S. B.	*a* Specific gravity of bar. *b* Specific gravity of turnings from ingot.
2		100.00	0.00			8.667	Tile red	Earthy	55,104	1		10	2	16			M.	
3		100.00	0.00			8.921										93.16	Ma.	
4		100.00	0.00									301			81.1		C. J.	
5		100.00	0.00			8.794											Cr.	
6		100.00	0.00			8.921											Mar.	Cast copper.
7		100.00	0.00			8.952											Mar.	Sheet copper.
8		100.00	0.00												73.6	79.3	We.	
9		100.00	0.00			8.672			24,252								Na.	Mean of 9 samples.
10		98.59	1.41													62.46	Ma.	
11	$SnCu_{96}$.	98.10	1.90	97.89	1.90	8.564	Red	Vesicular			100.1						U. S. B.	Defective bar.
12		98.04	1.96														B.	Can be forged like copper.
13		98.00	2.00														La.	Ramrods for guns.
14		97.50	2.50			8.511	Red	Vesicular									U. S. B.	Defective bar.
15		96.97	3.03														W.	Resists action of hydrochloric acid.
16	$SnCu_{48}$.	96.27	3.73	96.06	3.76	8.649	Reddish yel.	Vesicular	32,000		70.3						U. S. B.	
17		96.00	4.00			8.947											Ri.	Annealed and compressed.
18		95.00	5.00				Golden yel.										W.	Hard malleable.
19		94.10	5.90														B.	Pieces of machines.
20		94.00	6.00			8.939											Ri.	Specific gravity after repeated tempering.
21		93.98	6.02													19.68	Ma.	

22	$SnCu_{25}$.	93.17	6.83			8.620						602.8					C. J.	
23	$SnCu_{24}$.	92.80	7.20			8.694	Reddish yel.	Vesicular	28,540		21.9						U. S. B.	
24		92.50	7.50			8.684	" "	"	27,900		43.2						U. S. B.	
25		92.00	8.00														B.	Bronze for medals.
26		91.75	8.25														W.	Shows liquation.
27		91.74	8.26														B.	English Ordnance.
28		91.70	8.30														B.	Ordnance-metal.
29		91.66	8.33														B.	8-pounder guns.
30	$SnCu_{20}$.	91.49	8.51			8.793						639.58					C. J.	
31		91.30	8.70														B.	Toothed wheels.
32		90.91	9.09						32,093								Mus.	Prussian ordnance.
33		90.90	9.10														B.	Ordnance-metal.
34		90.73	9.27														B.	French ordnance.
35		90.10	9.90														B.	
36		90.00	10.00	90.27	9.58	8.669	Grayish yel.	Earthy	26,860		18.0						U. S. B.	Compressed ordnance-bronze.
37		90.00	10.00			8.875											De.	After repeated compression.
38		90.00	10.00			8.935											Ri.	Railroad-car bearings.
39		90.00	10.00														B.	Ordnance-metal.
40		89.30	10.70														B.	Small bar cast in iron mould.
41		89.29	10.71			8.953			37,688								Wa.	Small bar cast in clay mould.
42		89.29	10.71			8.313			25,783								Wa.	Mean of 12 gun-heads.
43		89.29	10.71			8.353			26,011								Wa.	Ordnance-metal.
44		89.23	10.77														B.	
45	$SnCu_{15}$.	89.00	11.00			8.84											Ri.	
46	$SnCu_{15}$.	88.97	11.03			8.825						772.92					C. J.	Mean of 83 gun-heads.
47		88.89	11.11			8.523			29,655								Wa.	
48		88.39	11.61													12.10	Ma.	Gun-metal.
49		88.00	12.00														La.	
50		87.65	12.35													10.15	Ma.	
51		87.50	12.50			8.648	Grayish yel.	Earthy	31,100		7.3						U. S. B.	
52		86.80	12.40														W.	
53	$SnCu_{12}$.	86.57	13.43	87.15	12.73	{ 8.681*a* 8.943*b* }	{ Mottled white and yellow }	Fine vesic.	29,430		13.9						U. S. B.	{ *a* Specific gravity of bar. *b* Specific gravity of fine turnings. }
54		86.21	13.79			8.87											W.	Densest of all alloys (?) (Riche).
55		86.00	14.00														W.	Axle-bearing Seraing locomotive.
56		85.71	14.29						44,071								Mus.	
57		85.09	14.91													8.82	Ma.	
58	$SnCu_{10}$.	84.33	15.67			8.87											Ri.	
59		84.39	15.68			8.832						916.66					C. J.	
60		84.29	15.71			8.561	Reddish yel., 1	Fine cryst.	36,064	2		8	6	15			Ml.	

TABLE XX.—*Continued.*

PROPERTIES OF ALLOYS OF COPPER AND TIN.

Number.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity, silver = 100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
61		84.00	16.00														B.	Axle-bearings.
62		83.30	16.70														B.	Jewelers' punches.
63	$SnCu_9$	82.81	17.19			8.462	Reddish yel., 2	Fine cryst.	34,048	3		5	7	14			Ml.	
64		82.50	17.50			8.792	Reddish gray	"	36,200		0.32						U. S. B.	Strongest of series.
65		82.00	18.00			8.927											R.	Annealed and tempered.
66	$SnCu_8$	81.15	18.85			8.86											Ri.	
67	$SnCu_8$	81.10	18.90			8.459	Yel'wish red, 2	Fine cryst.	39,648	4		4	10	13			Ml.	
68				80.43	19.57	8.953											Th.	Chinese gong.
69		81.00	20.00			8.7											B.	Bells of Reichenhall, 300 years old.
70		80.00	20.00						35,739								Mus.	
71		80.00	20.00			8.850											Ri.	Annealed and tempered.
72		80.00	20.00			8.955											Ri.	After repeated compression.
73		80.00	20.00	80.95	18.84	8.740	Reddish gray	Fine gran.	32,980		0.40						U. S. B.	
74		79.20	20.80			8.927											Ri.	Annealed and tempered.
75	$SnCu_7$	79.02	20.98			8.90											Ri.	
76	$SnCu_7$	78.97	20.03			8.728	Yel'wish red, 1	Vitr. conch.	30,464	5		3	11	12			Ml.	
77		78.00	20.00														B.	Best bell-metal.
78		77.50	22.50			8.917	Pinkish gray	Fine gran.	24,650		0.03						U. S. B.	
79	$SnCu_6$	76.32	23.68	76.64	23.24	8.565		Smooth	22,010		0.02						U. S. B.	
80	$SnCu_6$	76.31	23.69			8.91											Ri.	
81	$SnCu_6$	76.29	23.71			8.750	Bluish red	Vitreous	21,728	0		2	12	11			Ml.	
82		76.20	23.80			9.1(?)											B.	Church bell in Reichenhall, 600 years old.
83		75.20	24.80														B.	Swiss clock bells, brittle.
84		75.00	25.00			8.879	Reddish white										W.	
85	$SnCu_5$	42.91	27.09			8.87											Ri.	
86	$SnCu_5$	72.90	27.10			8.965						Broke			20.7		C. J.	

87	$SnCu_5$	72.80	27.20			8.575	Bluish red	Conchoidal	10,976	0		1	13	10			Ml.	
88		72.50	27.50			8.925	Reddish white	Conchoidal	6,493		0.003						U. S. B.	
89		70.00	30.00	69.84	29.89	8.932	White	Conchoidal	5,585		0.008						U. S. B.	
90		68.82	31.18														B.	Mirror of telescope.
91	$SnCu_4$	68.28	31.72			8.80											Ri.	
92	$SnCu_4$	63.27	31.73			8.948						Broke			15.5		C. J.	
93	$SnCu_4$	68.25	31.75	68.58	31.26	8.938	White	Conchoidal	1,620								U. S. B.	
94	$SnCu_4$	68.21	3 .79			8.400	Ash gray	Conchoidal	1,568			6	14	9			Ml.	
95		63.21	31.70							0							B.	Mirror metal.
96		67.50	32.50			8.907	White	Conchoidal	2,536		0.009						U. S. B.	
97		66.67	33.33				Steel gray										W.	Hard, uniform.
98		66.67	33.33						1,017								Mus.	
99		65.00	35.00	65.34	34.47	8.947	Bluish gray		2,201		0.002						U. S. B.	
100		62.50	37.50			8.956	Dark gray	Rad. cryst.	1,561		0.001						U. S. B.	
101	$SnCu_3$	61.79	38.21			8.954						Broke			49.4		C. J.	
102	$SnCu_3$	61.79	38.21			8.96											Ri.	
103	$SnCu_3$	61.71	38.29			8.970	Dark gray	Rough, stony	688		0.003						U. S. B.	Greatest density, weakest.
104	$SnCu_3$	61.69	38.31			8.539	Dark gray	Tabul'r cryst.	1,120	0		.7	16	8			Ml.	
105		60.00	40.00														B.	White bell-metal.
106		57.50	42.50			8.781	Light gray	Stony.	1,377		0.001						U. S. B.	
107	Sn_5Cu_{12}	56.32	43.68	56.70	43.17	8.682	"	"	1,455		0.003						U. S. B.	
108		52.50	47.50			8.643	"	"			0.001						U. S. B.	Weakest under transverse stress.
109	$SnCu_2$	51.84	48.16			8.57											Ri.	
110	$SnCu_2$					8.512											Cr	
111	$SnCu_2$	51.83	48.17			8 533						Broke			42.8		C. J.	
112	$SnCu_2$	51.80	48 20	51.62	48.09	8.560	Light gray		2.555		0.003						U. S. B.	Remarkable for liquation.
113	$SnCu_2$	51.75	48.25			8.416	Grayish white	Vit. conch.	3,808	0		9	15	7			Ml.	
114		50.00	50.00						725								Mus.	
115		50.00	50.00			8.79	Bluish white										W.	Very slightly malleable.
116	Sn_7Cu_2	47.95	52.05	47.61	52.14	8.442	Grayish white	Fine grain	1,525		0.003						U. S. B.	
117		47.50	52.50			8.446	"	Crystal	2,407		0.003						U. S. B.	
118	Sn_2Cu_3	44.67	55.33			8.30											Ri.	
119	Sn_3Cu_3	44.63	55.37	44.52	55.28	8.312	Grayish white	Crystal	3,010		0.003						U. S. B.	
120		42.50	57.50			8.437	"	"	2,098		0.006						U. S. B.	
121	Sn_3Cu_4	41.74	58.26	42.38	57.30	8.302	"	"	3,910		0.007						U. S. B.	
122		40.00	60.00														B.	White bell-metal.
123	Sn_5Cu_6	39.20	60.80	38.37	61.32	8.182	Grayish white	Crystal	2,820		0.005						U. S. B.	
124		37.50	62.50			8.101	"	"	2,400		0.004						U. S. B.	
125	SnCu	34 99	65.01			8.12											Ri.	
126	SnCu	34.98	65.02			7.992						Broke			41.5		C. J.	
127	SnCu					8.072											Cr.	
128	SuCu	34.95	65.05	34.22	65.80	8.013	Grayish white	Crystal	3,371		0.005						U. S. B.	
129	SnCu	34.92	65.08			8.056	"	Tabul'r cryst.	3,136	0		11	9	6			Ml.	
130		33.33	66.67				White										W.	Brittle; uniform.
131		32.50	67.50			7.931	Grayish white	Crystal	2,322		0.014						U. S. B.	

TABLE XX.—*Continued.*

PROPERTIES OF ALLOYS OF COPPER AND TIN.

Number.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity, silver = 100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
132	Sn_4Cu_3	28.72	71.28	25.85	73.80	7.918	Grayish white	Crystal	1,648		0.011						T.	
133		27.50	72.50			7.915	“	“	4,380		0.018						T.	
134		25.00	75.00			7.813	Bluish white	“									W.	
135	Sn_5Cu_3	24.38	75.62	23.35	76.29	7.835	Grayish white	Fine cryst.	6,775		0.03						T.	
136		22.50	77.50			7.774	“	“	5,000		0.12						T.	
137		21.74	78.26	21.38	77.63	7.53	Whitish										W.	Yellow, greenish white, shining.
138	Sn_2Cu	21.21	78.79			7.738						135.42			43.1		C. J.	
139	Sn_2Cu	21.21	78.79			7.74											Ri.	
140	Sn_2Cu	21.18	78.82	20.25	79.63	7.770	Grayish white	Crystal	4,337		0.06						T.	
141	Sn_2Cu	21.15	78.85			7.387	“	Coarse cryst.	8,736	0		12	8	5			Ml.	
142	Sn_5Cu_2	17.68	82.32			7.652											Cr.	
143		17.50	82.50			7.690	Grayish white	Crystal	2,816		0.20						T.	
144		16.40	83.60													12.76	Ma.	
145	Sn_3Cu	15.21	84.79			7.53											Ri.	
146	Sn_3Cu	15.21	84.79			7.606						104.17			42.3		C. J.	
147	Sn_3Cu	15.29	84.81	15.08	84.62	7.657	Grayish white	Crystal	6,520		0.92						T.	
148	Sn_3Cu	15.17	84.83			7.447	“	Coarse cryst.	6,944	0		13	15	4			Ml.	
149		12.50	87.50			7.543	“	Crystal	3,798		4.71						T.	
150	Sn_4Cu	11.86	88.14			7.558						95.81			40.6		C. J.	
151	Sn_4Cu	11.84	88.16	11.49	88.47	7.552	Grayish white	Crystal	6,380		7.08						T.	
152	Sn_4Cu	11.84	88.16			7.50											Ri.	
153	Sn_4Cu	11.82	88.18			7.472	Grayish white	Coarse cryst.	6,944	8		14	4	3			Ml.	
154	Sn_5Cu	9.73	90.27			7.517						83.33			39.6		C. J.	
155	Sn_5Cu	9.73	90.27			7.52											Ri.	
156	Sn_5Cu	9.70	90.30	8.57	91.39	7.487	Grayish white	Granular	6,450		23.47						T.	
157	Sn_5Cu	9.68	90.32			7.442	“	Earthy	3,360	6		15	3	2			Ml.	
158		9.09	90.91			7.472											W.	Slightly malleable.
159		7.50	92.50			7.417	Grayish white	Granular	6,069		40.06						U. S. B.	

160	....	6.43	93.57	......	......	....	....	....	......	....	....	......	....	....	....	12.03	Ma.
161	$Sn_{12}Cu$.	4.29	95.71	3.72	96.31	7.360	Grayish white	Granular	4,780	....	56.77	......	....	....	....	......	U. S. B.
162	....	2.50	97.50	......	......	7.342	"	Fibrous	5,600	....	121.9	......	....	....	....	......	U. S. B.
163	$Sn_{48}Cu$.	1.11	98.89	0.74	99.02	7.305	"	"	3,650	....	133.9	......	....	....	....	......	U. S. B.
164	$Sn_{96}Cu$.	0.56	99.44	0.32	99.46	7.299	"	"	4,475	....	208.8	......	....	....	....	......	U. S. B.
165	Sn	0	100	......	......	7.293	"	"	3,500	....	219.8	......	....	....	....	......	U. S. B.
166	....	0	100	......	......	7.291	White	"	6,040	7	....	16	1	1	....	......	Ml.
167	....	0	100	......	......	7.297	....	....	2,122	....	....	......	....	....	....	......	Wa.
168	....	0	100	......	......	7.294	....	....	......	....	....	......	....	....	....	11.45	Ma.
169	....	0	100	......	......	7.305	....	....	......	....	....	......	....	....	....	......	Cr.
170	....	0	100	......	......	....	....	....	......	....	....	27	....	....	42.2	......	C. J.
171	....	0	100	......	......	....	....	....	......	....	....	......	....	....	15.2	17.0	We.

List of Authorities.

Abbreviations.

B.—Bolley. *Essais et Recherches Chimiques*, Paris. 1869, pp. 345, 348.

Cr.—Croockewit. *Erdmann's Journal*, 1848, vol. 45, pp. 87–93.

C. J.—Calvert and Johnson. Specific Gravities, *Phil. Mag.*, 1859, vol. 18, pp, 354-359 ; Hardness, *Phil. Mag* , 1859, vol. 17, pp. 114-121 ; Heat Conductivity, *Phil. Trans.*, 1858, pp. 349–368.

De.—S. B. Dean. *Ordnance Notes*, No. XL., Washington, 1875.

La.—Lafond. *Dingler's Journal*, 1855, vol. 135, p. 269.

Mi.—Millit. *Phil. Mag.*, 1842, vol. 21, pp. 66–68.

Ma.—Matthiessen. *Phil. Trans.*, 1860, p. 161 ; *ibid.*, 1864, pp. 167–200.

Mar.—Marchand and Scheerer. *Journal für Praktische Chemie*, vol. 27, p. 193 (Clark's " *Constants of Nature* ").

Mus.—Muschenbroek. *Ure's Dictionary*, article " Alloy."

Ri.—Riche. *Annales de Chimie*, 1873, vol. 30, pp. 351-419.

U. S. B.—*Report of Committee on Metallic Alloys of United States Board appointed to test iron, steel, etc.* (Thurston's determinations).

T.—Thomas Thomson. *Ann. de Chimie*, 1814, vol. 89, pp. 46–58.

W.—Watts's *Dictionary of Chemistry* (compiled from several authorities).

Wa.—Major Wade, United States Army. *Report on Experiments on Metals for Cannon*, Phila., 1856.

We.—Weidemann. *Phil. Mag.*, 1860, vol. 19, pp. 243, 244.

In the above table the figures or order of ductility, malleability, hardness, and fusibility are taken from Mallet's experiments on a series of sixteen alloys, the figure 1 representing the maximum and 16 the minimum of the property. The ductility of the brittle metals is represented by Mallet as 0.

The relative ductility given in the table of the alloys experimented on by the U. S. Board, is the proportionate extension of the exterior fibres of the pieces tested by torsion as determined by the autographic strain-diagrams. It will be seen that the order of ductility differs widely from that given by Mallet.

The figures of relative hardness, on the authority of Calvert and Johnson, are those obtained by them by means of an indenting tool. The figures are on a scale in which cast iron is rated at 1,000. The word "broke" in this column indicates the fact that the alloy opposite which it occurs broke under the indenting tool, showing that the relative hardness could not be measured, but was considerably greater than that of cast iron. The quality of the iron is not specified.

The figures of specific gravity show a fair agreement among the several authorities for the alloys containing more than 35 per cent. of tin, except those given by Mallet, which are in general very much lower than those by all the other authorities. In the alloys containing less than 35 per cent. of tin there is a wide variation among all the different authorities; Mallet's figures, however, being generally lower than the others. Several of the figures of specific gravity have been selected from Riche's results of experiments on the effects of annealing, tempering, and compression, which show that the latter especially tends to increase the specific gravity of all the alloys containing less than 20 per cent. tin to about 8.92. This result, as stated in the discussion on specific gravity above, is due merely to the closing up of the blow-holes, and thus diminishing the porosity. The specific gravity of 8.953 was obtained by Major Wade by casting a small bar in a cold iron mould from the same metal which gave a specific gravity of only 8.313 when cast in the form of a small bar in a clay mould. The former result is exceptionally high, and indicates the probability that every circumstance of the melting, pouring, casting, and cooling was favorable to the exclusion of the gas which forms blow-holes, and to the formation of a perfectly compact metal.

The figures of tenacity given by Mallet, Muschenbroek, and Wade agree with those found in the experiments described in this volume as closely as could be expected from the very variable strengths of alloys of the same composition which have been found by all experimenters.

Mallet's figure for copper, 24.6 tons, or 55,104 pounds, is probably much too high for cast copper; the piece which he tested was probably rolled or perhaps drawn into wire. Haswell's Pocket Book gives the following as the tensile strength of copper; the names of the authorities are not given:

	Pounds per square inch.
Copper, wrought	34,000
Copper, rolled	36,000
Copper, cast (American)	24,250
Copper, wire	61,200
Copper, bolt	36,800

This table of comparison of authorities is by no means complete. No account is taken of a vast number of ancient bronzes, weapons, medals, coins, and sonorous instruments which have been described by various writers. These, however, differ but little in composition and properties from the ordnance and bell metal given in the tables.

It will be observed that while there is considerable irregularity in the tenacity of the alloys containing more than 27.5 per cent. of tin, they are all extremely weak, the highest strength found by any experimenter being only 8,736 pounds, and valueless for all purposes in which strength is required.

It has been shown that the useful alloys, those which contain less than 27.5 per cent. of tin, have strengths which are nearly proportional to their densities.

CHAPTER V.

THE BRASSES AND OTHER COPPER-ZINC ALLOYS.

84. **Brass** is a term which is applied by many, and especially older, authors indifferently to all alloys composed principally of copper, combined with either tin or zinc. The alloy of copper and tin and its minor modifications are now becoming better known as bronze, and the name brass is generally restricted to the designation of alloys consisting mainly of copper and zinc. "Brass" ordnance is properly called *bronze* ordnance, and the compositions used in the bearings of machinery, which are usually of somewhat similar composition, are also properly called bronzes. The alloys of copper, tin and zinc, which occupy intermediate positions between the bronzes and the brasses, are as often known by the one name as by the other.

85. **Copper and Zinc** together form "Brass," which is usually made nearly in the proportion, copper, 66⅔, zinc 33⅓. Brasses of certain other proportions have specific names, as Tourbac, Pinchbeck. The mixture and fusion of the metals must be so conducted that the loss of zinc by volatilization may be the least possible; there is always some loss, and it may not only be serious as a matter of cost, but the introduction of oxides into the alloy is exceedingly injurious to its quality. The fusion is generally performed in crucibles heated in air-furnaces.

The change of color and of other qualities with the introduction of zinc is gradual and very similar in character to that produced by the admixture of tin; but the quantity of zinc demanded to produce the same modification is about twice as much as of tin. On adding zinc, the deep red color of copper is changed at once, becoming lighter and lighter, and finally shading into a grayish white and then assuming more of the color of zinc. The alloy generally increases in hardness and loses ductility as the percentage of zinc is increased, up to a maximum, which being passed, ductility increases again. The most ductile are, however, those which contain 70 to 85 per cent. copper, 30 to 15 of zinc, the first being called "tombac," the latter "brass."

86. **Mallet's Classification.**—The following is Mallet's table of the copper-zinc alloys:

TABLE XXI.

PROPERTIES OF COPPER-ZINC ALLOYS.

AT. COMP.	COPPER	S. G.	COLOR.	FRACT.	TENACITY.	ORDER OF Mall.	ORDER OF Hard.	ORDER OF Fus.
Cu Zn	by anal. per ct.				Tons per sq. in.			
1 : 0	100.	8.667	red	....	24.6	8	22	15
10 : 1	98.80	8.605	red-yellow	coarse	12.1	6	21	14
9 : 1	90.72	8.607	"	fine	11.5	4	20	13
8 : 1	88.60	8.633	"	"	12.8	2	19	12
7 : 1	87.30	8.587	"	"	13.2	0	18	11
6 : 1	85.40	8.591	yellow-red	fine fibre	11.1	5	17	10
5 : 1	83.02	8.415	"	"	13.7	11	16	9
4 : 1	79.65	8.448	"	"	14.7	7	15	8
3 : 1	74.58	8.397	pale yellow	"	13.1	10	14	7
2 : 1	66.18	8.299	deep "	"	12.5	3	23	6
1 : 1	49.47	8.230	" "	coarse	9.2	12	12	6
1 : 2	32.85	8.263	dark "	"	19.3	1	10	6
8 : 17	31.52	7.721	silver white	"	2.1	very brittle	5	5
8 : 18	30.36	7.836	silver white	"	2.2	"	6	5
8 : 19	29.17	7.019	light gray	"	0.7	"	7	5
8 : 20	28.12	7.603	ash "	vitreous	3.2	brittle	3	5
8 : 21	27.10	8.058	light "	coarse	0.9	"	9	5
8 : 22	26.24	7.882	" "	"	0.8	"	1	5
8 : 23	25.39	7.443	ash "	fine	5.9	slight duct.	1	5
1 : 3	24.50	7.449	" "	"	3.1	brittle	2	4
1 : 4	19.65	7.371	" "	"	1.9	"	4	3
1 : 5	16.36	6.605	dark "	"	1.8	"	11	2
0 : 1	0.	6.895		....	15.2	....	23	1

In the above table, the minimum of hardness and fusibility is denoted by 1.

The conclusion of Storer * that these alloys are mixtures rather than true compounds, is accepted by Watts and other authorities.

87. **Uses of Brass.**—*Brass* is the alloy commonly employed in the arts in the construction of scientific apparatus,

* Mem. Am. Acad., N. S., vol. viii, p. 97.

mathematical instruments, and small parts of machinery. It is cast into parts of irregular shape, drawn into wire, or rolled into rods and sheets. It is harder than copper, very malleable and ductile, and can be "struck up" in dies, formed in moulds, or "spun" into vessels of a wide variety of forms if handled cold or slightly warm; it is brittle at a high temperature. A common proportion for making brass is copper 66, zinc 34. This alloy is a much slower conductor of electricity and of heat than copper, is more fusible, oxidizes very slowly at low temperatures, but rapidly at a high heat.

The brass of Romilly, which works remarkably well under the hammer, is composed of copper 70, zinc 30; English brass is often given 33 per cent. zinc, and for rolled brass 40 per cent. This constitutes "Muntz sheathing metal," as patented by G. F. Muntz in 1832. The proportion of zinc ranges, however, for such purposes, from 37 to 50 per cent. copper 63 to 50.

88. **Muntz Metal** is thus described by its inventor:—"I take that quality of copper known in the trade by the appellation of 'best selected copper,' and that quality of zinc, known in England as 'foreign zinc,' and melt them together in the usual manner in any proportion between 50 per cent. of copper to 50 per cent. of zinc, and 63 per cent. of copper to 37 per cent. of zinc, both of which extremes, and all intermediate proportions, will roll and work at a red heat; but as too large a proportion of copper increases the difficulty of working the metal, and too large a proportion of zinc renders the metal too hard when cold, I prefer the alloy to consist of about 60 per cent. of copper to 40 per cent. of zinc. This compound I cast into ingots of any convenient weight, and then heat them to a red heat, and roll or work them while at that heat into bolts and other like ship's fastenings, in the same manner as copper is rolled or worked, but only taking care not to overheat the metal so as to produce fusion, and not to put it through the rolls or work it after the heat has left it too much, say, when the red heat goes off."

This alloy is cast into ingots, and rolled, hot, into sheets, which are cleaned by pickling and washed before they are sent into the market. As this alloy is cheaper and more durable than copper sheathing, and equally effective, it has displaced the latter almost entirely in the protection of wooden ships. When made on a large scale, the alloy is melted in a reverberatory furnace.

89. **Special Properties.**—Farmer has deposited brass by electrolysis and obtained an alloy containing copper 75, zinc 25, as ductile and malleable as rolled brass.

The brasses, or copper-zinc alloys, although probably of more extended use than the bronzes or copper-tin alloys, are not as well studied as the latter.

The metals, as already stated (§ 85), mix in all proportions, and produce alloys of which the general character has been shown in the introductory chapter of this part of the work and in the earlier paragraphs of this chapter.

The red color of copper, in this series, fades into yellow very gradually, and becomes golden-yellow at about 40 per cent. zinc; the color then becomes lighter, and at 60 per cent. zinc is bluish-white or silvery. With the change of color occurs the same change of strength and ductility noted with the copper-tin alloys, but it requires about twice as much zinc as tin to produce it. The white metals richest in copper are, like those of the bronze class, too brittle to be of use in engineering construction, but the yellow metals obtained with from 40 to 50 per cent. zinc are very valuable.

Brass has a high coefficient of expansion, 0.000054 to 0.000056 per Cent. degree (0.00003 to 0.000033 per degree F.).* Yellow brass fuses at from 1,870° F. (1,021° C.), and other compositions from 1,000° F. (550° C., nearly) to 2,000° F. (1,100° C., nearly), and loses strength and ductility as its temperature rises. The composition of the several most useful brasses is given elsewhere. Brass for fine work is often made of copper, 80; zinc, 17; tin, 3; "fine brass" of 2 copper, 1 of zinc; sheet brass of 3 copper, 1 zinc. A hard solder is made of 3 parts brass to 1 of zinc, etc., etc. Castings shrink in cooling $\frac{3}{16}$ inch to the foot (0.015).

* *Vide* Chapter I.

Hydrochloric acid reddens brass by dissolving its zinc; ammonia whitens it by taking up the copper.

Brass may be made tough and soft, hard and brittle, strong or weak, elastic or inelastic, dull of surface or lustrous as a mirror, friable or nearly as malleable and ductile as lead, as may be desired, by varying its composition. No known material, perhaps not even excepting iron, can be given so wide a range of quality or so wonderful a variety of uses. All the common varieties are composed of 67 to 70 parts copper and 33 to 30 of zinc. A little lead is often added to soften and cheapen it and tin in small proportion to strengthen it.

Brass is subject to flow under stress, like all other metals of what the Author has called the "tin class," and it is not safe to leave heavy loads upon it. Weights should not usually be hung upon brass chains, or upon brass tie-rods. The alloy is capable of being considerably hardened by compression, as when rolled into sheets, or by wire-drawing, and becomes much stronger and is less liable to permanent change under load. Some compositions are very elastic and make good springs for intermittent and occasional use.

The thin sheet brass used for metallic cartridges and other purposes requiring a metal in this form of great strength combined with ductility, is subject, frequently, to a singular deterioration with age which seem to be partly a physical and partly a chemical change. It results, sometimes in a very brief interval, in the entire destruction of the essential properties of such forms of this alloy. This has been studied by Egleston, but the results of investigation are not yet fully known.

Weems has found * that a pressure of 4,000 tons (or tonnes) being applied to brass, in the endeavor to produce brass tubes by "squirting" as is usual with lead, causes a separation of the zinc, which issues as a zinc pipe, leaving the copper behind. This is considered a proof that this alloy is a mixture rather than a chemical compound.

90. Applications in the Arts.—Bronze and brass have innumerable uses in the arts: locks, keys, shields, escutcheons,

* *Lond. Engineer,* 1883.

hinges, journal-bearings, pump-plungers, screw propellers, all small parts of machinery, optical and other philosophical instruments, cabinet-makers' fittings, sheathing of ships. Even so-called copper castings usually contain a small amount of zinc—2 to 5 per cent., to give them soundness.

The copper and brass manufactures of the United States are very extensive and of excellent character, both as to material and workmanship, and in those departments which are purely mechanical, are probably unequalled elsewhere. The purest copper is at their doors and the best of zinc; while tin is likely, in time, to be largely produced in this country also.

Brass to be used in the rolling mill in the manufacture of sheet metal, is cast between marble blocks which are separated to a distance which determines the thickness of the ingot or slab. The marble is coated with a thin layer of loam prepared for the purpose; the sides are closed with moulding sand. The slabs, when cast, are rolled, several "passes" being necessary, and the sheets are annealed at intervals, and when finally finished are "pickled" to give them a good surface. For fine work, the surfaces must sometimes be repeatedly scraped during the process of rolling to remove surface impurities and defects.

Wire brass is similarly treated, and the plates are then slit into rods in the "slitting mill," rolled to give them a section which can be handled in the wire-mill, and the rods are then drawn as in making iron wire.*

Brass tubes for steam boilers, condensers and other purposes, are usually drawn, as are many other forms of section.

91. **Working Brass.**—Yellow brass, and several compositions of similar character, are so easily worked cold that many articles are made by "striking up" in a die, under a press or a drop-hammer. Where a considerable change of form is necessary, the work is done by a succession of operations alternating with annealing. Rolls may often be used to form brass into the desired shape and they are still oftener employed to impress a pattern on the sheet.

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* Part I, § 138, p. 196.

"Spinning" is a peculiar and very interesting, as well as useful process. It is employed in altering the shape of a disk or of a cylinder which can be "chucked" and held in a lathe, while the tool of the workman, pressing on the edge, turns it over and forces it into a new shape.

Spinning brass often consists merely in forming a flat sheet, turning in the lathe, by the pressure of a smooth burnishing tool. Chasing is done with a graver, and matting and embossing with formers and hammers. In burnishing to give high lustre, the metal is kept wet with sour beer, while the burnisher by a steady friction produces the polish.

"Burnishing" consists in giving a fine lustrous surface by the pressure and friction of a smooth, highly polished steel tool, lubricated well, as above. The surface is first prepared by giving it a good polish by the usual methods. The "burnishers" are made of fine steel, carefully polished with crocus and oil, and kept in the most perfect possible condition.

The working of brass in the lathe requires especial care, not only in the handling, but also in the form of the tool. The cutting edge is given a much larger angle than in cutting iron and steel; hand-tools require to be given precisely the right inclination and a constant rotation; the velocity of cutting greatly exceeds that usual with iron.

Brass tubes are sometimes made by simply rolling sheet-brass, cut to exact size, upon a mandrel and brazing or soldering the joint; but they are more usually "drawn."

The roll and its mandrel are sent through the draw-plate together and the tube is thus drawn to size and the soldered lap becomes distinguishable only by the color of the joint.

Locomotive tubes, and others required to bear very high temperatures and pressures, are drawn solid and seamless.

Brass condenser tubes should be made of copper 70, zinc 30, as prescribed by the British Admiralty. Boiler tubes are made of copper 18, zinc 32. The metals should be pure.

In many cases peculiar and ornamental shapes are given by modification of the form of mandrel or of draw-plates. Patterned sheets are produced by the use of rolls with properly cut surfaces. The "die" in which the metal is given shape under the blows of a "drop," or of a heavy hammer, is very extensively used in working brass.

92. **The Properties of Brasses,** as described by the best authorities, are exhibited in the most concise manner in the following table, which was originally collated for the Committee on Alloys of the U. S. Board,* as was that already given for the bronzes. It includes the results of work done for that board.

A more complete exhibit of the mechanical properties of the bronzes and brasses will be given in succeeding chapters describing investigations, usually conducted by the Author, as above.

Experimental investigation by Mr. Sperry has shown that the presence of bismuth, even in as small amount as 0.01 per cent., is very deleterious; often causing "brasses" to crack and always producing brittleness.† It is possible that the presence of this or other elements in minute quantity may produce that "checking" or cracking of brass rods (Cu. 65, Zn. 35, with small doses of lead), leaving the mill apparently sound, after transfer to the warehouse, or even when in the fitting shop.

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* Report, vol. ii, 1881, p 67.

† Trans. A. I. M. E., 1898, p. 427.

TABLE XXII.

PROPERTIES OF THE ALLOYS OF COPPER AND ZINC.

Comparison of several Authorities.

Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Order of malleability (Mallet).	Hardness (Mallet and Calvert and Johnson).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity, silver = 100.	Authority.	Remarks.
	Cu.	Zn.	Cu.	Zn.													
	100	0			8.874	Red	Fibrous	27,800		30.8						U. S. B.	
	100	0			8.667	Tile red	Earthy	55,104	8		1	22	15			Ml.	
	100	0			8.921										93.16	Ma.	
	100	0										30.1		81.1		C. J.	
	100	0			8.952											Mar.	Sheet copper.
	100	0												73.6	79.3	We.	
	100	0			8.672			24,252								We.	Mean of 9 samples.
	99.15	0.85														Bo.	Tombac for buttons.
	97.80	2.20															Red tombac of Vienna.
	97.50	2.50	97.83	1.88	8.791	Yellow red	Vesicular	27,240		118.9						U. S. B.	
	97.20	2.50														Bo.	Railway axle boxes, porous.
	95	5	96.07	3.79	8.825	Yellow red	Vesicular	11,500		37.9						U. S. B.	Defective bar.
	93.6	6.4														Bo.	Pinchback.
	92.5	7.5	92.32	7.68	8.746	Yellow red	Vesicular									U. S. B.	
	92.5	7.5														Bo.	Bearings, Austria.
	92	8														Bo.	Red tombac of Paris.
	91	9														Bo.	Tombac.
$Cu_{10}Zn$...	90.72	9.28			8.605	Red yellow	Coarse cryst.	27,104	6		13	21	14			Ml.	
$Cu_{10}Zn$...	90.65	9.35		9.60	8.834											Ri.	Sp. gr. of ingot, 8.753.
	90	10	90.56	9.42	8.773	Yellow red	Vesicular			169.1						U. S. B.	
	90	10														Bo.	French oreide.
Cu_9Zn ...	89.80	10.20			8.607	Red yellow	Finely cryst.	25,760	4		11	20	13			Ml.	
	88.89	11.11												27.3	25.5	We.	
Cu_8Zn ...	88.60	11.40			8.633	Red yellow	Finely cryst.	28,672	2		10	19	12			Ml.	

	87.50	12.50	88.94	10.97		Yellow red	Vesicular									U. S. B.	
Cu_7Zn ...	87.30	12.70			8.587	"	Finely cryst.	29,568	9		9	18	11			Ml.	
	86.67	13.33												29.9	30.9	We.	
	86.38	13.61														Bo.	Very delicate castings.
	86	14														Bo.	Ornaments of Hanover.
	85.5	14.5														Bo.	French oreide.
Cu_6Zn ...	85.4	14.6			8.591	Yellow red	Fine fibrous	31,584	5		8	17	10			Ml.	
Cu_6Zn ...	85.34	14.66		14.90	8.710											Ri.	Sp. gr. of powder, 8.584.
	85.3	14.7														Bo.	Paris jewelry.
	85	15	89.80	10.06	8.656	Red yellow	Earthy			250.1						U. S. B.	
	85	15														Bo.	Tombac of Oker.
	84.6	15.4														Bo.	Gold leaf.
	84.21	15.79														Bo.	Tombac for buttons.
	83.99	17.1														Bo.	Bronze powder.
Cu_5Zn ...	83.02	16.98			8.415	Red yellow	Finely cryst.	30,688	11		2	16	9			Ml.	Bath metal.
Cu_5Zn ...	82.95	17.05			8.673							427.08		71.5		C. J.	
	82.54	17.46														Bo.	Alloy of jewelry.
	82.5	17.5	82.93	16.98	8.633	Red yellow	Earthy	32,600		105.3						U. S. B.	
	82.46	17.54												31.1	29.2	We.	
	82.3	17.7														Bo.	Ornaments.
	80	20	181.91	17.90	8.598	Yellow	Earthy	32,670		113.1						U. S. B.	
Cu_4Zn ...	79.65	20.35				Yellow red	Finely cryst.	52,928	7		3	15	8			Ml.	Dutch brass.
Cu_4Zn ...	79.56	20.44			8.650							468.75		66.6		C. J.	
Cu_4Zn ...	79.51	20.49		21.80	8.638											Ri.	Sp. gr. of powder, 8.367.
	77.9	22.1														Bo.	Vienna gold-leaf.
	77.5	22.5	77.39	22.45	8.574	Yellow	Earthy	35,630		97.5						U. S. B.	
	75.7	24.3														Bo.	Bristol metal.
	75	25	76.65	23.08	8.528	Yellow	Earthy	30,520		76.7						U. S. B.	
	74.62	25.38														Bo.	Ship sheathing.
Cu_3Zn ...	74.58	25.42			8.397	Pale yellow	Finely cryst.	29,344	10		4	14	7			Ml.	Rolled sheet brass.
Cu_3Zn ...	74.48	25.52			8.576							468.75		63.8		C. J.	Brass of { 32 copper. 12 zinc.
	72.73	27.27														Bo.	
	72.5	27.5	73.20	26.47	8.465	Yellow	Earthy	31,580		88.7						U. S. B.	
	72	28														Bo.	Chrysorin.
	71.5	28.5														Bo.	Tombac.
	70.1	29.9														Bo.	Suitable for forg'g or leaf.
	70	30	71.20	28.54	8.444	Yellow	Earthy	30,510		77.8						U. S. B.	
	67.74	32.26												25.8	25.4	We.	
	67.54	32.46														Bo.	Suitable for forging.
	67.5	32.5	69.74	30.06	8.384	Yellow	Earthy	28,120		49.1						U. S. B.	
	67.2	32.8														Bo.	Bristol metal.
	66.7	33.3														Bo.	Chrysorin.
	66.6	33.4														Bo.	Common brass.
Cu_2Zn ...	66.18	33.82			8.299	Full yellow	Finely cryst.	28,000	3		6	13	6			Ml.	
Cu_2Zn ...	66.16	33.84			8.392											Cr.	
Cu_2Zn ...	66.06	33.94			8.488							472.92		62.1		C. J.	

TABLE XXII.—*Continued.*

Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Order of malleability (Mallet).	Hardness (Mallet, and Calvert and Johnson).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity, silver = 100.	Authority.	Remarks.
	Cu.	Zn.	Cu.	Zn.													
	66	34														Bo.	Suitable for forging.
	65.98	34.02		34.50	8.410											Ri.	Sp. gr. of powder, 8.390.
	65.4	34.6														Bo.	Good brass wire.
	65.3	34.7														Bo.	Mosaic gold.
	65	35	66.27	33.50	8.371	Red yellow	Earthy	37,800		72.8						U. S. B.	
	65	34.76														Bo.	Suitable for forging.
	63.5	36.5														Bo.	" "
	62.5	37.5	63.44	36.36	8.411	Red yellow	Earthy	48,300		60.6						U. S. B.	
	61.25	38.75														Bo.	Strong solder for brass.
	60.8	39.2														Bo.	Bristol metal.
	60.16	39.71														Bo.	Suitable for forging.
	60	40	60.94	38.65	8.405	Red yellow	Earthy	41,065		49.0						U. S. B.	
	60	40															Muntz metal.
	59.5	40.5														Bo.	Ship-sheathing.
Cu_3Zn_2...	59.36	40.64			8.224											Cr.	
Cu_3Zn_2...	59.26	40.74		40.10	8.412											Ri.	Sp. gr. of powder, 8.329.
	58.33	41.77														Bo.	Suitable for forging.
	57.5	42.5	58.49	41.10	8.363	Red yellow	Earthy	50,450		12.1						U. S. B.	
	55	45														Bo.	Bath metal.
	55	45	55.15	44.44	8.283	Red yellow	Earthy	44,280		19.5						U. S. B.	
	54.9	45.1														Bo.	V'ry ductile brass (Storer).
	54	46														Bo.	" "
	52.5	47.5	54.86	44.78	8.301	Red yellow	Coarsely gran.	46,400		7.4						U. S. B.	
	50	50	49.66	50.14	8.291	"	"	30,990		3.1						U. S. B.	
CuZn	49.47	50.53			8.230	Full yellow	Coarse cryst.	20,608	12		5	12	6			Ml.	German brass.
CuZn	49.32	50.68			7.808							604.17		68.8		C. J.	
CuZn	49.23	50.76		50.30	8.304											Ri.	Sp. gr. of ingot, 8.263.
	47.5	52.5	48.95	50.82	8.216	Pinkish gray	Coarsely gran.	26,050		0.36						U. S. B.	
	45	55	47.56	52.28		"	"	24,150		0.26						U. S. B.	
	43	57														Bo.	Escutcheons of locks.
	42.5	57.5	43.36	56.22	8.034	Pinkish gray	Finely gran.	9,170		0.02						U. S. B.	
	40	60	41.30	58.12	8.061	Silver white	Vitreous conch.	3,727		0.01						U. S. B.	
Cu_2Zn_3...	39.27	60.73		60.35	8.171											Ri.	Sp. gr. of ingot, 8.039.
	37.5	62.5	38.36	61.05	7.982	Silver white	Vitreous conch.	3,087		0.02						U. S. B.	
Cu_3Zn_5...	36.88	63.12			7.939											Cr.	
	35	65	36.62	62.78	7.974	Silver white	Vitreous conch.	2,656		0.006						U. S. B.	

	33.34	66.66														Bo.	Strong solder for brass.
$CuZn_2$ ...	32.85	67.15			8.283	Deep yellow	Coarse cryst.	43,232	1		7	10	6			Ml.	Watchmakers' brass.
$CuZn_2$ ...	32.74	67.26			7.859							Broke		42.8		C. J.	
$CuZn_2$ ...	32.66	67.34		64.80	8.048											Ri.	Sp. gr. of ingot, 7.796.
	32.5	67.5	35.68	63.71	7.966	Silver white	Vitreous conch.	2,397		0.11						U. S. B.	
Cu_8Zn_{17}..	31.52	68.48			7.721	"	Conchoidal	4,704	0		22	5	5			Ml.	Very brittle.
Cu_8Zn_{18}..	30.30	69.70			7.836	"	Vitreous conch.	4,928	0		23	6	5			Ml.	"
	30	70	32.94	66.23	7.811	"	"	1,774		0.005						U. S. B.	
Cu_8Zn_{19}..	29.17	70.83			8.019	Silver gray	Conchoidal	1,568	0		21	7	5			Ml.	Very brittle.
Cu_8Zn_{20}..	28.12	71.88			7.603	Ash gray	Vitreous	7,168	0		19	3	5			Ml.	Brittle.
	27.5	72.5	29.20	70.17	7.766	Light gray	"	6,414		0.009						U. S. B.	
Cu_8Zn_{21}..	27.10	72.90			8.058	Silver gray	Conchoidal	2,016	0		18	9	5			Ml.	Brittle.
Cu_8Zn_{22}..	26.24	73.76			7.882	"	"	1,792	0		20	8	5			Ml.	Very brittle.
	25.4	74.6														Bo.	Protect iron from rust.
Cu_8Zn_{23}..	25.39	74.61			7.443	Ash gray	Finely cryst.	13,216	0		15	1	5			Ml.	Barely malleable.
	25	75			7.675	Bluish gray	Finely gran.	9,680		0.002						U. S. B.	
$CuZn_3$ ...	24.64	75.36			7.736							Broke		53.1		C. J.	
$CuZn_3$ ...	24.50	75.5			7.449	Ash gray	Finely cryst.	11,424	0		16	2	4			Ml.	Brittle.
	22.5	77.5	21.82	77.43	7.416	Bluish gray	Finely gran.	7,000		0.004						U. S. B.	
	20	80	20.81	77.63	7.418	"	"	9,000		0.002						U. S. B.	
	20	80														Bo.	Metal for buttons.
$CuZn_4$ ...	19.65	80.35			7.371	Ash gray	Finely cryst.	4,256	0		14	4	3			Ml.	White button metal.
$CuZn_4$ ...	19.57	80.43			7.445							Broke		58.9		C. J.	
$CuZn_4$ ...	19.52	80.48		79.30	7.863											Ri.	Sp. gr. of ingot, 7.215.
	17.5	82.5	17.49	81.62	7.225	Bluish gray	Finely gran.	5,350		0.003						U. S. B.	
$CuZn_5$ ...	16.36	83.64			6.605	Very dark gray	Finely cryst.	4,032	0		17	11	2			Ml.	Brittle.
$CuZn_5$ ...	16.30	83.70			7.442							Broke		59.5		C. J.	
	15	85	14.19	85.10	7.163	Bluish gray	Finely gran.	8,500		0.004						U. S. B.	
	12.5	87.5	12.12	86.67	7.238	"	"	12,413		0.009						U. S. B.	
$CuZn_8$ ...	10.82	89.18		89.90	7.315											Ri.	Sp. gr. of ingot, 7.299.
	10	90	10.30	88.88	7.253	Bluish gray	Finely gran.	14,450		0.10						U. S. B.	
	7.5	92.5	7.20	92.07	7.131	"	"	10,650		8.04						U. S. B.	
	5	95	4.35	94.59	7.108	"	Finely cryst.	18,065		0.84						U. S. B.	
	2.5	97.5	2.45	96.43	7.080	"	Tab. cryst.	11,400		2.67						U. S. B.	
	0	100			7.143	Bluish white	"	5,400		26.51						U. S. B.	
	0	100			6.895	Bluish gray	"	34,048	13		12	23	1			Ml.	Brittle.
	0	100			7.148									29.02	27.39	Ma.	
	0	100												62.8		C. J.	
	0	100												28.1	27.3	We.	

LIST OF AUTHORITIES.

Bo.—Bolley. *Essais et recherches chimiques*, Paris, 1869.
Cr.—Croockewit. *Erdmann's Journal*, xlv., 1848. pp. 87–93.
C. J.—Calvert and Johnson. *Phil. Mag.*, 18, 1850. pp. 354–359; *ibid.*, 17, 1859, pp. 114–121; *ibid.*, 16, 1858, pp. 381–383.
Ma.—Matthiessen. *Phil. Trans.*, 1860. pp. 161–184; *ibid.*, 1864, pp. 167–200.
Ml.—Mallet. *Phil. Mag.*, v. 21, 1842, pp. 66–68.
Ri.—Riche. *Annales de chimie*, 30, 1873, pp. 351–410.
U. S. B.—Report of Committee on Metallic Alloys of United States Board appointed to test iron, steel, etc. (Thurston's Investigations).
We.—Weidemann. Pogg. Annalen, 108, 1859, pp. 393–407.

Note on the Table.—Alloys having the name of Bolley appended, are taken from Bolley's "Essais et Recherches Chimiques," which gives compositions and commercial names, and mentions valuable properties, such as are given in the columns of remarks, but does not give results in figures, as recorded by other authorities. The same properties and the same name are accorded by Bolley to alloys of different compositions, such as those which in the column of remarks are said to be "suitable for forging." It might be supposed that such properties belonged to those mixtures and not to other mixtures of similar composition. It seems probable, however, that when two alloys of different mixtures of copper and zinc are found to have the same strength, color, fracture, and malleability, it will also be found that all alloys between these compositions will possess the same properties, and hence that, instead of the particular alloys mentioned only being suitable for forging, all the alloys between the extreme compositions mentioned also possess that quality.

In the figures given from Mallet under the heads of "order of ductility," "order of malleability," "hardness," and "order of fusibility," the maximum of each of these properties is represented by 1.

The figures given by Mallet for tenacity are confirmed by experiments of the Author, with a few very marked exceptions. These exceptions are, chiefly, the figures for copper, for zinc, and for $CuZn_2$ (32.85 copper, 67.15 zinc). The figures for $CuZn_2$, as given by Mallet, can, in the opinion of the Author, only be explained on the supposition that the alloy tested was not $CuZn_2$ (32.85 copper, 67.15 zinc), but another, containing a percentage of copper probably as high as 55. The figure for the specific gravity (8.283) given by Mallet, indicates this to be the case, as does the color. The figure for ductility would indicate even a higher percentage of copper. The name "watchmaker's brass" in the column of remarks must be an error, as that alloy is a brittle silver-white, and extremely weak metal.

The figures of Calvert and Johnson and Riche, as well as those of the Author, give a more regular curve than can be constructed from the figures of Mallet.

The specific gravities in Riche's experiments were obtained both from the ingot and from powder. In some cases one, and in some cases the other, gave highest results. In the table, under the head of "specific gravity," Riche's highest average figures are given, whether these are from the ingot or from fine powder, as probably the most nearly correct. The figures by the other method, in each case, are given in the column of remarks. The figures of Riche and Calvert and Johnson are scarcely sufficient in number to show definitely the law relating specific gravity to composition, and the curves from their figures vary considerably. The figures of the Author being much more numerous than those of earlier experimenters, a much more regular curve is obtained, especially in that portion of the series which includes the yellow, or useful metals. The irregularity in that part of the curve which includes the bluish-gray metals is, no doubt, due to blow-holes, as the specific gravities were in all cases determined from pieces of considerable size. If it were determined from powder, it is probable that a more regular set of observations could be obtained, and that these would show a higher figure than 7.143, that obtained for cast zinc. Matthiessen's figure for pure zinc, 7.148, agrees very closely with that obtained by the Author for the cast zinc, which contained about 1 per cent. of lead.

The figures for hardness given by Calvert and Johnson were obtained by means of an indenting tool. The figures are on a scale in which the figure for cast iron is taken as 1,000. The alloys opposite which the word "broke" appears, were much harder than cast iron, and the indenting tool broke them instead of making an indentation. The figures of alloys containing 17.05, 20.44, 25.52, and 33.94 per cent. zinc, have nearly the same figures for hardness, varying only from 427.08 to 472.92. This corresponds with what has been stated by the Author in regard to the similarity in strength, color, and other properties of alloys between these compositions.

CHAPTER VI.

THE KALCHOIDS AND MISCELLANEOUS ALLOYS.

93. **Other Alloys than Bronzes and Brasses** exist in immense variety and have numerous applications in the Arts, although of far less common application than the classes of alloys already described.

Of these alloys, the most important are those which most closely resemble the true bronzes and brasses in composition, as alloys consisting of bronze or brass with which are united smaller proportions of lead, iron, nickel, antimony, bismuth, and other common metals. In this class also fall the "*Kalchoids*," as the Author would call them, or the copper-tin-zinc alloys which are usually called brass or bronze accordingly as zinc or tin predominates. The white "anti-friction" or "anti-attrition" metals, the fusible alloys, and type and stereotype metals, all come within this classification.

94. **The Kalchoids** (Gr. *Kalchos*), or Copper-Tin-Zinc Alloys, are of great value and include the strongest, and probably the hardest, possible combinations of these metals. They are, in most respects, usually, intermediate between the brasses and the bronzes obtained by uniting two metals.

According to Margraff, these alloys are often very valuable and have the character as per table on next page.

Mackensie finds the alloy, copper 58, zinc 25, tin 17, excellent for castings and a good statuary bronze; and proposes copper 50, zinc 22, tin 28, for mirrors for telescopes; it is slightly yellow and takes a very fine polish. Bronzes in which equal parts tin and zinc are used are of common use for very small articles—as "brass" buttons. Knives for cotton printers' rolls are often made of copper 82, zinc 10, tin 8. Depretz' "chrisocalle" is of copper 92, tin 6, zinc 6, it has a beautiful golden color. Another composition imitating gold is, copper 81.5, zinc 8, tin 0.5; and still another, which retains its lustre well, is of copper 80, zinc 17, tin 3; it is used for the small parts of ornamented pistols, etc. Alloys containing these metals are used for bronze medals, the zinc and tin being introduced to the extent of from 2 to 8 per cent. and the total of both being usually 10 per cent. or less. The percentage of zinc is usually kept under 3 or 4 in ordnance metal.

TABLE XXIII.

COPPER-TIN-ZINC ALLOYS.

NO.	COPPER.	TIN.	ZINC.	REMARKS.
1	100	100	100	Very white, brittle, subject to liquation.
2	100	50	50	" but finer grain.
3	100	25	50	Yellowish tint, hard, fine, not malleable.
4	100	25	25	Brittle.
5	100	20	20	Brittle, hard, yellow.
6	100	16	16	" " " close grained.
7	100	14	14	Yellow, slightly malleable.
8	100	12.5	12.5	" more malleable.
9	100	11	11	" " "
10	100	10	10	Fine yellow, fine grain, malleable.
11	100	8	8	Yellow, softer, more malleable.
12	100	7	7	Golden, malleable, soft.
13	100	6	6	" " "

The use of 8 to 15 per cent. of tin and 2 per cent. zinc in alloy with copper is probably as common as the employment of the bronzes without zinc; the latter is added to improve the color. Alloys of copper containing from 3 to 8 or 10 per cent. zinc and from 8 to 15 per cent. tin are used in engineering very extensively, the softer alloys for pump-work, the harder for turned work and for nuts and bearings. An alloy of 5 per cent. tin, 5 zinc and 90 copper is cast into ingots and remelted for general purposes. It is tough, strong and sound. Copper 75, tin 12, zinc 13 makes a good mixture for heavy journal-bearings. Copper 76, tin 12, zinc 12, is as hard as tempered steel and was made into a razor-blade by its discoverer, Sir F. Chantrey.* When copper and brass are mixed in equal proportions and their sum is equal to the weight of tin, the alloy constitutes a solder.

95. **Copper, Zinc and Iron** unite with some difficulty, and the presence of iron is thought to make brass harder, to weaken it, and to increase its liability to tarnish. A ternary alloy of this character was introduced in England as early as 1822 and was claimed to be stronger and better for the presence of the iron. An alloy of 1 per cent. brass with 99 of iron was advised for castings exposed to corrosion, and Karsten found that it was harder than the cast iron, and considered it well adapted for use in steam engine cylinders and heavily loaded journal bearings. Herve found the zinc less desirable in copper-iron alloys than tin. He states that alloys containing 1.33 to 4 per cent. copper and 0.65 to 3 per cent. zinc were stronger than the cast iron with which they were alloyed. Sterro-metal, elsewhere described, is a metal of this kind, containing also a small amount of tin.

96. **Copper, Tin and Iron** may be alloyed to make a ferrous bronze of great value. The introduction of cast-iron into gun-bronze (copper 89, tin 11, or copper 90, tin 10) is not only useful, in small amounts as a flux, but this ferrous alloy is harder and stronger than the bronze alone. This alloy was made in Russian arsenals about 1820–5, and used for ordnance. The maximum proportion of iron was from 12 to 25 per cent., according to the use intended. The guns made of these alloys were found, according to Depretz, to excel good gun-bronze ordnance in strength and endurance. Similar alloys were made in France by the Messrs. Darcet † and by M. Dussaussoy, of the artillery, and on a large scale, in the government foundry at Douai.

The latter experiments were made with alloys containing:

Copper.	Tin.	Iron.	Copper.	Tin.	Iron.
90	10	6	90	10	4
90	10	3			

* Holtzapffel.

† Alliages Métalliques, p. 333.

The results were not such as to lead to the adoption of these alloys in making field guns.

Wrought iron was introduced into standard gun-bronze by Dussaussoy as early as 1817, using tin-plate for the purpose. When the proportion of iron exceeded 2 per cent. the result was not satisfactory. For small articles, the ferrous bronze was found an improvement, it being stronger, harder and less fusible. Gen. Goguel, of the Russian Army, added 12 per cent. of wrought iron to gun-bronze, and reported that the ordnance made of this alloy proved much superior to that made of common gun-bronze. Subsequently, an extended investigation was made by the order of the French government by MM. Gay Lussac and Darcet, and later by M. Herve of the French Artillery. The former research led to no result; the last named investigator concluded that the use of tin in securing an alloy of iron with copper is of advantage and that re-fusion is advisable to secure the best results.

97. **Manganese Bronze** is said to have qualities resembling those of phosphor-bronze, the introduction of manganese increasing the strength, ductility and homogeneousness of the alloy. The manganese alloys are usually white tinged with red, ductile, hard and tenacious. They are often known as white brass, white bronze or white alloys; they take a fine polish; those richest in copper have a decided rose hue. These alloys, as well as the phosphor-bronzes, are in somewhat extensive use, especially in Great Britain.

Copper and manganese alloy easily, or with difficulty, under different conditions, making a metal of considerable malleability, red in color, turning green when weather stained. It is less fusible than copper, lighter in color, and more liable to tarnish; it may be made by fusing together copper and the black oxide of manganese. Manganese bronze contains iron, also, and is made by melting together copper and spiegeleisen or "ferro-manganese." When containing 10 per cent. manganese, the alloy of copper and this metal is dense, grayish-white with a tinge of red, very ductile and malleable.

and of rather a short fracture; with 20 per cent. manganese, the color is silver-white to tin white, strong and ductile, with a fine lustre; with 30 per cent. manganese, the properties remain little altered; with 40 per cent., the alloy becomes iron-gray, malleable and ductile, very strong, fracture inclined to fibrous. Thus, according to Berthier, all these alloys are ductile, strong, compact and homogeneous.

Manganese-bronze is very similar in its general characteristics to phosphor-bronze; but is a white alloy and differs in being a triple compound of the metals, copper, tin and manganese, instead of an alloy of copper and tin fluxed with a metalloid. It possesses some peculiarities which give very great value to this metal as a material of construction. It is remarkably hard, tough and elastic, has rather a high elastic limit, as compared with ordinary bronze, and is found to be very durable when used for bearings of machinery. A common proportion of its constituents is, copper, 88, tin, 10, manganese, 2.

98. Preparation and Uses of Manganese-Bronze.—As described by the inventor, Mr. P. M. Parsons, white bronze, or manganese-bronze, is prepared by combining ferro-manganese, in different proportions, with various bronze alloys, thus producing qualities suited to various uses. The ferro-manganese is first subjected to a refining process, by which the silicon is eliminated, and the proportion between the iron and manganese adjusted in various degrees, for use according to the quality of bronze to be produced. To effect this combination, the temperature of the copper must be brought up to the melting point of the ferro-manganese, which is melted separately and then added in a fluid state.

The effect of this combination is similar to that produced by the addition of ferro-manganese to decarbonized iron in the Bessemer converter. The manganese in its metallic state having a strong affinity for oxygen, cleanses the copper of oxides, and renders the metal more dense and homogeneous. A portion of the manganese is utilized in this manner, while the remainder, with the iron, becomes permanently combined with the copper, and plays an important part in improving and modifying the quality of the bronzes prepared from the copper thus treated, the effect being to increase their strength, hardness, toughness in various degrees, according to the quality and quantity of the ferro-manganese employed. Manganese, when once incorporated with the copper, is not driven off by remelting; the quality of the manganese-bronze is improved by remelting.

Manganese-bronze, as is stated, when forged, is remarkable for its strength and toughness, having an average tensile strength equal to mild steel, and elongating as much before breaking. It is suitable for forgings of all kinds, for bolts and nuts for engine and machine work, for ships' bolts, rudder and other fittings, screws, pins, nails, pump-rods, wire, and for all purposes for which yellow metal, brass, and copper are employed. In forging this metal, it should be heated to a clear cherry red (not bright), when it may be hammered, rolled, pressed, or worked in any way as long as it retains any color. It should not be worked at a black heat, but when the color is just fading it should be reheated.

In rolled sheets and plates it can be worked both hot and cold. In working hot, the instructions given for forgings should be followed. The metal can be rolled, stamped, pressed, and worked cold like brass or copper, being annealed as required. It is stronger, stiffer, and harder than copper, brass, or yellow metal, for which it can be substituted for purposes to which these are applied.

The rods, plates, sheets and angles are supplied of mild, medium, or high qualities, as required. The mild and medium qualities have a tensile strength of 28 tons per square inch (4,410 kgs. per sq. cm.), with an elastic limit at 40 per cent. and stretch from 28 to 45 per cent. before breaking. These qualities can be worked and riveted up cold, and are claimed to be greatly superior to yellow metal or gun metal.

When ships' screws are made of this material, they are given less thickness than when made of mild steel or of common bronze; it is not subject to alteration of form when taken from the mould or by the annealing which must be done with steel castings; it retains a clean surface remarkably well, but its cost is considerable.

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The ferro-manganese used to mix with gun metal contains from 10 to 40 per cent. of metallic manganese; with brass alloys, 5 to 20 per cent., and with bronze alloys, the proportion lies between the above, according to the proportions of tin and zinc employed. To prepare ferro-manganese containing a given amount of metallic manganese, the inventor melts rich ferro-manganese, containing up to 70 per cent., in a crucible under powdered charcoal, and with a quantity of the purest wrought-iron scrap. If it is desired to employ a ferro-manganese to mix with any of the alloys containing 20 per cent. of manganese, a ferro-manganese containing 60 per cent. of metallic manganese, and, say, 1 per cent. of silicon, is melted with wrought-iron scrap, in the proportion of 100 of ferro-manganese to 300 scrap. Then a ferro-manganese containing 20 per cent. of metallic manganese will be obtained, in which there is only one-third of 1 per cent. of silicon.

Dry sand or loam moulds are recommended for casting. Metal moulds render the alloy somewhat harder and closer in texture.

Manganese-bronze is said to be much less subject to corrosion in salt water than is pure copper. Alloys containing from 75 to 85 per cent. copper are most usually adopted for machinery. Zinc often forms a constituent of these alloys, in the proportion of from 2 to 10 per cent.

The addition of manganese to bronzes and brasses gives them much lighter color, greater hardness and tenacity, without proportionally decreasing ductility and resilience. Copper and manganese alone form white alloys of great hardness, strength and ductility. Some of these alloys forge well and can be rolled with ease. They are somewhat susceptible to the action of the atmosphere at high temperature, and should be worked as little and at as low temperature as possible.

99. **Aluminium-Bronze.**—Aluminium is added to copper and to the bronzes and brasses with good results. The alloy, copper 90, aluminium 10, may be worked cold or hot like wrought iron, but not welded. Its tenacity is sometimes

nearly 100,000 pounds per square inch (7,030 kilos per square mm.), and its average is not far from three-fourths as great. It is hard and stiff and very homogeneous. Wire has been given a tenacity exceeding 125,000 pounds per square inch (8,776 kilos per square mm.). Its specific gravity is 7.7. In compression this alloy has been found capable of sustaining a little more than in tension (130,000 pounds per square inch, 9,139 kilos per square mm.), and its ductility and toughness were such that it did not even crack when distorted by this load. It is so ductile and malleable that it can be drawn down under the hammer to the fineness of a cambric needle. Measuring its stiffness, the Messrs. Simms found * that it had three times that of gun-bronze and 44 times that of brass. It works well, casts well, holds a fine surface under the tool, and when exposed to the weather; and it is, in every respect, considered the best bronze yet known. Its high cost alone prevents its extensive use in the arts. Alloying 2 to 8 per cent. copper with aluminium raises its tenacity 65 to 90 per cent., making it, weight for weight, stronger than machinery steel.† Pure, it has a tenacity of about 30,000 lbs. per square inch, and a modulus about 11,000,000.

The density of aluminium-bronze has been determined by M. Riche,‡ with the following results:

BRONZE CONTAINING TEN PER CENT. OF ALUMINIUM.

	DENSITY.	
	I. WT. = 120gr.568.	II. WT. = 120gr.275.
After casting	7.705	7.704
After tempering	7.706	7.704
After annealing	7.706	7.705
After tempering	7.707	7.707
After annealing	7.703	7.704
After impact	7.703	7.702
After tempering	7.701	7.702
After impact	7.699	7.703

* Ure's Dict., Art. Aluminium.

† *Railway Review*, Jan. 7, 1891.

‡ *Ann de Chimie*, vol. xxx.. 1873, pp. 351–419. Appendix.

BRONZE CONTAINING FIVE PER CENT. OF ALUMINIUM.

	DENSITY.	
	I. WT. = 129gr. 575.	II. WT. = 129gr.161.
After casting	8.252	8.262
After tempering	8.259	8.259
After annealing	8.255	8.262
After tempering	8.257	8.262
After annealing	8.257	8.262
After impact	8.264	8.264
After tempering	8.263	8.264
After impact	8.263	8.265

Tempering, annealing, and mechanical action produce no noticeable variation in the volume.

Adding 5 to 6 per cent. copper to aluminium doubles its tenacity, and higher proportions are sometimes advantageous.

100. **Uses of Aluminium-Bronze.**—Aluminium-bronze, composed of 9 parts copper and 1 part aluminium, was proposed in 1864 as a material for small coins, and with this object in view the assayer of the United States mint made a number of careful experiments with it. The assayer states that aluminium-bronze possesses much greater hardness than copper alone, but less malleability and ductility. When rolled into sheets, it requires annealing at every third passage through the rolls; when drawn into wire it must also be frequently annealed. To strike a coin of this bronze required unusual force. It tarnishes quite readily, but not more so than copper.

Aluminium-bronze containing 7½ per cent. of aluminium is greenish in color, according to Morin, while other compositions on either side are golden. Even 1 per cent. added to copper causes a considerable increase in ductility and fusibility, and enables it to be used satisfactorily in making castings. Two per cent. gives a mixture used for castings which are to be worked with a chisel. The standard aluminium-bronze—10 per cent. aluminium—is brittle after the first fusion, but becomes more ductile as well as stronger by repeated refusion. It makes good castings, is easily worked, and may be forged at a red heat, and is fairly ductile under the hammer even when cold. It is softened by sudden cooling from a red heat. It takes a fine polish, is a half stronger than good wrought iron in tension, but has less strength in compression. Its coefficient of expansion is small at ordinary temperatures. Its liability to crack in large masses makes it difficult to get large castings. It has great elasticity when made into springs; it is found useful for watches, and has the decided advantage over steel of being but little liable to oxidation ; the addition of 5 per cent. silver is advised to pure aluminium to make springs. Kettles of this alloy have been used in making fruit syrup and preserves.

The alloy of aluminium with 4 to 5 per cent. silver is used in making balances for chemists. The introduction of a very minute proportion of bismuth makes this metal very brittle.

Steel containing but 0.08 per cent. aluminium is said to be greatly improved by its presence.

An alloy of 2 or 3 copper and 97 or 98 aluminium is found useful in making ornamental silver-colored castings which are to be chased and engraved.

The alloys of aluminium and copper may be made by fusing together the oxides with metallic copper and enough carbon and flux to reduce them. The electric arc is the usual, and only commercial, reducing agent for the Cu.-Al. alloys, and the aluminium bronzes are now all made in this way.

101. **Copper and Nickel** are quite easily alloyed, giving a metal of usually white color, hard, rather brittle, and quite easily oxidized. When the nickel forms 30 per cent. of the whole, the alloy is easily fused, strong, and tough, of a silvery-gray color, and slightly magnetic. White copper and German silver are used for high electrical resistance.

Copper and nickel unite in a wide range of proportions. In color they range from the red of copper to the blue-white of nickel, according to their proportions. Adding nickel in the proportion of 0.10, the alloy is very ductile, light copper-red in color, and moderately strong; with 0.15 nickel, the color becomes very light red and the ductility is still great; 0.25 nickel gives an alloy nearly white; 0.30 nickel produces a silver-white metal. Berthier's alloy, copper 0.682, nickel 0.318, is fusible, ductile, strong, bluish-white, slightly magnetic and somewhat crystalline near the surface.

A "white copper," Cu. 70, Ni. 18, Zn. 12, has a tenacity of about 60,000, ductility 10 to 15 per cent.

Nickel coinage is now used by several nations; it was first privately coined by Feuchtwanger, of New York City, in 1837; Switzerland began using it in 1850, the United States in 1857, and Belgium in 1860. The U. S. coins now contain copper 75, nickel 25.

102. German Silver.—Copper, zinc, and nickel alloy readily. These compositions were used at a very early date in China, and have been known as packfong, tutenag, and white copper. The East Indian or Chinese tutenag is a grayish-white alloy, somewhat sonorous, and brittle. Its composition has been given as copper 44, zinc 40, nickel 16. The other alloys above named are nearly silver-white, malleable hot or cold, have a beautiful lustre, and very sonorous. The specific gravity is 8.5. Alloys of European manufacture, of similar characteristics, are now common. Viennese alloys have been found by Gersdorff to contain:—

Table utensils;	copper, 50;	zinc, 25;	nickel, 25.
Ornaments	" 55;	" 25;	" 20.
Sheet metal	" 60;	" 20;	" 20.

Frick's alloys contain copper, 50 to 55; zinc, 30 to 31; nickel, 17 to 19. These are white and hard but ductile, and have a specific gravity from 8.5 to 8.6; they are used in making table utensils and ornamental objects. The alloy, copper 56, zinc 5, and nickel 39, makes a fine white metal of the same class with the preceding.

German silver, as made by good makers, consists usually of

Copper	60
Zinc	20
Nickel	20
	100

Guillemin introduces sodium, thus:

Copper	58.00
Zinc	16.65
Nickel	25.00
Sodium	0.35
	100.00

Sound castings are secured by the use of borax, glass, or other good flux. German silver is rolled cold, and the rolls are necessarily made of very great strength ; frequent annealing is necessary during the process.

103. **Copper and Iron** unite, when the latter is in small amount, to produce a stronger metal than can be obtained without the iron, even when the copper is alloyed with other strengthening elements ; and iron forms a part of nearly all manganese bronzes, of the bronze known as Austrian "sterro-metal," and of various other useful compositions. The ductility is rather improved than otherwise.

Copper and iron unite at high temperatures, if the heat is sufficiently prolonged, and in any proportions. The addition of copper to iron causes brittleness, or "red-shortness." The Author has found that minute doses of copper confer increased strength on some steels, and Tredgold states that the same effect is observed on cast iron. Berthier and Rinmann think that one per cent. copper will have a good effect on cast iron.

The color of the alloy changes, losing the gray and becoming red, as the proportion of copper increases, up to equal parts copper and iron, when the alloy loses all tint of gray. An alloy of copper 66.67, iron 33.33, is the strongest of these alloys. Mushet has made a number of these alloys. He finds that the presence of carbon causes difficulty in making them. Karsten found that the copper-iron alloys do not as readily dissolve in sulphuric acid as does iron.

A ductile alloy was made by Rinmann of copper 16, iron 1 ; it is magnetic, harder than copper, and the fractured surface has a beautiful red color. Eight parts copper and from

1 to 4 parts iron produce alloys harder than the preceding, but not appreciably less ductile or less red than copper.

Copper and cast iron alloy to form a strong metal, also.

Riche has successfully produced alloys of copper and iron; but they are somewhat variable in composition and quality; thus:

He heated in a temperature sufficient to melt cast iron—

Copper	90
Cast iron	10

The ingot obtained contained, at the top, iron uncombined.

He heated very hot and held some time in fusion—

Copper	90
Rivets	10

The ingot obtained furnished upon analysis—

Top	1,600 iron.
Bottom	365 iron.

He heated very hot and kept melted some time—

Copper	96
Rivets	6

The metal appeared very homogeneous. Its density, taken at two different points, gave—

8.881
8.876

The metal is easily forged, stretches and coils upon itself without breaking. It is rolled with such facility that, without annealing, a bar of it can be reduced from a thickness of 9 millimetres (0.35 inch) to that of 1 millimetre (0.04 inch). Its tenacity exceeds that of copper.

Examining with a magnifying glass the plates 1 millimetre in thickness mentioned above, gray spots may be seen at certain points, but analysis of these points shows no material difference between them and other portions. There was found—

Iron	5.383	5.285	5.236

This substance made very hot in the crucible gives a button in which there remains only—

Iron	0.167 per cent.

These two metals were alloyed in variable proportions, melted in earthen tubes 15 centimetres (5.9 inches) in length, and after being kept three hours in fusion, were left to cool slowly. Analysis then gave:—

	IRON, PER CENT.		
	Top of bar.	Bottom of bar.	Density.
1	12.693	4.545	8.839 to 8.771
2	9.290	3.680	....
3	6.876	3.652	....
4	4.619	4.520	....
5	4.226	4.288	8.885
6	2.950	2.600	....

The addition to copper of small quantities of foreign matter, iron, for example, increases the porosity, as do small quantities of oxygen. The copper acquires tenacity and elasticity by this addition of iron, while retaining some malleability.

104. **Copper-Antimony Alloys.**—*Antimony*, added to the copper-tin alloys, rich in the latter metal, is largely used for a lining metal in journal-bearings. Babbitt's Metal is the best known of these metals, and contains 4 parts copper, 96 of tin, 8 of regulus of antimony. It is made* by melting 4 parts of copper, adding 12 parts best tin, 8 of regulus of antimony, then 12 of tin while cooling the molten mixture. Of this "hardening metal," one part is added to twice as much tin to make the lining metal. Copper 1, tin 9, without antimony, is also known as Babbitt Metal; it is a usual composition in

* Haswell.

government work. This composition has been found excellent in locomotive practice and more satisfactory than that containing antimony. Cu. 4, Sb. 8, Sn. 12 works well.

Copper and antimony alloy in the proportion, copper 85, antimony 15, to form, according to Karsten, a brittle metal of little value. Equal parts copper and antimony unite to make a brittle, light-violet colored alloy, of which no use is made in the arts.

105. **Copper and Bismuth** unite readily and at a temperature below that of fusion of copper. The addition of bismuth causes brittleness, and all ductility is lost when the proportion approaches 1 per cent. Minute quantities may be added to copper, and if not above 0.5 per cent. the alloy may be hammered and rolled; exceeding that proportion, the alloy becomes brittle with working and too much so to be safely used. The color of the alloy is light red; its density is the mean of its constituents. Prince's Metal is said to be an alloy of copper and bismuth.

106. **Bismuth-Bronze.** — Webster's bismuth-bronze is made of various proportions. According to the statement of the discoverer, its composition and qualities are as follows:

For a hard alloy, take 1 part of bismuth and 16 parts of tin, both by weight, and, having melted them, mix them thoroughly. For a hard bismuth bronze, take 69 parts of copper, 21 parts spelter, 9 parts nickel and 1 part of the alloy of bismuth and tin. This bismuth-bronze is a hard, tough and sonorous metallic alloy, which is proposed for use in the manufacture of screw-propeller blades, shafts, tubes and other appliances employed partially or constantly in sea water. In consequence of its toughness it is thought to be well suited for telegraph wires and other similar purposes where much stress is borne by the wires. From its sonorous quality it is well adapted for piano and other wires. For domestic utensils and articles exposed to atmospheric influences, use 1 part bismuth, one part aluminium and 15 parts tin melted together to form the separate or preliminary alloy, which is added in the proportion of 1 per cent. to the above described alloy of copper, spelter and nickel.

This bronze forms a bright and hard alloy suited for the manufacture of utensils or articles exposed to oxidation.

107. **Copper and Cadmium** form an alloy similar in character to those of bismuth and copper.

108. **Copper and Lead** unite with difficulty, and a good alloy can only be obtained with a small quantity of lead. One-tenth per cent. lead gives a mixture observably less ductile than copper, and when three times this quantity is introduced the alloy has the singular property of working better cold than hot. The combining temperature is so high that the lead usually gives off fumes of oxide ; the cooling should be done rapidly. The alloy has a lower density than the mean of its constituents and is rarely stable.

An alloy of copper 20, lead 80, is sometimes used in type-foundries for large type. This, like all those alloys, if kept in a state approaching that of fusion, is subject to separation or "liquation," the lead separating and leaving the copper in a porous mass. When the alloy oxidizes, the oxide is found to contain much more than the proportion of lead contained in the alloy. Common "pot-metal" contains 20 per cent. lead. It is brittle when heated ; larger amounts of lead render the alloy difficult to work and injure it seriously. The fusibility is greatly increased by the presence of the lead.

Copper and lead are not easily alloyed, but form, when combined, a metal of gray color, brittle, and of feeble affinity. An alloy of lead 4, copper 1, is sometimes used for large type. The constituents are very liable to separation, when kept molten, by liquation. Norway copper, from Drontheim, contains a half per cent. lead ; it is preferred in making brass. Other coppers often contain 1½ or 2 per cent. lead.

109. **Copper and Silicon,** with or without tin, may be alloyed to form "silicon-bronze." Weiller's alloy is made by the introduction of sodium to reduce silica in the crucible. This bronze has been used to take the place of phosphor-bronze for telegraph wires in Southern Europe.

The inventor recommends the following proportions : fluo-silicate of potash, 450 grams ; glass in powder, 600 grams ; chloride of sodium, 250 grams ; carbonate of soda, 75 grams ;

carbonate of lime, 60 grams; and dried chloride of calcium, 500 grams. The mixture of these substances is heated, in a plumbago retort, to a temperature a little below the point when they begin to react on one another, and it is then placed in a copper or bronze bath, when the combination of the silicium takes place, as already said.

110. **Use of Silicon-Bronze.**—The superiority of silicon is claimed to be due to its better adaptability to being worked at a high temperature, by its penetrating the metal better, and, consequently, insuring the indispensable homogeneity. It is said of silicon-bronze, that it possesses the conducting qualities of the best copper, with the resisting qualities of the best iron, and that each of these advantages may be varied at will, at the expense of the other.

Applied to aërial telegraph lines, the present galvanized wires of the great lines, 5 millimetres (0.2 inch) in diameter, and weighing 155 kilos per kilometre (120 pounds per mile), can be replaced by silicon-bronze wires of 2 millimetres (0.08 inch) in diameter, weighing only 26 kilos to the kilometre (20 pounds per mile); while the ordinary steel telephone wires of 2 millimetres (0.08 inch) diameter, and 25 kilos to the kilometre (20 pounds per mile), may be replaced by silicon wires of only $1\frac{1}{10}$ millimetre (0.04 inch) in diameter, and weighing 8 kilos to the kilometre (6 pounds per mile).

111. **Copper, Tin, and Lead** alloy readily, and are thus used in the manufacture of art-castings, for which purpose this composition was also used by the ancients. Statues made by the Romans have been found to contain lead in a proportion equal to about one-fourth that of the tin. Klaproth finds in an antique mirror, copper 62, tin 32, lead 6. The presence of lead in bronze **promotes durability** under wear.

Bronzes containing 2 to 15 per cent. lead make the best of bearings. Lead is very liable to promote liquation.

112. **Copper, Tin, Antimony, and Bismuth** united, form a "pewter," once in common use for tableware; it is a beautiful alloy resembling silver, but too readily tarnished, and too soft to be very valuable. It contains copper 3½, tin 88½, antimony 7, bismuth 1.

113. **Copper, Tin, Zinc, and Iron** are found in bell metal, and make, in certain proportions, an excellent alloy. The alloy is not made for the market. The above metals, alloyed with *nickel*, form "*melchior*," a composition containing: of copper, 55; nickel, 23; zinc, 17; iron, 3; tin, 2. *Argenthal* is a similar metal. They are white alloys and used for ornamental castings. Their lustre is silvery and quite permanent.

114. **Copper and Mercury** alloy freely. A composition of 25 parts copper in fine powder, obtained by precipitation from solutions of the oxide by hydrogen, or of the sulphate by zinc, washed with sulphuric acid and amalgamated with 7 parts of mercury, after being well washed and dried, is moderately hard, takes a good polish, and makes a fine solder for low temperatures. It will adhere to glass.

Dronier's malleable bronze is made by adding one per cent. of mercury to the tin when hot, and this amalgam is carefully introduced into the molten copper.

115. **Complex Copper Alloys.**—An alloy imitating gold is made thus: Melt together pure copper, platinum, and tungstic acid, in proportion as follows: Copper 800, 25 of platinum, 10 of tungstic acid, 175 of gold. When completely melted, stir and granulate by running into water containing 500 parts of slacked lime, and the same of carbonate of potash for every cubic metre of water. The granulated metal is next collected, dried, and, after remelting in a crucible a small quantity of fine gold is added. An alloy results which, when run into ingots, presents the appearance of red gold of the standard of 750–1000ths, bears a strong acid test, and has nearly the density of gold.

A so-called unoxidizable alloy has the following composition: Iron, 10 parts; nickel, 35 parts; brass, 25 parts; tin, 20 parts; zinc, 10 parts. The castings made of this alloy are cleaned by immersion, while white hot, in a mixture of 60 parts sulphuric acid, 10 parts nitric acid, 5 parts hydrochloric acid, and 25 parts of water.

Copper and all its alloys should be avoided where superheated steam is employed.

116. Bismuth Alloys.—The properties of alloys of bismuth and other useful metals are given in considerable detail by Guettier, as follows:—*

Alloys of Bismuth and Copper.—These alloys are easily made, notwithstanding the difference in the points of fusion of the two metals. They are brittle, and of a pale red color, whatever the proportions employed. For description of the useful alloys with copper, see Articles 105–6, page 186.

Alloys of Bismuth and Zinc.—These alloys are seldom made, and produce a metal more brittle, exhibiting a larger crystallization, with less strength, than zinc or bismuth taken singly. They have little value in the arts.

Alloys of Bismuth and Tin.—The combinations of bismuth and tin take place easily and in all proportions. A very small quantity of bismuth imparts to tin more hardness, sonorousness, lustre, and fusibility. On that account, and for some purposes, a little bismuth is added to tin in order to increase its hardness. But bismuth, being easily oxidized, and often containing arsenic, the alloys of tin and bismuth would be dangerous, if used for the manufacture of culinary vessels. The alloys of bismuth and tin are more fusible than either of the metals taken separately. An alloy of equal parts of the two metals is fusible between a temperature of 100° to 150° Centigrade (212°–302° F.). When tin is alloyed with as little as 5 per cent. of bismuth, its oxide acquires the peculiar yellowish-gray color of the bismuth oxide. According to Rudberg, melted bismuth begins to solidify at 264°, and tin at 288° C. (507°–550° F.). For the alloys of the two metals the "constant point" is 143° C. (289° F.).

Alloys of Bismuth and Lead.—These two metals are alloyed by simple fusion, with ordinary precautions. The alloys are malleable and ductile as long as the proportion of bismuth does not exceed that of lead; they are more tenacious than lead. The alloy of bismuth 2 and lead 3 is ten times harder than pure lead. The compounds of bismuth and lead generally have a dark gray color with a tint intermediate between the color of tin and that of lead. Their

* Guettier: "Guide Pratique des Alliages Metalliques." Paris, 1865.

fracture is lamellar, and their specific gravity greater than the mean specific gravity of either metal taken singly. An alloy of equal parts of bismuth and lead has a specific gravity of 10.71. It is white, lustrous, sensibly harder than lead, and more malleable. The ductility and malleability diminish with an increased proportion of bismuth, while they increase with the excess of lead in the alloy. An alloy of bismuth 1 and lead 2 is very ductile, and may be rolled into thin sheets without cracking. Berthier gives its point of fusion as 166° C. (331° F.).

Alloys of Bismuth and Iron.—Authorities disagree as to the possibility of combining bismuth and iron. The presence of bismuth in iron tends to render this metal brittle.

Alloys of Bismuth and Antimony.—These alloys are grayish, brittle, lamellar, like the alloys of bismuth and zinc, and have no value in the arts.

It will be seen from the preceding that the alloys of bismuth are not at present of importance in the arts, excepting the fusible alloys made of bismuth and certain white metals, such as tin, lead, etc. The alloys of bismuth with tin, the latter predominating, are the most interesting. The great fusibility of the alloys of bismuth and lead will have the effect of making these alloys useful, as also those with tin, as soon as bismuth can be obtained in abundance and at small cost.

The action of the bismuth in alloys is to increase their hardness, fusibility, and brittleness. But, although bismuth renders brittle the metals with which it combines, it does so to a considerably less degree than either arsenic or antimony.

Tin and Bismuth alloy to form metals of greater hardness, sonorousness, and fusibility than either tin or bismuth. Equal parts give an alloy which melts at about 300° F. (150° C. nearly), and is called "cuttanego," of which the oxide makes a white enamel. Tin 2, bismuth 1, gives an alloy melting at about 325° F. (165° C.), and the alloy tin 8, bismuth 1, at 480° F. (200° C.). Tin itself melts at about 440° F. (228° C.), bismuth at 510° F. (265° C.).

Riche gives the densities of alloys of tin and bismuth as follows:

	THEORETICAL DENSITY.	EXPERIMENTAL DENSITY.	DIFFERENCE.	REMARKS.
Bi_2Sn	9.426	9.434	+.008	
Bi Sn	9.135	9.145	+.010	
$BiSn_2$	8.740	8.754	+.014	
$BiSn_3$	8.491	8.506	+.015	
$BiSn_4$	8.306	8.327	+.021	
$BiSn_5$	8.174	8.199	+.025	Maximum contraction.
$BiSn_6$	8.073	8.097	+.024	
$BiSn_7$	7.994	8.017	+.023	

The maximum contraction should take place in the alloy Bi Sn_5, which is a silvery-white metal formed of little crystalline grains commingled. This alloy was not attacked by distilled water; at the end of several hours it retained its brilliancy and its silvery lustre.

The maximum contraction is seen with the alloy Bi Pb_3, and on either side of this alloy a very regular diminution in contraction will be noticed. The differences being very great both between the theoretical and experimental density, and between the density of each alloy and that of its neighbors, he made but two determinations for each alloy. As analysis of the ends and of the middle of the ingot formed by the alloy $BiPb_3$ gave the same numbers, it seems, therefore, that this alloy should be considered as a chemical compound.

Lead and bismuth unite readily, when fused, to form a malleable alloy if the lead is in excess, but a brittle compound if the bismuth is present in large amount. Its color is dark gray, fracture often lamellar, and the density greater than that given by calculation. Equal parts give an alloy having the specific gravity 10.71, white, lustrous, harder and also even more malleable than lead; with lead 3, bismuth 1, an alloy of 6 times the tenacity of lead is produced; lead 2, bismuth 1, gives a very malleable alloy, easily rolled into thin sheets, melting at 325° F. (165° C.), the melting-point of the alloy of equal parts.

Riche finds the following densities of alloys of lead and bismuth:

Density of the lead.............................11.364
Density of the bismuth......................... 9.830

	THEORETICAL DENSITY.	EXPERIMENTAL DENSITY.	DIFFERENCE.	REMARKS.
Bi_2Pb..........	10.099	10.232	+0.133	
Bi Pb	10.288	10.519	+0.231	
$BiPb_2$..........	10.536	10 931	+0.395	
Bi_2Pb_5.........	10.622	11.038	+0 416	
$BiPb_3$..........	10.448	11.108	+0.660	Maximum contraction.
Bi_2Pb_7.........	10.748	11.166	+0.418	
$BiPb_4$..........	10.797	11.194	+0.397	
$BiPb_5$..........	10.874	11.209	+0.335	
$BiPb_6$..........	10.932	11.225	+0.293	
$BiPb_7$	10.979	11.235	+0.254	

117. **Bismuth, Tin, and Lead** form a series of "fusible alloys" used in obtaining impressions from objects made of the less fusible metals, and in making "fusible plugs" and other safety apparatus or gauges of temperature. These alloys are also used as "soft solders."

Newton's alloy consists of bismuth 50, tin 30, lead 20; it melts at about the boiling-point of water. These alloys are all weak and are of a dull gray color and tarnish readily.

Darcet's alloys are the following:

TABLE XXIV.

DARCET'S FUSIBLE ALLOYS.

NO.	BISMUTH.	LEAD.	TIN.	REMARKS.
1	7	2	4	Softens at the boiling-point of water.
2	8	2	6	Ditto; easy of oxidation.
3	8	2	4	Ditto; like butter.
4	16	4	7	Softens still more.
5	9	2	4	" less.
6	16	5	7	Becomes nearly liquid at boiling-point.
7	8	3	4	" quite " "
8	8	4	4	" very " "
9	16	9	7	Ditto.
10	8	5	3	Melts at 205° F. (95° C.).
11	8	6	2	Ditto.
12	8	7	1	Softens.
13	16	15	1	Does not melt at 212° F. (100° C.).

The fusible metals of most common use are:

D'Arcet's: Bismuth, 8; lead, 5; tin, 3 parts.

Walker's: Bismuth, 8; tin, 4; lead, 5 parts; antimony, 1 part. The metals should be repeatedly melted and poured into drops, until they can be well mixed previous to fusing them together.

Onion's: Lead, 3; tin, 2; bismuth, 5 parts. Melts at 197° Fahr. (93° C.).

If, to the latter, after removing it from the fire, one part of warm quicksilver be added, it will remain liquid at 170° Fahr., and become a firm solid only at 140° Fahr. (77° C.: 60° C.).

Another: Bismuth, 2; lead, 5; tin, 3 parts. Melts in boiling water.

They are frequently used to make toy spoons, which surprise the uninitiated by melting in hot liquors. A little mercury may be added to lower the melting points.

The first two are specially adapted for making electrotype moulds. French cliché moulds are made with the second alloy. These alloys are also used to form pencils for writing, also as metal baths in the laboratory, or for soft soldering joints.

The committee of the Franklin Institute, experimenting on steam boilers in 1836, made an examination on the behavior of the "fusible metals," and reported:

That the impurities of the commercial metals, lead, tin and bismuth, do not usually affect the melting points of these alloys; and that the compounds made by alloying them in chemically equivalent proportions do not present the characteristics of chemical compounds. They found that alloys ranging between $SnPb$ and $SnPb_6$ give nearly the same temperatures of fusion, but differ in their rates of change from the solid, through the plastic to the liquid state. The temperatures of casting and rates of cooling do not affect the melting points. Separation of the metals could be effected by pressure—a conclusion confirmed by the later experiments of Weems; these alloys, when used in "safety plugs" of steam boilers, should not be exposed to the pressure of the steam. Very little change is effected in the melting point of an alloy of equal parts lead and tin by adding tin; its melting point was found to be a few degrees lower than reported by Parkes.

Parkes and Martin obtain the following:

TABLE XXV.

FUSION OF ALLOYS OF BISMUTH, TIN AND LEAD.

BISMUTH.	LEAD.	TIN.	TEMPERATURE.	
Parts.	Parts.	Parts.	Fahr.	Cen.
8	5	3	202°	94.44°
8	6	3	208	97.78
8	8	3	226	107 64
8	8	4	236	112.20
8	8	6	243	116.05
8	8	8	254	122.10
8	10	8	266	127.60
8	12	8	270	130.90
8	16	8	300	147.40
8	16	10	304	149 60
8	16	12	294	141.90
8	16	14	290	139.70
8	16	16	292	140.80
8	16	18	298	144.10
8	16	20	304	147.40
8	16	22	312	152.80
8	16	24	316	154.00
8	18	24	312	152 90
8	20	24	310	151.90
8	22	24	308	151.80
8	24	24	310	152.90
8	26	24	320	158.40
8	28	24	330	163.00
8	30	24	342	170.50
8	32	24	352	176.00
8	32	28	332	165 00
8	32	30	328	163.90
8	32	32	320	158.40
8	32	34	318	157.30
8	32	36	320	158.40
8	32	38	322	159.50
8	32	40	324	160.60

The thermometer is observed to rise about one degree, Fahr., at the instant of solidifying.

These alloys are especially valuable for baths used in tempering steel articles of small size. They give a very exact temperature, which may be adjusted to the purpose intended. They are used by placing the article on the surface of the unmelted alloy, and gradually heating until fusion occurs and they fall below the surface, at which moment their temperature is right; they are then removed and quickly cooled in water. It is not easy, even if possible at all, to give as uniform a temperature by the ordinary processes of heating, or to obtain the exact heat desired, and the quality of the tool is not so easy of adjustment by any other method.

The Homberg alloy consists of equal parts of these metals, and melts at about 254° F. (122° C.); it is silver white. Krafft's alloy is composed of bismuth 63, lead 25, tin 12; it melts at 220° F. (104° C.). Rose's alloy is a more common one—40 bismuth, 20 lead, 20 tin, or 50 bismuth, 20 lead, 30 tin. Another, Rose's alloy, is of 50 bismuth, 25 each lead and tin, and melts at 205° F. (95° C.). According to Ermann, this alloy fuses at 200° F. (94° C.) and expands from a volume 1, at the boiling point of water, to 1.0083 at 114° F. (44° C.), contracts to 0.9913 at 148° F. (70° C.) and then expands to 1.0083 at the melting point.

Dobereiner's alloy, bismuth 46.6, tin 19.4, lead 34, melts at 210° F. (99° C.).

Bismuth, Lead and Zinc in equal parts form an alloy which melts in boiling water, according to Mackensie.

The melting points of fusible alloys, as determined by Grehm, are as follows (see Art. 120):

ALLOYS.		SOFTENS		MELTS	
Tin.	Lead.	at F.	at C.	at F.	at C.
2	2	365°	185°	372°	189°
2	6	372	189	383	195
2	7	377½	193	388	198
2	8	395½	202	406 to 410	216

118. Lead and Antimony uniter eadily and in all proportions, forming alloys of intermediate character, of which the most familiar is a "type metal," lead 34, antimony 1. The proportions vary with the size of type and with the character of the work to be done. The alloy is ductile, quite strong, hard enough to bear considerable use without wear or deformation, and not so hard as to injure the paper. It fuses at a low cherry-red heat, is not easily oxidized, and differs from lead in most of its qualities simply by possessing greater hardness.

Keys of flutes and similar parts of instruments are made of lead 2, antimony 1. Shot for guns is often hardened with antimony, and rifle bullets for large game are very frequently similarly made, introducing very small quanties of either tin or antimony or both. Low grade lead sold to shot-makers often contains 1 or 2 per cent. antimony.

The alloy of lead with even a very small percentage of antimony has been found, by Bischoff, to be subject to rapid corrosion by even very pure water. As the salts of lead are poisonous, any use of lead or of its alloys under conditions favorable to the formation of solutions liable to enter into drinking-water or food must be carefully avoided.

Riche reports the densities of alloys of lead and antimony as below:

Density of the antimony 6.641
Density of the lead 12.364

	THEORETICAL DENSITY.	EXPERIMENTAL DENSITY.	DIFFERENCE.	REMARKS.
$Sb_4 Pb$	7.237	7.214	−.023	
$Sb_3 Pb$	7.385	7.361	−.024	
$Sb_2 Pb$	7.651	7.622	−.029	
$Sb Pb$	8.271	8.233	−.038	
$Sb Pb_2$	9.046	8.999	−.047	Maximum dilatation.
$Sb Pb_3$	9.510	9.502	−.008	
$Sb Pb_4$	9.819	9.817	−.002	
$Sb Pb_5$	10.040	10.040	Nulle.	
$Sb Pb_6$	10.206	10.211	+.005	
$Sb Pb_7$	10.335	10.344	+.009	
$Sb Pb_8$	10.438	10.455	+.017	
$Sb Pb_9$	10.521	10.541	+.020	
$Sb Pb_{10}$	10.592	10.615	+.023	Maximum contraction.
$Sb Pb_{11}$	10.652	10.673	+.021	
$Sb Pb_{12}$	10.702	10.722	+.020	
$Sb Pb_{13}$	10 746	10.764	+.018	
$Sb Pb_{14}$	10.785	10.802	+.017	

The maximum of contraction corresponds to an atomic alloy $SbPb_{10}$, which has a rather simple composition, and near the alloy $SbPb_2$ is found the maximum of dilatation.

These alloys are crystalline. The alloys near $SbPb_2$ crystallize in quite large scales.

119. Tin and Antimony are easily alloyed, forming a silver or tin-white alloy, according to the proportion of tin, usually brittle, and often sonorous when the antimony is present in considerable amount; its specific gravity is less than the mean of the two constituents. Berzelius states that the alloy of 3 parts tin to 1 of antimony can be worked hot, although liable to crack along the edges. Berthier found the alloy, tin 4, antimony 1, very malleable and excellent for making hollow ware and for white-metal cocks; the mixture, tin 6, antimony 1, is also used for such purposes and also for various "pewter" (so-called) articles. This alloy takes a good polish, which slowly disappears with long exposure to the atmosphere. For domestic utensils an alloy of these metals is often used, as free from danger of injuring food cooked or kept in them; the alloy is not usually affected by the acids to which it is there exposed.

Chaudet investigated these alloys with considerable care.* He found that containing equal parts of tin and antimony harder than the latter, brittle and weak, and easily powdered. Its fracture was white and fine grained, and its specific gravity 6.8.

The alloy of tin 3, antimony 1, had a specific gravity of 7.06, was somewhat malleable under the hammer, but very liable to crack; it had much less ductility than tin.

Nitric acid oxidizes these alloys without dissolving them, and the oxide dissolves readily in hydrochloric acid, from which the addition of water causes the precipitation of the metals.

120. Tin and Lead alloy freely in all proportions, and the two metals are often found associated in nature. The addition of lead hardens tin, weakens it, alters its color from

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* "Alliages Metalliques."

white to gray, and changes its texture. When 3 parts tin and 1 of lead are used, the hardest and strongest alloy is produced; its density is 8. An alloy of tin 1, lead 2, is used for a lead-solder and known as plumber's solder, and the proportions are variable up to equal parts of each; its density is 9.4 to 9.6. Tin 2 or 3, lead 1, produce alloys which are very fusible, harder than either lead or tin, and which are used as tinner's solders; fluxed with resin, they are found valuable in joining all kinds of tin-smith's work; the proportion of the constituents is sometimes 1 to 1, and these alloys are known as "soft-solder."

According to Watson the densities of these alloys are as follows:

TIN.	LEAD.	S. G.
0	1	11.3
10	1	7.2
32	1	7.3
16	1	7.4
8	1	7.6
4	1	7.8
2	1	8.2
1	1	8.8

These alloys have a large number of applications in the arts in making small instruments, apparatus and utensils; they are used in plating copper, in making organ-pipes, and formerly in domestic utensils—for which, however, they are unfitted by the solubility and the poisonous properties of the lead, which are, however, greatly reduced by the presence of the tin. The alloy containing 16 to 18 per cent. lead is not sensibly attacked by vinegar or fruit acids. Alloys used in plating copper contain from 40 to 50 per cent. lead. Of the alloys of these two metals, that containing little or no observable amount of lead is used for domestic utensils; 8 per cent. lead gives a useful alloy for other dishes; 20 per cent. lead gives an alloy in considerable demand for ornamental castings.

Messrs. Parkes and Martin have determined and tabulated the melting points of these alloys, as in the following table:

TABLE XXVI.

MELTING POINTS OF TIN-LEAD ALLOYS.

PROPORTIONS.		MELTING POINTS.		PROPORTIONS.		MELTING POINTS.	
Tin.	Lead.	Fahr.	Cent.	Tin.	Lead.	Fahr.	Cent.
4	4	372°	187°	4	28	527°	271°
6	4	336	167	4	30	530	274
8	4	340	169	4	32	532	275
10	4	348	174	4	34	535	277
12	4	336	178	4	31	538	278
14	4	362	182	4	38	540	279
16	4	367	184	4	40	542	281
18	4	372	188	4	42	544	282
20	4	378	190	4	44	546	283
22	4	380	191	4	46	548	284
24	4	382	193	4	48	550	285
4	4	372	187	4	50	551	285
4	6	412	209	4	52	552	286
4	8	442	225	4	54	554	287
4	10	470	241	4	56	555	288
4	12	482	248	4	58	556	288
4	14	490	258	4	60	557	289
4	16	498	256	4	62	557	289
4	18	505	260	4	64	557	289
4	20	512	264	4	66	557	289
4	22	517	267	4	68	557	289
4	24	519	268	4	70	558	289
4	26	523	270				

Parkes and Martin propose the following alloys for baths used by cutlers and others in tempering and heating steel articles:

TABLE XXVII.

BATHS FOR TEMPERING.

NO.	USE.	LEAD.	TIN.	MELTING POINTS.	
				F.	C.
1	Lancets......................	7	4	420°	213°
2	Other surgical instruments....	7½	4	430	221
3	Razors......................	8	4	442	226
4	Pen-knives.............	8½	4	450	232
5	Knives, scalpels, etc..........	10	4	470	241
6	Chisels, garden knives........	14	4	490	252
7	Hatches....................	19	4	509	262
8	Table knives................	30	4	530	274
9	Swords, watch-springs........	48	4	550	285
10	Large springs, small saws.....	50	4	558	289
11	Hand saws	Oil boiling.		600	312
12	Articles of low temper........	1	4	612	319

Tin and lead in equal parts make an alloy used for organ pipes. It is cast in sheets on a table; these sheets are beaten smooth with a "planer," trimmed to size, rolled into shape and soldered together at the abutting edges.

121. Tin and Zinc unite, in all proportions, readily and uniformly, the quality varying less with variation of proportions than in alloys generally, as may be seen by studying the change of strength exhibited by the map and model shown in the chapter on the ternary alloys. The introduction of zinc increases the hardness of tin, and rather increases its whiteness, when in small proportion; in larger quantities it reduces ductility perceptibly. The alloy is of granular, sometimes crystalline, structure, as revealed by fracture, and is somewhat sonorous. With equal parts tin and zinc the alloy is rather hard, moderately ductile, and of a very brilliant lustre.

According to Koechl, the following are melting-points of these alloys:

TABLE XXVIII.

FUSION OF TIN-ZINC ALLOYS.

TIN.	ZINC.	TEMPERATURE OF FUSION.		REMARKS.
		Deg. Fahr.	Deg. Cent.	
1	3	500–572	260–300	Pure metals.
2	4	572–662	300–350	" "
3	2	428–680	220–360	" "
1	1	472–662	250–350	Commercial.
1	1	680–932	460–500	Pure metals.

The alloy of equal parts of tin and zinc is said by some authorities to be nearly as strong as brass, to be much cheaper, and a better anti-friction metal; but it is necessary that the zinc should be very pure. This alloy has been used in the form of roofing sheets. The alloy tin 75, zinc 25, makes excellent metal patterns, the alloy flowing freely, running "sharp" and expanding slightly when solidifying; it should not be overheated, and should be constantly stirred while pouring, to insure uniformity. This metal works easily, turns well in the lathe, and does not clog the file.

122. **Antimony, Bismuth, and Lead** unite to form an alloy which expands on cooling, and which is therefore used for type-metal. Mackensie's alloy is antimony 16, bismuth 16, lead 68. Stereotype plates of good quality may be made of this composition.

123. **Antimony, Tin, and Lead** are alloyed in the proportion of antimony 17, tin 13, lead 70, to form another Mackensie metal for stereotype plates and other printers' work. Sheets of this, or a similar alloy, are used in engraving music for printing; a composition reported by Berthier is antimony 5, tin 60, lead 35.

124. **Antimony, Tin, and Zinc,** in the proportions antimony 12, tin 44, zinc 44, make an alloy considered excellent for lining pump-barrels.

125. **Antimony, Bismuth, Tin, and Lead,** in the proportions tin 76, bismuth 8, antimony 8, lead 8, form the "Queen's Metal," which is one of the "pewter" alloys of greatest beauty and durability.

126. **Pewter and Britannia Metal.**—*Pewter* has a wide range of composition, from tin 20, copper 1, to tin 2, copper 1. The alloy is often mixed with lead, of which the Pewterers' Company in 1772 * permitted enough to bring the density of the pewter from $\frac{1835}{1820}$ to $\frac{1985}{1820}$ that of tin. The best *Britannia*, a metal of this class, is said to be tin 77, antimony 15, copper 7, zinc 2; the alloy is cast in flat ingots and rolled into sheets.

Britannia wares, made in Sheffield, are often composed of 3½ parts block tin, 28 parts antimony, 8 of copper, and 8 of brass. The tin is melted and kept at a red heat while the antimony, the copper, and the brass are successively added, molten. The liquid alloy is ladled into the ingot moulds, which are slab-shaped cast-iron boxes, and the slabs thus made are subsequently rolled into sheets or recast into the form desired, or into such shapes as may be easily modified to the necessary extent. Spherical vessels are usually "spun up" in halves, which are then united by soldering. The

* British Industries. Bevan, 1871.

solder is any very fusible composition of this class, and is often made of tin 75, lead 25. The fusibility of the metal is such that it requires some dexterity and great care to prevent its injury in the process of soldering. Britannia is easily shaped by all the familiar processes; it may be cast, rolled and hammered, and cut in the lathe or by hand tools with equal facility.

127. **Iron and Manganese** have a strong affinity. In small proportions manganese confers whiteness upon iron, and the alloy called "ferro-manganese" is considerably used in making steels containing very little carbon; the carbide of this alloy, known as "spiegeleisen," or simply "spiegel" in the trade, is used in carburetting iron to produce steels "higher" in carbon.

A small proportion of manganese renders iron less fusible, and is said to increase its tenacity. Many of the ingot-irons in the market, called "mild" or "low" steels, contain more manganese than carbon and are very strong and ductile, and make excellent material for use where great changes of temperature are not met; this alloy is not considered suitable for springs, however. In large doses, manganese does not reduce the ductility and malleability of iron to the extent observed with the introduction of carbon. Karsten found that nearly 2 per cent. manganese improved iron. Mushet found that the alloy iron 71, manganese 29, was not magnetic, and concluded that the maximum attainable in iron was 40 per cent. manganese. As the percentage of manganese increases, the alloy becomes whiter, harder, more infusible, and more brittle if the manganese is present in considerable amount; it is more subject to oxidation also.

128. **Platinum and Iridium** alloy to form a composition, according to Matthey,* which is homogeneous and is capable of being forged. Its density is 21.5 when of the composition, platinum 98.5, iridium 12.5 by mixture, and platinum 90, iridium 10 by analysis. The density of the iridium was 22.38. The coefficient of expansion was from 0° to 16° C. (32° to 41° F.), 0.0000254.

* Proc. Royal Society, 1878.

129. Spence's "Metal" is not, strictly speaking, a metal, but is a compound obtained by dissolving metallic sulphides in molten sulphur,* which is found capable of receiving into solution nearly all known compounds of sulphur and the useful metals. It was discovered by J. B. Spence in the year 1879. The solution, on cooling, solidifies, forming a homogeneous, tenacious mass of the specific gravity 3.37 to 3.7 at 0° C. (32° F.). According to Dr. Hodgkinson, when finely powdered, it is acted upon slowly by concentrated HCl and NO_2HO in the cold; in large lumps, little or no action takes place; the expansion coefficient appears to be small. The fracture is not conchoidal, but somewhat like that of cast iron.

It is said to be exceedingly useful in the laboratory for making the air-tight connections between glass tubes by means of caoutchouc, and a water or mercury jacket, where rigidity is no disadvantage; the fusing point is so low that it may be run into the outer tube on to the caoutchouc, which it grips on cooling, like a vice, and makes it perfectly tight. It melts at 320° F. (160° C.), expands on cooling, is claimed to be capable of resisting well the disintegrating action of the atmosphere, is attacked by but few acids and by them but slowly, or by alkalies, and is insoluble in water, and may receive a high polish; it makes clear, full castings, taking very perfect impressions; it is cheap and easily worked. It has been used as a solder for gas-pipes, and as a joint-material in place of lead.

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* Jour. Society of Arts. London, 1879.

CHAPTER VII.

MANUFACTURE AND WORKING OF ALLOYS.

130. Alloys of General Application; Brass Working.—Of the alloys described in the preceding chapter but a few are employed by the engineer in his professional work, and still fewer are familiar and in common use. Of all the known alloys, the bronzes and the brasses, the coin alloys and a few compounds of tin, lead, zinc, antimony and bismuth, only, are so well known as to be properly classed among the materials of constructive engineering. All the others are of use only in a restricted range of application and for a few special purposes.

The methods of preparation are practically the same for all, and the "brass foundry" is usually resorted to in making them all.

Brass work is divided into several branches, which, according to Aitken, are:

1. Brass casting, or ordinary foundry work;
2. Bell and cabinet-ware casting;
3. Pot-metal and plumbing work;
4. Stamped brass-work;
5. Rolled brass; wire-work; sheathing;
6. Tube making;
7. Lamp making;
8. Gas fitting;
9. Naval brass-founding.

Several of these lines of work may often be carried on together, but it is usual to combine those most nearly related—as those involving casting, those in which the metal is rolled or wire-drawn, stamping, tube-making and brass finishing.

Casting is described at length in Arts. 131–2, on the brass foundry.

Sheet-rolling is a very important branch of brass-making, employing a large number of work-people and sustaining a host of minor trades.

The ingot brass for sheet-brass rolling is cast in broad, shallow, iron ingot-moulds, or when larger masses are to be used, in stone moulds, cut out of the solid block. They are well oiled and powdered with charcoal before filling them.

The cast ingots of brass are called "strips," and are rolled, cold, by several successive "passes" through heavy rolls, with occasional annealing as they become hardened by the operation of the rolling-mill. When the surface of the sheet is found to be irregular and to contain spots of impurity, the hand-scraper, or a scraping machine, is employed to remove them, and thus to prevent liability to cracking and raggedness of surface or edges. When rolled nearly to gauge, the sheet is "pickled," to remove the oxidized surface, and is then passed through the finishing rolls, which are finely polished and give the sheet its final finish. Muntz metals can be rolled hot, and therefore much more cheaply than other brass.

Wire-drawing is conducted as in the drawing of iron and steel wire; but the rods to be drawn are cut, by a slitting-mill, from sheet-brass. Like iron wire, brass must be occasionally annealed, in passing from wire-block to wire-block.

Stamping in dies can be practised with any of the soft and ductile brasses, or other alloys. It is by this process that a large proportion of the cheap brass ornaments are made, as well as many parts of various utensils, as lamps, door-fixtures and kitchen utensils. The die on the anvil is made of the desired form, and the metal is "struck" into it by the blow of a "drop-hammer" carrying a companion die, the drop falling from one to five feet according to weight and power. Heavy drops are always worked by steam power. The "force," or die carried by the drop, is usually of soft metal; the die on the anvil is of steel. For fine and small intricate work, several blows are struck. This kind of work does not compare favorably with cast brass, or bronze, in clearness and fineness of lines.

Brass Tubes are made by either of several methods. Sheet-brass is rolled, over a form, into a tube, and the edges soldered together, or they are rolled into cylindrical shape and soldered. For exact sizing, a mandrel is placed within the tube and on this it is rolled to gauge. Seamless tubes, such as are used in steam boilers and elsewhere under pressure, are made by rolling, or by drawing down cast cylinders in a mill consisting of several sets of steel rolls.

Brass-finishing includes lacquering, bronzing, dipping and burnishing and other methods of giving a surface finish, described at the end of this chapter.

131. **The Brass Foundry** is usually an adjunct to large manufacturing establishments. It is generally small, and the moulding room and casting room are in one. A drying room, or core-oven, is conveniently located at the moulding room side; it may be heated by either steam or by stoves, the former being the better plan. A cleaning room and, beyond it, a finishing or dressing room, should be attached to the foundry, and, for fine work, a lacquering room is also required.

The "patterns" are of wood or iron, as in iron founding, or they may be of stucco and pipe-clay. Patterns for brass castings must be larger than for iron, as shrinkage is one-half greater, *i.e.*, $\frac{3}{16}$th inch to the foot, or about 20 cm. per metre. The "shrink-rule" used for iron will not apply for brass-work. The flasks, and all details of apparatus, tools, and work are very similar to those used in an iron foundry, and the methods are the same in the main. Castings are cooled rapidly, often with water, to soften and toughen them.

132. **Melting and Casting.**—In the melting of the materials in the making of alloys in the foundry, two general methods of procedure are practised; in the one, all the constituents are fused at the same time in the same crucible or melting pot; in the other they are fused one after another in a definite order, which is determined by their relative fusibility, volatility, and liability to oxidation, or to absorb oxygen and other gases. The first of these methods is, perhaps, the most

common, but the second is by far the better; thus in making the most common ternary alloys, those of copper, tin, and zinc, the copper is best melted first, the tin should be next introduced, and the zinc, which is volatile and oxidizable, is added last. If lead is to be introduced into such an alloy, it is found best to put it into the crucible last.

Other things being equal, the metals should be added in the order of their non-volatility; the next controlling quality is infusibility; the least fusible should generally be melted first.

The casting and cooling of the alloy is hardly less a matter of importance than the methods of fusion. Liquation is very liable to occur in certain cases, as in many alloys of copper with tin, and to prevent it the most prompt cooling possible is resorted to; the use of "chills," or metal moulds, is sometimes found essential to success. In these cases, it is not advisable to pour the alloy "cold," as liquation may have already commenced; they should be poured hot—"sharp," as the term is often used in the foundry—and yet compelled to chill quickly, if possible.

The apparatus of the foundry, in which alloys are mixed and cast, consists of an air, or wind, furnace, sufficiently large to receive the crucibles in which the metals are melted, or, sometimes, when the masses handled are very large, a reverberatory "open hearth" furnace, which is preferably heated with gas or liquid fuel; of a collection of crucibles, which may be iron melting-pots for lead and alloys which melt at a low heat and have no affinity for iron, but which are usually of clay, of graphite, or of graphite mixed with clay; and utensils for weighing and handling the metals, fuels, and crucibles. In some cases platinum and silver crucibles are used, as in laboratory work, but these are rarely needed. The crucibles should be carefully selected, since the cost of these vessels is often an important item of the expense account.

In melting, the constituents of the charge being introduced in the order decided to be, on the whole, best, the liquid metal should be carefully stirred after each addition, and in such a manner as to secure most complete intermixture without liability to injure it by exposure to an oxidizing atmosphere. When the alloy is not homogeneous and sound, it may sometimes be greatly improved by refusion. In making large castings, the several metals to be alloyed are usually melted separately and all finally poured together into a reservoir in which they are thoroughly mixed before "pouring the casting." Where a reverberatory furnace is used, the process may be conducted as in crucibles; in this case, especial precautions must be observed to preserve a deoxidizing flame within the furnace. When they are used in making bronzes, great care is taken to keep the mass constantly stirred to prevent liquation and the floating of the tin to the top.

The fuel used in the mint-furnace is generally coke, which should be dense, hard, bright, and should ring when struck.

In large establishments, and especially in melting bronzes, the open-hearth reverberatory is very generally used. Bell founders use a peculiar dome-topped furnace, melting at more moderate heat.

In "pouring," the small castings are made first and the heavier are poured with the cooler metal.

Sheet-brass is first cast in plates between heavy marble blocks washed with loam and well dried, or, often in ingots. They are rolled in heavy plate-mills and occasionally annealed as they become hard and unmalleable in the rolls.

In making brass-plates and sheet-brass, the surface is pickled, after the sheet is reduced nearly to size, in order to give it a clean surface, and then, when a finish is demanded, it is given by a set of polished rolls.

Wire-brass is cast and rolled into plates, which are cut into narrow strips in a "slitting-mill" by narrow interlocking roll-collars. These strips are rolled to a conveniently small size, and are then sent to the wire-mill to be finished in the draw-plates.

133. **Furnace Manipulation.**—In filling the furnaces, the crucibles are slowly heated to avoid danger of breaking; they are at first set bottom upward. When well heated, they are set mouth upward and charged with the broken copper. The tin or zinc is heated at the mouth of the furnace and is added gradually to the copper as the latter becomes fluid.

The zinc is liable to volatilization, and is, therefore, when introduced, plunged well below the surface of the molten copper. The Author has sometimes had it wrapped in dry paper or other protecting material to secure protection from loss by volatilization and oxidation. Great care is needed to prevent the introduction of cold and especially of damp metal; seriously dangerous explosions are sure to take place if this should happen.

The fumes arising from the molten alloys when poured are unhealthy, and a form of intermittent fever known as the "brass ague" is often produced by them where proper precautions in handling and in securing ventilation are not observed.

The brass-founder's furnace consists of a vertical cast-iron cylinder or other casing—often a brick structure—lined with fire-brick to a diameter of 10 to 15 inches. The flue is led off at one side at the top, and the whole is covered with a plate having an opening of sufficient size to permit the crucible to enter and fitted with a cover plate. The grate is usually composed of loose bars which can be easily and independently withdrawn or inserted.

Each furnace contains one crucible, and large castings are only made where several furnaces are in use or where the alloy can be melted in a reverberatory furnace. Tuyeres are sometimes fitted for the purpose of increasing the rapidity of melting, and the crucibles are then, when large castings are to be made, emptied as fast as ready into a ladle which serves as a collecting reservoir from which the mould is filled.

The fuel is usually either coke or charcoal.

134. **The Preparation of the Alloys** involves considerable knowledge of the behavior of the mixture and its constituents while fusing and while the alloy is being formed, and can only be successful when the skill and judgment of an experienced founder aid in the work of melting and casting. There are two methods of making alloys: the one is that of weighing out the constituents in proper proportions and mixing and melting all together; the other is that of mixing and melting the constituents successively and in an order

dependent upon the character of the metals and the alloy made of them. The first is the usual method and is the least troublesome and expensive; but it does not usually give as sound, uniform, and strong castings of the alloy as the second. In the latter case, the metal of highest melting point is usually first fused and the others are added in the order of fusibility or volatility. The order of introduction into the crucible or melting-pot has an appreciable effect on the quality of the alloy.

After the alloy has been made and poured into the ingot, or other mould, it may change in composition by the process of separation or "liquation," to which reference is elsewhere made, either by the denser metal settling out or by the change due to formation of other definite alloys of greater stability at various points in the mass, thus altering the composition of the metal all around those points. Thus in gun-metal (bronze) the surface of fracture often has a variegated color due to separation of the tin and the production of a variable composition of alloy. This will be noted in the description of the behavior of many alloys made by the Author. It will be seen that the rapid cooling secured by the use of metal moulds is the best means of preventing this liquation. Slow cooling, affording ample time for the separation and reconcentration of the constituents, and for the production of crystals, permits, often, very serious loss of quality. It will be noted that the best alloys are usually made most successfully when the molten metal is poured "sharp," *i. e.*, hot, and then rapidly cooled to the point of solidification.

The process of liquation is sometimes usefully applied, as in the Pattinson process of separating the metals in argentiferous galena, or in cupriferous ores of lead.

The desired alloy is very rarely made of its essential constituents only. A simple binary alloy of copper and tin is, for example, rarely made in commercial work. Lead is often added to give color, zinc to cheapen it or to flux it, and sometimes other metals to give special qualities. Statuary bronze usually contains some lead and zinc to give it its peculiar "patina"; bronze used in "hardware" and architectural work, in bearings, etc., contains lead to give color and to make it wear well; brass is hardened greatly, and strengthened, by the addition of one per cent. tin, or more, as in the "maximum alloys" discovered by the Author. In such cases, the metal is added in small quantity to the mixture, after the latter is in fusion and alloyed.

135. **Minute Quantities of Alloy** often greatly influence the properties and quality of metals. Thus, it is stated * that lead alloyed with 0.003 per cent. of antimony turns perceptibly freer than pure lead; that an addition of 0.007 per cent. copper unfit leads for use in the manufacture of white lead; that gold containing 0.05 per cent. of lead exhibits greatly decreased ductility; that copper containing 0.5 per cent. iron has but 40 per cent. of the conductivity of pure copper.

Nickel is too brittle to work; but, alloyed with 0.1 per cent. magnesium or 0.3 per cent. phosphorus, it can be rolled and worked. Brittle steel is sometimes made tough and malleable by alloying it with 0.08 per cent. manganese or magnesium. A difference of 0.01 per cent. in the amount of phosphorus present in the best Swedish irons can be plainly observed by a change of malleability.

136. **Art Castings in Bronze** represent the most perfect work known in the department of foundry work. It has been practised from the earliest known and even pre-historic periods, and the analyses of art castings found in the Egyptian tombs and in Nineveh prove that the composition then adopted was substantially that of the statuary bronze, and that of the art-work of to-day. The Greeks began to make bronzes several hundred years before the Christian era, and before the commencement of that era, had attained great skill in the art. The statue of Apollo, at Rhodes, made by the pupil of Lysippus, Chares, 330 B.C., was about 100 feet (30 metres) high, and after having been shaken down by an earthquake some 60 years later, lay over 900 years prostrate, and was then carried away by a Jew who purchased it from the Saracens, making a load, as it is said, for 900 camels. The Chinese and Japanese first made use of bronze at some

* *Der Techniker*, 1883.

unknown but very early date. The art was long lost in Europe, but was revived in the 16th and 17th centuries, and now constitutes an exceedingly important industry.

Art castings of large size are moulded and cast precisely as other brass-founding is done; but great precaution is taken in the selection of materials, in determining exactly the desired proportions and in all the details of foundry practice and manipulation. The usual mixtures are given elsewhere.

In making statuary, the model is first formed, and is then lined off by the founder in sections in such manner that each will be likely to be easily moulded and will "draw" readily; plaster patterns are made of these sections separately, which are used in obtaining metal copies, which latter are finally joined together. Where the piece is to be cast whole also, the mould must be often made in many parts, in order that every section of the mould may be readily removed. In some cases, an elastic mould is made within which a wax model is formed, the latter being moulded in the sand in the usual manner. For such work, a plaster cast is usually first made, which is coated with any oily or glutinous substance which will not allow moisture to be transferred, and will not permit the adherence of the cope or mould, to be formed over it. By covering the model with a thin coating of wax, an outer mould can be constructed, and the inner and outer shapes may thus be separated by a thin space which represents that to be filled by the molten bronze, and determines the thickness of the casting. This space is often filled with wax and the latter is melted out when the mould is sent into the drying room or oven. Properly made, the mould has smooth, perfect surfaces of the exact form to be reproduced, and the bronze, when removed from it, is an exact reproduction of the model, only requiring a small amount of work to make it marketable. If the composition and the work are what is desired, the surface of the casting is smooth, precise in form, sharp in outline, and of good color. Statues thus made acquire, with age, a color or "patina" which distinguishes all good bronzes.

Statuary bronze, and bronze for art-work generally, should have, when newly cast, a fresh, yellow-red color, and a fine grain, should be easy to work with file or chisel, very fluid when melted, taking the finest impressions of the mould, and when exposed to the atmosphere in the finished casting, should take the peculiar green patina characteristic of old bronze statuary of good quality. These qualities are not usually obtained in so high a degree in the copper-tin or copper-zinc alloys, the common bronzes and brasses, as in alloys containing the three metals. According to Guettier, the best of these alloys are:

COPPER.	ZINC.	TIN.
92	6	2
85	11	5
65	32	3

It is very usual to add 1 or 2 per cent. of lead; ancient bronzes contain as much as 6 per cent. According to Pliny, bronze was made by melting copper first, then adding 12½ per cent. of an alloy of equal parts tin and lead, known as *plumbum argentarium.*

137. **Stereotype Metal,** of which a good quality is made of 16 parts antimony, 17 parts tin, and 67 parts lead, is worked thus:

The type is brushed over with a small quantity of black-lead and oil, placed in a casting-frame, and a cast taken in plaster of Paris. This cast is dried in a hot drying-oven until absolutely free from all moisture, and is held in form, meantime, by securing it to a flat cast-iron plate. The stereotype metal is cast upon the matrix thus produced, and the plate thus obtained is planed up to a gauge and fitted to the press, or mounted on wooden blocks of the right height to work in the press. Damaged type are cut out and replaced with perfect ones.

A later process is the following:* A sheet of tissue paper covered with printing paper is placed upon a perfectly smooth metal plate, and the two sheets are pasted together.

These sheets are laid over the type, beaten into their interstices, covered with other sheets similarly beaten down, and

* Spon.

this process is continued until the mass of paper forms a matrix of satisfactory thickness and strength. Heavier paper, as cartridge paper, is used for the last layers. This matrix is dried carefully between surfaces which hold it in shape, is then brushed over with French chalk or black lead, and laid in the casting box, where the stereotype metal is cast over it and a plate thus made.

138. **German Silver** is made by English founders of small bells and similar articles of copper 57, zinc 19, nickel 19, lead 3, tin-plate 2. The copper and nickel are fused together first, the zinc added after their fusion, and the other metals last. Commercial zinc containing lead is rarely pure enough for the finer grades of this alloy which do not permit the introduction of lead. It is difficult to obtain this alloy in correct proportions and of good quality.

139. **Babbitt's "Anti-attrition" Metal** is usually not cast directly into the "brasses" to be lined with it. It is made by melting separately 4 parts copper, 12 Banca tin, 8 regulus of antimony, and adding 12 parts tin after fusion. The antimony is added to the first portion of tin, and the copper is introduced after taking the melting-pot away from the fire, and before pouring into the mould.

The charge is kept from oxidation by a surface coating of powdered charcoal. The "lining metal" consists of this "hardening," fused with twice its weight of tin, thus making 3.7 parts copper, 7.4 parts antimony and 88.9 parts tin.

The bearing to be lined is cast with a shallow recess to receive the Babbitt metal. The portion to be tinned is washed with alcohol and powdered with sal ammoniac, and those surfaces which are not to receive the lining metal are to be covered with a clay wash. It is then warmed sufficiently to volatilize a part of the sal ammoniac, and tinned. The lining is next cast in between a former—which takes the place of the journal—and the bearing.

Founders often prefer to melt the copper first in a plumbago crucible, then to dry the zinc carefully and immerse the whole in the barely fluid copper.

A report of a committee of the American Master

Mechanics' Association, reporting on the use of Babbitt metal, state that thirty-five replies to their circular gave the following facts relating to the use of Babbitt metal: Four use gibs with Babbitt; four use the solid octagon brass without Babbitt; seven use octagon with Babbitt; seven use half-round solid brasses without Babbitt; four use half round brasses in three pieces with Babbitt, and one makes no report of the use of Babbitt. All, with one exception, report that the Babbitt metal should extend the entire length of the journal and should be put on in strips ¾ to 1½ inches wide, at a point between the top and the front and back points of the journal bearing; one inserts it by drilling holes in the brass and then filling in with the metal. The Committee have observed that, in engines of from thirty-two to thirty-five tons weight, the half-round brass does not give as good results as in lighter engines. Good results may be obtained from a hexagon-shaped brass if properly fitted. The Babbitt metal will wear until it is cut through into the cast-iron. The recess in the top of the brass is of advantage also as a reservoir for oil; and as there is less bearing at that point, the brass wears away and the shaft beds itself into the brass, so that there is no lost motion or pounding between the shaft and the brass. The Committee is of opinion that the use of Babbitt metal is advisable.

140. Solders are alloys used in joining metallic surfaces, and parts of apparatus or constructions, by fusing them upon the surfaces of contact, and allowing them to cool, obtaining a more or less firm and tenacious union. They have a wide range of composition; the "soft solders" are made of tin and lead; "hard solders" are usually made of brass; and special solders are composed of various alloys of copper, zinc, lead, tin, bismuth, gold and silver. Haswell's table of solders is given later.

In soldering copper, brass, or iron with soft solder, a "soldering iron" is used to melt, and to apply the solder to the work. This instrument consists of a copper head, shaped somewhat like a machinist's hammer, the large end of which is inserted longitudinally in the claw-shaped end of an iron holder, which is itself carried by a wooden handle; it is heated in a small charcoal-furnace, or "brazier," which is especially constructed for the purpose.

A "soldering fluid," usually a solution of zinc in hydrochloric acid, is used to remove the oxide from the surfaces to be joined and to give them a coating of zinc, to which the solder will promptly adhere.

Soldering is often successfully performed by cleaning the surfaces thoroughly, fitting them nicely together with a file, if necessary, placing a piece of tin-foil between them, binding them firmly together with "binding wire," and heating in the flame of a lamp or a Bunsen burner, or in the fire, until the tin melts and unites with both surfaces. Joints carefully made may be united, in this way, so neatly as to be invisible. When using the more fusible solders, as those containing bismuth, a fire is seldom needed. When one joint has been made with hard solder, it is not always safe to make another near it with the same composition; a softer solder should then be used.

Soft solders are not malleable, and where this quality is demanded, the solder is necessarily of the hard variety. An excellent solder for such work is made with silver and brass in equal parts.

Coin silver, in thin sheets, is an excellent solder for copper, hard brass, and wrought iron. Cast iron cannot be readily soldered, and the attempt is rarely made.

In making solders, great care is to be taken to secure uniformity of composition; they are often granulated by pouring from the crucible or ladle through a wet broom or from a considerable height into water, or they are cast in ingots and reduced to a powder by filing or by machinery. The silver and the gold solders are usually rolled into sheets; the soft solders are generally sold in sticks, as is also pure tin; those which are rich in tin are distinguished by their peculiar "tin-cry," which is destroyed by a very small admixture of other metals. In making solders, as all other such alloys, the most infusible metal is first melted, and the other constituents are added in the order of infusibility. Soft solders are very fusible and are melted under tallow, and the hard solders are prepared under a covering of powdered charcoal to prevent oxidation.

Yellow brass, containing from 65 to 80 per cent. copper, will be found useful at times in brazing wrought iron, mild steel, and all the common brasses and bronzes containing less than 10 per cent. tin or lead. Equal parts of copper and zinc make a good solder for yellow brass and is known as "broom" solder. Tin and lead are sometimes added, but probably without advantage, the one making the solder hard, the other weakening it. For brazing iron, yellow brass is excellent.

In using these solders, the surfaces to be brazed should be well cleansed, sprinkled with borax, and bound tightly together with fine iron wire. A clay "dam" around the joint is useful in confining the solder in place when melting. The heating should be gradual and the temperature brought slowly up to a red heat, occasionally adding borax, and, finally, the heat should be more quickly raised until the solder melts and fumes, when the piece is cooled.

Silver and yellow brass make good solders for steel, melting at a moderately high heat and having considerable strength. Both solder and flux should be used sparingly to secure good work. Cast iron and alloys containing either tin or lead in considerable quantities cannot be easily soldered.

The soldering fluid answers as a flux for soft solders; borax is used with the hard varieties, as it dissolves the oxides of all metals thus treated, and leaves the clean metallic surface which is essential to perfect union. Sal ammoniac is often added to the soldering fluid when soft solders are used, and resin is a common, and in some respects the best, flux for tinner's work.

Platinum is soldered with gold, and German silver with a solder of equal parts of silver, brass, and zinc.

The essentials of a good solder are that it shall have an affinity for the metals to be united, should melt at a considerably lower temperature, should be strong, tough, uniform in composition, and not readily oxidized. (See tables, pp. 221, 241.)

141. **Standard Compositions** are often adopted by en-

gineers for the various purposes to which they apply the alloys. The tables hereafter presented are full of examples. In further illustration, we have the following as the compositions adopted by the Paris, Lyons, and Mediterranean Railway of France:

TABLE XXIX.

STANDARD ALLOYS.

ALLOY.	PROPORTIONS.					USES.
	Copper.	Tin.	Zinc.	Lead.	Ant.	
Gun-metal, 1.	82	16	2	..	..	Bearings.
" 2.	84	14	2	..	..	Valves, Screws, etc.
" 3.	90	8	2	..	..	Cocks, Whistles, etc.
Brass, 1.	70	..	30	..	..	Tubes.
" 2.	67	..	33	..	..	Stuffing-boxes, etc.
" 3.	65	..	35	..	..	Handles, Latches.
" 4.	63	..	37	..	..	Plates, Washers.
White metal.	5	71	..	..	24	Bearings.
Packing "	..	14	..	76	10	Stuffing-boxes.
Solder.	..	45	..	55	..	For tin plate.
"	..	40	..	60	..	" zinc "

The useful alloys are, as already seen, exceedingly numerous, and are of extraordinary variety in appearance and physical qualities. They are applied to an almost equally wide range of uses. The following very complete lists will give an idea of their number, quality and applications.*

* Chas. Haswell; Pocket-book, 1882. C. Bischoff: Das Kupfer und seine Legirungen; Berlin, 1865. P. A. Bolley: Recherches Chimiques; Paris, 1869. A. Herve: Alliages Métalliques, Manuel-Roret; Paris, N.D.

TABLE XXX.

ALLOYS AND COMPOSITIONS.—HASWELL.

	COPPER.	ZINC.	TIN.	NICKEL.	LEAD.	ANTIMONY.	BISMUTH.	SILVER.	COBALT OF IRON.	IRON.	ARSENIC.
Argentan	55.	24.	....	21.	....	....	....	....	....	....	....
Argentiferous alloy	50.	2.5	2.5	40.	2.5	....	....	....	....	2.5	....
Babbitt's metal	3.7	....	89.	....	....	7.3	....	....	....	....	....
Brass, common	84.3	5.2	10.5	....	....	....	....	....	....	....	....
" "	75.	25.	....	....	....	....	....	....	....	....	....
" " hard	79.3	6.4	14.3	....	....	....	....	....	....	....	....
" mathematical instruments	92.2	....	7.8	....	....	....	....	....	....	....	....
" Pinchbeck	80.	20.	....	....	....	....	....	....	....	....	....
" red tombac	88.8	11.2	....	....	....	....	....	....	....	....	....
" rolled	74.3	22.3	3.4	....	....	....	....	....	....	....	....
" tutenag	50.	31.	....	19.	....	....	....	....	....	....	....
" very tenacious	88.9	2.8	8.3	....	....	....	....	....	....	....	....
" wheels, valves	90.	....	10.	..	....	....	....	....	....	....	....
" white	10.	80.	10.	....	....	....	....	....	....	....	....
" wire	67.	33.	....	....	....	....	....	....	....	....	....
" yellow, fine	66.	34.	....	....	....	....	....	....	....	....	....
Britannia metal	....	....	25.	....	....	25.	....	....	....	....	....
" when fused add	....	....	....	....	....	25.	25.	....	....	....	....
Bronze, red	87.	13.	....	....	....	....	....	....	....	....	....
" red	86.	11.1	2.9	....	...	....	....	....	....	....	....
" yellow	67.2	31.2	1.6	....	....	....	....	....	....	....	...
" cymbals	80.	....	20.	....	....	....	....	....	....	....	....
" gun metal, large	90.	....	10.	....	....	....	....	....	....	....	....
" " small	93.	....	7.	....	....	....	....	....	....	....	....
" metals	93.	....	7.	....	....	....	....	....	....	....	....
" statuary	91.4	5.5	1.4	....	1.7	....	....	....	....	....	....
Chinese silver	65.1	19.3	....	13.	....	....	....	2.48	12.	....	....
Chinese white copper	40.4	25.4	2.6	31.6	....	....	....	....	....	....	....
Church bells	80.	5.6	10.1	....	4.3	....	....	....	....	...	....
"	69.	....	31.	....	....	....	....	....	....	...	...
Clock bells	72.	....	26.5	....	....	....	....	....	....	1.5	....
Clocks, musical bells	87.5	....	12.5	....	....	....	....	....	....	....	....
German silver	33.3	33.4	....	33.3	....	....	....	....	....	....	....
"	40.4	25.4	....	31.6	....	....	....	....	....	2.6	....
" fine	49.5	24.	....	24.	....	....	....	....	....	2.5	....
Gongs	81.6	....	18.4	....	....	....	....	....	....	....	....
House bells	77.	....	23.	....	....	....	....	....	....	....	....
Lathe bushes	80.	....	20.	....	....	....	....	....	....	....	....
Machinery bearings	87.5	....	12.5	....	....	....	....	....	....	....	....
" hard	77.4	7.	15.6	....	....	....	....	....	....	....	....
Metal that expands in cooling	....	....	....	....	75.	16.7	8.3	....	....	....	....
Muntz metal	60.	40.	....	....	....	....	....	....	....	....	....
Pewter, best	....	....	86.	....	....	14.	....	....	....	....	....
"	....	....	80.	....	20.	....	....	....	....	....	....
Printing characters	....	....	....	....	80.	20.	....	....	....	....	....
Sheathing metal	56.	45.	....	....	....	....	....	....	....	....	....
Speculum "	66.	....	22.	....	....	....	....	...	....	....	12.
" "	50.	21.	29.	....	....	....	....	....	....	....	....
Telescopic mirrors	66.6	....	33.4	....	....	....	....	....	....	....	....
Temper *	33.4	....	66.6	....	....	....	....	....	....	....	....
Type and stereotype plates	....	....	....	....	69.	15.5	15.5	....	....	....	....
White metal	7.4	7.4	28.4	....	....	56.8	....	....	....	....	....
" hard	69.8	25.8	4.4	....	....	....	....	....	....	....	....
Oreide	73.	12.3	Magnesia..... 4.4 Sal-ammoniac 2.5				Cream of tartar 6.5 Quicklime......1.3				

* For adding small quantities of copper.

TABLE XXX.—*Continued.*

SOLDERS.

	COPPER.	TIN.	LEAD.	ZINC.	SILVER.	BISMUTH.	GOLD.	CALCIMINE.	ANTIMONY.
Tin	..	25	75	..	..	..	..	..	..
"	..	58	16	..	..	16	..	..	10
" coarse, melts at 500°	..	33	67	..	..	..	..	..	..
" ordinary, melts at 360°	..	67	33	..	..	..	..	..	..
Spelter, soft	50	..	..	50	..	..	..	..	..
" hard	67	..	..	33	..	..	..	..	..
Lead	..	33	67	..	..	..	..	..	..
Steel	13	..	..	5	82	..	..	..	..
Brass or copper	50	..	..	50	..	..	..	..	..
Fine brass	47	..	..	47	6	..	..	..	..
Pewterers' or soft	..	33	45	..	..	22	..	..	..
" "	..	50	25	..	..	25	..	..	..
Gold	4	..	..	..	7	..	89	..	..
" hard	66	..	..	34	..	..	..	..	..
" soft	..	66	34	..	80	..	..	..	..
Silver, hard	20	..	..	..	67	..	..	21	..
" soft	12	..	..	..	..	..	..	..	..
Pewter	..	40	20	..	..	40	..	..	..
Iron	66	..	..	33	..	..	..	..	1
Copper	53	47	..	..	..	..	..	.	..

FUSIBLE COMPOUNDS.

COMPOUNDS.	ZINC.	TIN.	LEAD.	BISMUTH.	CADMIUM.
Rose's, fusing at 200°	....	25	25	50	..
Fusing at less than 200°	33·3	..	33·3	33·4	..
Newton's fusing at less than 212°	....	19	31	50	..
Fusing at 150° to 160°	....	12	25	50	13

142. **Special Recipes.**—The best bronze compositions for use in engineering are, according to Guettier,* the following: For pumps, bolts and similar pieces:

Copper	88	Copper	90
Tin	12	Tin	10
	100		100

The latter is the softer of the two. Often from one to four per cent. of zinc is added, as already stated.

* Guide Pratique ; Paris, 1865.

For eccentric-straps and connecting-rod bearings:

Copper......	83	84	83	84	82	85.25
Tin.........	15	14	15	14	16	12.75
Zinc........	2	2	1.5	1.5	2	2
Lead........	..	..	0.5	0.5	..	.....
	100	100	100.0	100.0	100	100.00

The addition of lead and increase of copper gives softer alloys. Lead is often used more freely than above.

Locomotive driving-axle bearings:

Copper........	74	80	85.25	86	89
Tin...........	9.5	18	12.75	14	8
Zinc..........	9.5	2	2.00	..	3
Lead..........	7	..	....	..	..
	100.0	100	100.00	100	100

The Author prefers gun-bronze to either of the above.

For Locomotive Slide Valves—

Copper phosphide....................	3.50
Copper..............................	77.85
Tin.................................	11.00
Zinc................................	7.65
	100.00

Connecting-Rod Brasses—

Copper phosphide....................	3.5
Copper..............................	74.5
Tin.................................	11.0
Zinc................................	11.0
	100.0

Axle-boxes—

	No. 1.	No. 2.
Copper phosphide....................	2.5	1.5
Copper..............................	72.5	73.5
Tin.................................	8.0	8.0
Zinc................................	17.0	19.0
	100.0	100.0

Parts demanding greater strength—

Copper phosphide	3.5
Copper	85.5
Tin	8.0
Zinc	3.0
	100.0

Zinc is here added to the bronze to aid in securing that homogeneousness which is essentially the result of the addition of phosphorus.

For pistons (rarely needed): copper, 89.75; tin, 2.25; zinc, 8.

For car and locomotive axle bearings:

Copper	80	79	86	89
Tin	18	18	14	2.5
Zinc	2	2.5	..	8.5
Lead	..	0.5	..	...
	100	100.0	100	100.0

For ordinary stationary machine journal-bearings: copper, 82; tin, 18.

For whistles of locomotives and bells:

Copper	80	81	78		79	78		71
Tin	18	17	20		23	22		26
Antimony	2	2	2	Zinc	6	..	Zinc	1.8
							Iron	1.2
	100	100	100		100	100		100.0

The last is the alloy of the famous "silver-bell" of Rouen.

For pump-buckets, valves and cocks:

Copper	88	88	86.8
Tin	10	10	12.4
Zinc	1.75	2	0.8
Lead	0.25	..	..
	100.00	100	100.0

For hammers (for use on finished work): copper, 98; tin, 2. This alloy will forge like copper; it may be hardened by adding more tin.

For wagon axle bearings:

Copper	78	Copper	25
Tin	20	Cast-iron	70
Zinc	2	Tin	5
	100		100

The best brasses may be taken, for general purposes, as accepted by good makers, as follows:

For turned work:

Copper	61.6	66.5	74.5	79.5
Zinc	35.3	33.0	25.0	20
Tin	0.5	0.5	0.5	0.5
Lead	2.5	....	....	....
	100.0	100.0	100.0	100.0

The richer colors are given by the higher proportions of copper. The official recipe for work in French dock-yards is:

Copper	65.80	76.0	85
Zinc	31.80	24.0	15
Tin	0.25	....	..
Lead	2.60	0.5	1
	100.45	100.5	101

The hardest compositions are used for the smallest pieces. These are used in the ornamentation of engines, for brass straps, for hinges, and for pulley-sheaves.

Cheap alloys for bearings have been made of the following wide range of composition:

Copper	56	5.5	58
Tin	28	19.5	28
Zinc	16	80.0	14
	100	100.0	100

The first—Fenton's alloy—is said to wear well, not to be specially liable to heating, and to be very durable. The last —Margraff's alloy—is of similar quality. The second composition is much cheaper and lighter, and takes the place of the white alloys used in bearings.

Other white metals for similar uses are:

Copper	4	1	9	1
Tin	96	50	73	50
Antimony	8	5	18	5
	108	56	100	56

The first is used for common bearings; the latter for small bearings carrying light loads. Still other alloys are:

Tin	..	..	18.0
Lead	32	85	4.5
Zinc	18	..	75.0
Antimony	50	15	2.5
	100	100	100.0

The following are British (Woolwich) official recipes:

Copper	20	6	7	8	10
Tin	2	1	1	1	1
Zinc	1		.	.	..
	23	7	8	9	11

which are used as hard as metals are desired.

Kingston's metal, formerly much used for bearings, is made by melting 9 parts copper with 24 parts tin, remelting, and adding 108 parts tin, and finally 9 parts of mercury.

An alloy of 90 per cent. tin, 8 per cent. antimony, and 2 per cent. copper has been found excellent for crank and connecting-rod bearings on the Moscow and Nishni Railroad of Russia. On the Kursk-Charcow-Asow Railroad an alloy of 78.5 per cent. tin, 11.5 antimony, and 10 copper is considered very superior for pivots of all kinds, slide valves, eccentrics, stuffing-boxes, etc. The Swiss Nordöstbahn Company, in ordering locomotives recently, required the following preparation as a composition for axle journals: 10 parts of antimony added to 10 parts of melted copper, with 80 parts of tin added, and the alloy run into bars, to be remelted for use.

Bronze for bearings of axles, as made for the Great Western Railway of Great Britain, has been given the following

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composition: copper, 22; tin, 67; antimony, 11. French railways have used copper, 82; tin, 18; and Italian roads have used an alloy of tin, 38; antimony, 25; and lead, 37, for a lining metal. The Perkins alloy for piston rings consists of copper 75, tin 25, and is used in steam engines worked at very high pressure without lubrication.

143. **A Classified Table of the Alloys** has been compiled, as follows, by Bolley,* from the works of Bischoff † and other authorities, which presents the most complete compendium of the compositions used by the engineer and in the trades, known to the Author. This table is here given, omitting the alloys of the "precious" metals.

TABLE XXXI.

CLASSIFIED LISTS OF ALLOYS.

Alloys of Copper.

BRASS.

RED BRASS.

	COPPER.	ZINC.	
Pinchbeck	93.6	6.4	
Austrian journal boxes	92.5	7.5	
French Oreide	90.0	10.0	
" "	85.5	14.5	
Tournay alloy for ornaments	82.54	17.46	
English " " "	86.38	13.62	
Halberland alloy for imitation	87.0	13.0	
Mannheim gold, 0.62 per cent. tin and	89.44	9.14	
Tissier's alloy for buttons	97.0	2.0	Arsenic, 1.0
Tombac, common	71.5	28.5	
Arcet tombac, gilded	82.3	17.7	
Hegermühle tombac, Paris	85.3	14.7	
Red " "	92.0	8.0	
" " Vienna	97.8	2.2	
Leaf " Lüdenscheid	99.15	0.85	
" " "	84.21	15.79	
Bronze powder	84.0	16.0	
Leaf bronze	84.6	15.4	
" " ("gold") Vienna	77.9	22.1	

* Recherches Chimiques. Paris, 1869.

† Das Kupfer und seine Legirungen. Berlin, 1865.

TABLE XXXI.—*Continued.*

YELLOW BRASS.

	COPPER.	ZINC.	
Malleable brass	70.1	29.9	
" " Lüdenscheid	72.73	27.27	
Chrysorin	72.0	28.0	
Common brass	66.6	33.4	
Bobierre " Muntz metal	74.62	25.38	
" " low grade	59.5	40.5	
Gedge Aich metal, for sheathing	60.0	38.2	Iron, 1.8
Brass wire, good	65.4	34.6	
" " low grade	65.5	32.5	Lead, 2.0
" " " "	64.2	33.1	Lead and tin, 2.7
" ductile (Storer)	54.0	46.0	
Mecht's malleable brass	65.24	34.76	
Malleable and ductile brass	60.26	39.74	
" " "	66.0	34.0	
Kessler's " "	58.3	41.7	
Chrysorin, Rauchenberger's	66.7	33.3	
Bristol brass	75.7	24.3	
" "	60.8	39.2	
Mosaic gold	65.3	34.7	
Brass solder	61.25	38.75	
" " strong	33.34	66.64	

WHITE METAL.

	COPPER.	ZINC.
Bath alloy	55.0	45.0
" Platine "	43.0	57.0
Button alloy, Lüdenscheid	20.0	80.0
Mallett " preservative of iron	25.4	74.6

BRONZE-LIKE BRASS.

Tombac Alloys.

	COPPER.	ZINC.	TIN.
French tombac	80.0	17.0	3.0
Golden bronze	89.97	9.96	0.07
" " for ornaments	82.0	17.5	0.5

TABLE XXXI.—*Continued.*

Statuary Bronze.

	COPPER.	ZINC.	TIN.	LEAD.	IRON.	NICKEL.	ANTIMONY.
The Shepherd, Potsdam Palace.	88.68	1.28	9.20	0.77	....	....	....
Bacchus, Potsdam Palace	89.34	1.63	7.50	1.21	0.18	....	....
Germanicus, Potsdam	89.78	2.35	6.16	1.33	....	0.27	....
Augsburg bronze.............	89.43	....	8.17	1.05	0.34	0.19	....
" "	94.74	0.54	1.64	0.24	....	0.71	0.84
Munich "	77.03	19.12	0.91	2.29	0.12	0.43	....
" "	92.88	0.44	4.18	2.31	0.15	....	....
Keller's Louis XIV...........	91.40	5.53	1.70	1.37	....	....	....
Henry IV., Paris............	89.62	4.20	5.70	0.48	....	....	....
Napoleon I., "	75.00	20.00	3.00	2.00	....	....	....
Column Vendome, Paris	89.20	0.50	10.20	0.10	....	....	....

For Small Objects to be Gilded. Arcet.

Copper................................	63.7 to 72.43
Zinc	33.55 to 22.75
Tin	2.50 to 1.87
Lead................................	0.25 to 2.97

Leaf and Wire Brass.

	COPPER.	ZINC.	TIN.	LEAD.
English wire.................	70.29	29.36	9.28	0.17
Augsburg wire	71.89	27.63	....	0.85
Jemmapes leaf................	64.60	33.70	1.40	0.20
Aix la Chapelle leaf...........	64.80	32.80	2.00	0.40

White Alloys for Buttons.

	COPPER.	ZINC.	TIN.	LEAD.
Bristol Alloy	57.9	36.8	5.3	
" "	61.12	36.11	2.77	
Jackson's Alloy............	63.88	30.55	5.55	
" "	63.01	35.61	1.39	
"Bidery"	48.50	33.32	6.06	12.12
"Gold"	58.71	33.03	5.50	2.75

TABLE XXXI.—*Continued.*

Pewter.

	COPPER.	ZINC.	TIN.	LEAD.
Berthier's alloy	71.9	24.9	1.2	2.0
Alloy to be cast and worked.	64.2	34.6	0.2	2.0
" " " " "	61.6	35.3	0.6	2.5
" " " " gilt	63.7	33.5	2.5	0.3
" " " " "	64.5	32.4	0.2	2.9
" for clock work	60.66	36.88	1.35	0.74
" " "	66.06	31.46	1.43	0.88
Bruns, Oreide, S. G. 8.79	68.21	31.52	0.48	0.24
Oker brass (Harz)	64.24	37.27	0.59	0.12

Sheathing Nails.

	COPPER.	ZINC.	TIN.	LEAD.
For ships	63.60	25.00	2.60	8.80

Solder (Strong).

	COPPER.	ZINC.	TIN.	LEAD.
Yellow, hard solder	53.30	43.10	1.30	0.30
Nearly white, soft	44.00	49.90	3.30	1.20
White, very soft	57.44	27.98	14.58	....

ALLOYS FOR BEARINGS AND CASTINGS.

Copper-Tin-Zinc.

	COPPER.	ZINC.	TIN.
Locomotive and Railroad work:			
Eccentric strap (Dutch)	85.25	2.00	12.75
Piston rings (Seraing)	89.00	9.00	2.00
Axle bearings (French)	82.00	8.00	10.00
" " hard (G. B.)	87.05	5.07	7.88
" " common (Fr.)	78.00	2.00	20.00
" " " "	97.20	2.50	
" " Lafond's alloys	80.00	2.00	18.00
Whistles (dull) " "	81.00	2.00	17.00
Hard bearings " "	82.00	2.00	16.00
Castings for pumps, etc., Lafond's alloys	88.00	2.00	10.00
Eccentric straps " "	84.00	2.00	14.00
Stuffing-boxes (Belgian)	90.20	6.30	3.50
Pistons and rods	74.10	22.20	3.70
Parts to be cast upon iron	78.70	15.00	6.30
Gearing	88.80	2.70	8.50
Weights, philosophical apparatus	90.00	2.00	8.00
Mathematical instruments, standards	82.10	5.10	12.80

TABLE XXXI.—*Continued.*

	COPPER.	ZINC.	TIN.	ANT.	LEAD.
Small, fine coatings	79.10	7.80	13.10	......	......
" " "	83.70	9.30	7.00	......	......
Medals	97.00	2.00	1.00	......	......
Coins (Fr.)	95.00	1.00	4.00	......	......
Bronze to take solder	87.00	......	12.00	1.00	......
Steam whistles	80.00	......	18.00	2.00	......
Mirrors	82.74	......	......	8.23	9.03
"Steam metal"	85	5	7	3	......
" " (hard)	90	3	4	3	......

	COPPER.	ZINC.	TIN.	LEAD.	ANT.
Machinery brass	74.40	8.90	9.50	7.10	......
Bearings of engines	79.00	5.00	8.00	8.00	......
Pistons " "	84.00	8.40	2.90	4.70	......
Parts at high temperature	90.70	5.30	2.70	1.30	......
Golden colored	74.00	10.00	1.00	15.00	......
" " harder	70.00	10.00	10.00	10.00	......
Parts under heavy friction (Lafond)	83.00	1.50	15.00	0.50	......
Sheathing nails (Percy)	63.60	24.60	2.60	8.70	......
Chinese white metal	72.50	14.30	4.70	18.50	......
Bearings and valves, etc	80.00	......	16.00	2.00	2.00

Alloys Containing Iron.

	COPPER.	ZINC.	TIN.	LEAD.	IRON.
Bearings of locomotives (G. B.)	89.00	7.80	2.40	......	0.80
" " " (German)	81.17	15.20	......	14.60	0.90
" " " durable	73.50	9.50	9.50	7.50	0.50
Piston-rings of " (Stephenson)	84.00	8.30	2.90	4.30	0.40

Alloys Principally Copper and Tin.

	COPPER.	TIN.	ZINC.	LEAD.	NICKEL.	IRON.
Bell metal	78 to 80	22 to 20	......	......	......	......
" "	60.00	40.00	......	......	......	......
" " sonorous	75.20	24.80	......	......	......	......
" of Reichenhall, S.G. 8.7	80.00	20.00	......	......	......	......
" metal, white silvery	78.00	22.00	......	......	......	......
" " Herbohn	75 to 73	25 to 27	......	......	......	......
" " "	60.00	35.00	5.00	......	......	......
" " "	71.43	26.40	2.17	......	......	......
" " Darmstadt	73.94	21.67	......	1.19	2.11	0.17
" " "	72.52	21.06	......	2.14	2.66	0.05

TABLE XXXI.—*Continued.*

Bearings: Copper, Tin, Lead.

	COPPER.	TIN.	LEAD.*
Ordinary bronze	87.50	12.50	....
"Arsenic" bronze "A"	89.20	10.00	....
" " "B"	82.20	10.00	7.00
" " "C"	79.70	10.00	9.50
"Phosphor" bronze (standard)	79.70	10.00	9.60
Bronze "K"	77.00	10.50	12.50
" "B."	77.00	8.00	15.00
"Plastic" bronze "A"	69.00	10.00	21.00
" " "B"	65.00	5.00	30.00
" " "C"	48.00	....	47.00

* Wear increases with lead.—Dr. Dudley.

Mirrors.

	COPPER.	TIN.	ZINC.	ARS.	PLAT.	SILVER.	NICKEL.	LEAD.	ANT.
Composition Cu_4Sn.....	68.21	31.70	.....	.....	.....	.....	....	....	....
Mudge's alloy..........	68.82	31.18	.....	.....	.....	.....	....	....	....
Laderig's alloy (excellent).	69.00	28.70	.....	.....	.....	.....	....	....	....
Good lustre (yellowish)..	50.00	28.60	21.40	.....	.....	.....	....	....	....
Edward's alloy..........	63.30	32.20	......	1.60	.....	.....	....	....	....
" "	69.80	25.10	2.60	2.40	.....	.....	....	....	....
Cooper's alloy..........	57.80	27.30	3.60	1.20	10.80	.....	....	....	....
Richardson's alloy......	65.30	30.00	0.70	2.00	.....	2.00	....	....	....
Sollit's "	64.60	31.30	......	.....	.....	.....	4.10	....	....
Chinese mirrors (Elsner).	80.80	......	......	.....	.....	.....	....	9.10	8.40

Machinery Bronze.

	COPPER.	TIN.
Malleable bronze (Lafond)............................	98.04	1.96
Eisler's yellow bronze (golden), hard and elastic........	94.10	5.90
Gearing..	91.30	8.70
Köchlin's alloy for bearings...........................	90.00	10.00
Seraing " " "	86.00	14.00
Carriage wheel " "	84.00	16.00
Dies work well on the bronze..........................	83.30	16.70

TABLE XXXI.—*Continued.*

GERMAN SILVER, ETC.

Nickel Alloy.

	COPPER.	NICKEL.
United States coin	82.88	18.15
Belgian "	75.00	25.00
U. S. Alloys in recent coinage :		
First legal standard	85	12
Recent coinage	75	25

German Silver.

	COPPER.	ZINC.	NICKEL.
Common formula	55.00	25.00	20.00
Wagner's "	50.66	19.31	13.18
Chinese alloy (Keferstein)	26.30	36.80	36.80
" " poor (Fyfe)	43.80	40.60	15.60
" tutenag, amber-colored, hard	45.70	39.90	17.40
Sheffield alloys :			
Commcn alloy, yellow	59.30	25.90	14.80
Silver, white	55.20	24.10	20.70
Electrum, bluish	51.60	22.60	25.80
Hard alloy can be worked cold	45.70	20.00	31.30
Berlin alloys (Schubarth) :			
Richest	52.00	26.00	22.00
Medium	59.00	30.00	11.00
Lowest	63.00	31.00	6.00
French alloy (Arcet)	50.00	31.30	18.70
" " "	50.00	30.00	20.00
" " (Chaval)	58.30	25.00	16.70
Austrian alloy, table-ware (Gersdorff)	50.00	25.00	25.00
" " " "	55.60	22.20	22.20
" " malleable "	60.00	20.00	20.00
Fricke's " bluish-yellow, hard	55.50	39.00	5.50
" " pale " ductile	62.50	31.20	6.30
" " silvery, hard	50.00	18.80	31.20
" " harder	59.00	30.00	10.00

Copper, Tin, Nickel.

	COPPER.	TIN.	NICKEL.
For castings	52.50	28.80	17.70
For bearings	50.00	25.00	25.50

TABLE XXXI.—*Continued.*

ALLOYS LARGELY GERMAN SILVER.

	COPPER.	ZINC.	NICKEL.	IRON.	COBALT.
Chinese Packfong, S. G. 8.432	40.40	25.40	31.60	2.60	....
White alloy, hard and brittle	48.80	24.40	24.40	2.40	....
" " " " "	53.00	23.00	22.00	2.00	....
Parisian "Maillechort." S. G., 7.18	65.40	13.40	16.80	3.40	....
Sheffield alloy (Ger. Silver)	58.20	25.50	13.30	3.00	....
English " " "	60.00	17.80	18.80	....	3.40
" " elastic	57.00	25.00	15.00	....	3.00

ALLOYS CONTAINING LITTLE COPPER.

Alloys Rich in Tin.

	COPPER.	TIN.	ANTIMONY.
Westphalian alloy	7.00	82.00	11.00
Magdeburg-Halberstadt alloy	11.00	74.00	15.00
Berlin alloy	5.00	85.00	10.00
Antifriction alloy (Karmarsch)	3.70	88.89	7.41
" " "	6.25	81.25	12.50
" " "	9.76	70.73	19.51
" " "	21.44	71.41	7.14
" " (English)	9.75	70.73	19.52
" " "	7.80	76.70	15.50
" " "	2.00	72.00	26.00
Bavarian alloy	2.00	90.00	8.00

Alloys Rich in Zinc.

	COPPER.	TIN.	ZINC.
Pump cocks	7.00	21.00	72.00
Rolls for print-works	5.00	15.80	78.30
Bearings	4.20	29.30	66.50

	COPPER.	TIN.	ZINC.	ANTIM.
Fenton's antifriction alloy	5.50	14.50	80.00	.....
" " "	5.50	.....	80.00	14.50
Bearing metal (Manchester)	5.69	17.47	76.14	.....
" " English	7.40	14.90	67.70	.....
" " (Chemnitz)	5.00	.....	8.50	10.00

TABLE XXXI.—*Continued.*

Alloys Principally Iron.

	COPPER.	TIN.	ANTIM.	IRON.
Hartshorn's alloy	8.35	1.38	1.38	88.89
French antifriction alloy	25.00	5.00	....	70.00

Alloy Largely Lead.

	COPPER.	LEAD.	ANTIM.
Bearings for railway work	8.00	80.00	12.00

Alloy of Zinc and Lead, etc.

	COPPER.	TIN.	ZINC.	LEAD.
Soft metal	3.00	15.00	40.00	42.00

Alloy Principally Tin and Antimony.

	COPPER.	TIN.	ANTIM.
White alloy	22.00	33.30	44.50

BRITANNIA METAL.

Alloys Principally Tin.

	COPPER.	TIN.	ANTIMONY.
Tournay's alloy	9.00	91.00	.....
For castings (Baumgartel)	1.80	81.90	16.30
Lüdenscheidt Britannia	4.00	72.00	24.00
Birmingham " (sheet)	1.50	90.60	7.80
" " (cast)	0.09	90.71	9.20
Asberry's "	2.80	77.80	19.40

	ANTIMONY.	COPPER.	TIN.	ZINC.	BISMUTH.	LEAD.
Hard spelter	7.50	1 90	90.00	.....	.....	.....
Alger's alloy, white, sonorous	1.00	5.00	94.00	.....	.....	.....
Beckmann's blue bronze	2.91	0.16	93.93	.....	.....	.....
Alger's alloy, hard, white, sonorous	.....	2.10	97.30	.....	0.60	.....
" " " " "	.....	2.40	97.00	.....	0.60	.....
White metal	.....	9.00	67.70	24.30	.....	.....
For tinning iron	.....	5.10	76.90	10.30	7.70	.....
Common spelter	.....	4.40	82.30	1.50	.....	11.80
Pewter	.....	5.70	81.20	1.60	.....	11.50
Britannia (Karmarsch)	6.30	3.10	90.10	0.50	.....	.....
" (Köller)	10.40	1.00	85.70	2.90	.....	.....
Pewter (leaf)	7.60	1.80	89.30	.....	1.80	.....
" "	1.70	6.80	84.70	.....	6.80	.....

TABLE XXXI.—*Continued.*

	COPPER.	TIN.	ANTIM.	ZINC.	BISMUTH.
Britannia (Karmarsch)....	3.60	85.00	5.00	1.40	5.00
" fine (Wagner)...	0.81	85.64	9.66	3.06	0.83
Pewter, often of	1.60	83.30	6.60	6.60	1.60

Alloys Principally Zinc.

	COPPER.	TIN.	ZINC.	LEAD.
Hamilton's alloy	3.50	.....	93.40	3.10
" " (loss 3 per cent. Zn) .	3.60	.....	93.20	3.20
Heine's "	11.40	1.40	84.30	2.90
" " (loss 3 per cent. Zn) .	11.80	1.50	83.80	2.90

Alloys Principally Tin and Zinc.

	COPPER.	TIN.	ZINC.	IRON.
No. 1	2.25	64.00	33.50	1.25
No. 2	3.00	48.00	48.00	1.00

Alloy Principally Antimony.

	COPPER.	TIN.	ZINC.	ANTIM.
White alloy, brittle, for castings..	10.00	20.00	6.00	64.00

Type Metal.

	COPPER.	LEAD.	ANTIM.	TIN.	NICKEL.	COBALT.	BISMUTH.
Best..	4.62	57.80	17.34	11.56	4.62	2.90	1.16

	ZINC.	TIN.	LEAD.	COPPER.
Ehrhardt's..................	89.00	4.00	3.00	4.00
"	93.00	3.00	3.00	2.00

ALLOYS FREE FROM COPPER.

Tin and Zinc.

	TIN.	ZINC.
Imitation silver leaf........................	1.00	11
Type metal (Johnson)	59	33

TABLE XXXI.—*Continued.*

Tin and Lead.

	TIN.	LEAD.
Solder	1	1
" weak	2	1
" hard and strong	1	2

Tin and Antimony.

	TIN.	ANTIM.
Britannia	9	1
Antifriction metal (Karmarsch)	3–7	1
Type " (Johnson)	75	25

Mercury and Tin.

	TIN.	MERCURY.
Amalgam for mirrors	70	30
" " curved mirrors	4	1

Lead and Antimony.

	LEAD.	ANTIM.
Type metal	16	1
" "	4	1

Lead and Arsenic.

	LEAD.	ARSENIC.
Shot metal	100	0.4–3.0

Bismuth and Mercury.

	BISMUTH.	MERCURY.
Amalgam for glass globes	80	20

TRIPLE ALLOYS.

Tin, Lead, and Bismuth.

	TIN.	LEAD.	BISMUTH.
Newton's fusible metal	3	5	8
Rose's " "	1	1	2
Solder	1–4	1–4	1
Printing rolls	3	2	1
Perrotine's alloy	1	1	1

Antimony, Lead, and Zinc.

	ANTIM.	LEAD.	ZINC.
Lafond's alloy for bearings	50	30	20

TABLE XXXI.—*Continued.*

Tin, Zinc, and Mercury.

	TIN.	ZINC.	MERCURY.
Kienmeyer's electrical amalgam	1	1	2
Singer's " "	1	2	3.5–6

OTHER ALLOYS.

Tin, Lead, Bismuth, and Mercury.

	TIN.	LEAD.	BIS.	MER.
Amalgam for curved mirrors	1	1	1	9
" " anatomical preparations.	7	4	12	20

Tin, Lead, Bismuth, and Antimony.

	TIN.	LEAD.	BIS.	ANTIM.
Queen's alloy	9	1	1	1
Perrotine's alloy for rolls	48	32.5	9	10.5

144. **Bronzing** is the process of staining or otherwise coloring the surface of brass, in imitation of bronze—usually imitating old bronze. The methods of bronzing and the bronzing liquids are different for different purposes and as practised in different localities and different trades. Brass is very seriously subject to oxidation, and when polished soon loses its brightness and its color. Polished surfaces are often protected by the process of lacquering (to be presently described), but the permanent preservation of the polish is rarely possible and a coloring or bronzing is very commonly resorted to. It was formerly customary to give scientific apparatus a fine polish and to cover this surface with lacquer; it is now becoming more generally customary to bronze them or to stain them either black or brown; these are, in fact, but modifications of one process.

To obtain the golden orange color characteristic of brasses rich in copper, the piece may be polished and immersed in a warm bath of the neutral solution of crystallized acetate of copper for a moment, washing in clean water and rubbing dry and bright. The chloride of antimony gives a dark rich violet color, if the article is heated to nearly the boiling point of water; sulphate of copper gives a watered surface and copper nitrate a black.

Larkin used the hydrochlorate of copper with a little free nitric acid, largely diluted, to produce a dark bronze; a little acetic acid added to the solution of the same salt gave a copper color, and the patina of antique bronze was imitated by adding ammonia solution in large amount, or a quantity of sal ammoniac.

"Bronze" paints are used for giving to the surface of iron, or of any other material, the appearance of bronze; they have a great variety of composition; some are composed of filings, or powder, of brass mixed in some oil paint which does not conceal the color of the bronze.

Graham's bronzing liquids, as published in 1861,* have a great range of composition and of application as follows:

TABLE XXXII.

BRONZING LIQUIDS.

To be used for Brass by simple Immersion.

No.	Water.	Nitrate of iron.	Perchloride of iron.	Permuriate of iron.	Nitrate of copper.	Tersulphide of arsenic.	Muriate of arsenic.	Potash solution of sulphur.	Pearlash solution.	Cyanide of potassium.	Ferrocyanide of potassium sol.	Sulphocyanide of potassium.	Hyposulphite of soda.	Nitric acid.	Oxalic acid.	
	pt.	dr.	dr.	pt.	oz.	gr.	oz.	dr.	dr.	oz.	pt.	dr.	dr.	dr.	oz.	
1	1	5	..	..	..	..	..	..	..	..	..	..	..	..	..	Brown, and every shade to black.
2	1	..	5	..	..	..	..	..	..	..	..	..	..	..	..	" "
3	1	16	..	..	..	..	..	..	..	..	..	..	16	..	..	Brown, and every shade to red.
4	1	..	..	..	..	..	..	..	..	..	..	..	16	1	..	" "
5	1	..	..	..	1	..	..	..	..	..	..	..	..	..	1	Brownish red.
6	..	..	..	..	..	..	..	..	..	..	1	..	..	3	..	"
7	1	..	..	..	..	..	..	..	..	1	..	..	..	4	..	Dark brown.
8	1	..	..	..	..	30	..	..	6	..	..	..	..	..	..	Yellow to red.
9	1	..	..	..	..	..	..	1	..	..	..	..	..	..	..	Orange.
10	2	..	..	1	..	..	..	..	..	..	..	..	..	..	..	Olive-green.
11	1	..	5	..	..	..	..	..	..	..	..	2	..	..	..	Slate.
12	1	..	..	..	..	..	..	..	..	..	..	..	20	..	..	Blue.
13	1	..	..	..	..	..	1	..	..	..	..	..	..	..	..	Steel-gray.
14	1	..	..	2	..	..	10	..	..	..	..	..	..	..	..	Black.

In the preparation of No. 5, the liquid must be brought to boil and cooled. In using No. 13, the heat of the liquid must not be under 180° F. No. 6 is slow in action, taking an hour to produce good results. The action of the others is, for the most part, immediate.

* Brass Founders' Manual, Lond. 1870.

TABLE XXXII.—*Continued.*

To be used for Copper by simple Immersion.

No.	Water.	Nitrate of iron.	Sulphate of copper.	Sulphide of antimony.	Sulphur.	Muriate of arsenic.	Pearlash.	Sulphocyanide of potassium.	Hyposulphite of soda.	Hydrochloric acid.	
	pt.	dr.	oz.	dr.	dr.	dr.	oz.	dr.	oz.	dr.	
15	1	5	..	..	..	..	..	..	..	..	Brown, and every shade to black.
16	1	5	..	..	..	..	..	2	..	..	Dark-brown drab.
17	1	..	1	..	..	..	..	..	1	2	" "
18	1	..	..	2	..	..	1	..	..	..	Bright red.
19	1	..	..	..	1	..	1	..	..	..	Red, and every shade to black.
20	1	..	..	..	..	1	..	..	..	..	Steel-gray, at 180° F.

For Zinc.

No.	Water.	Nitrate of iron.	Protochloride of tin.	Sulphate of copper.	Muriate of iron.	Muriate of Lead.	Pearlash.	Sulphocyanide of potassium.	Hyposulphite of soda.	Garancine infusion.	Logwood infusion.	
	pt.	dr.	dr.	dr.	dr.	oz.	oz.	dr.	dr.			
21	1	5	..	..	..	..	..	..	..	..	..	Black.
22	1	..	1	..	..	..	..	..	..	..	..	"
23	1	..	1	..	..	..	..	1	..	..	..	Dark gray.
24	2	..	..	1	1	..	..	..	..	..	..	"
25	..	..	..	..	..	*	..	..	..	..	..	"
26	2	..	..	..	1	..	..	..	..	..	..	Green-gray.
27	..	..	..	..	..	..	..	..	..	×	..	Red —— boil.
28	1	..	..	4	..	..	4	..	..	..	..	Copper color. Plates so c ∧ z.
29	1	..	..	8	..	..	..	..	8	..	..	Copper color, with agitation.
30	..	..	..	..	..	..	..	..	..	..	×	Purple —— boil.

145. **Lacquering** is the process of covering a polished surface of brass or of other metal with a transparent or translucent coating, which, while protecting it from oxidation and

* Made to the consistency of cream.

discoloration, does not wholly conceal it. It is a process of varnishing polished metal. It is applied also to the surfaces of bronzed objects. Lacquer is a solution, usually, of some vegetable gum or resin in alcohol or other effective colorless solvent. In its application, great care is taken to keep the piece to be lacquered warm and of uniform temperature, to apply the solution quickly, smoothly and uniformly. The usual solution is " shellac " in alcohol, and the best can, as a rule, be made with the " stick " lac. It may be colored by any permanent transparent alchoholic solution giving the desired tint. The red coloring matters are, usually, dragon's blood, red saunders or annotto; the yellow are gamboge, sandarac, saffron, turmeric or aloes. The following is Graham's table of lacquers:

TABLE XXXIII.

LACQUERS.

				SOLUTIONS.					REDS.			YELLOW.					
No.	Shellac.	Mastic.	Canada Balsam.	Spirits of wine.	Pyro-acetic ether.	Spirits of turpentine.	Turpentine varnish.	Simple pale lacquer.	Dragon's blood.	Annotto.	Saunders.	Turmeric.	Gamboge.	Saffron.	Cape Aloes.	Sandarac.	
	oz.	dr.	dr.	pt.	oz.	dr.	oz.	pt.	dr.	dr.	gr.	dr.	dr.	dr.	dr.	dr.	
1	4	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	Strong simple.
2	1	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	Simple pale.
3	1	..	..	1	..	..	..	..	..	..	..	..	1	..	3	..	Fine pale.
4	1	..	..	1	..	..	..	..	..	..	..	1	1	2	..	..	"
5	1	..	..	2	..	..	..	..	1	1	..	..	16	4	..	8	"
6	2	..	..	2	..	..	..	..	1	8	..	32	..	..	..	8	Plate gold.
7	2	..	..	1	..	..	..	..	..	..	..	..	2	..	4	..	Pale yellow.
8	5	..	..	3	30	..	..	..	..	..	..	..	..	..	..	..	" Ross's.
9	..	..	..	..	..	..	..	1	..	1	..	4	..	..	..	..	Full yellow.
10	3	..	..	1	..	..	..	..	..	2	..	16	..	2	..	..	Gold.
11	3	..	..	4	..	..	6	..	..	..	..	64	6	..	..	14	"
12	1	..	..	1	..	..	..	..	..	..	..	20	..	..	2	5	"
13	3	..	..	1	..	..	..	..	4	..	..	16	..	..	..	..	Deep gold.
14	3	..	..	1	..	..	..	..	4	..	..	1	..	..	..	..	"
15	3	..	..	1	..	30	..	..	40	..	12	10	..	..	..	..	"
16	..	..	..	..	..	..	..	1	8	32	..	..	..	..	..	..	Red.
17	1	..	..	..	..	..	1	..	8	24	..	..	..	..	..	27	"
18	15	30	30	6	..	..	..	..	20	..	..	60	..	10	..	..	Tin lacquer.
19	..	..	..	..	..	..	..	1	..	..	..	4	1	..	..	..	Green, for bronze.

The union of red with yellow produces a fine orange color.

The lacquers are kept in carefully stoppered bottles, and it is better that they should be of opaque material, or of glass impenetrable by actinic light capable of altering them; yellow glass is sometimes used. When in use, they are poured into dishes of convenient size and form and are laid on with a thin, wide flat brush.*

"Clouding" is performed by pouring on the surface a mixture of fine charcoal dust in water, stirring it to obtain the pattern, and then drying. The work is finally lacquered.

To Anneal Brass or Copper.—In working brass and copper, it becomes hard, and if hammered may crack. To prevent cracking, the piece must be heated to a dull red heat and plunged in cold water; this will soften it so it can be worked. One must be careful not to heat brass too hot, or it will fall to pieces. The piece should be annealed frequently during the process of hammering.

TABLE OF SOLDERS. (See p. 221.)

[*Mechanical World.*]

No.	Name.	Compositions.	Flux.	Fluxing Point.
1	Plumbers' coarse solder	Tin, 1; lead, 3	R	800° Fahr.
2	Plumbers' sealed solder	Tin, 1; lead, 2	R	441°
3	Plumbers' fine solder	Tin, 1; lead, 2	R	370°
4	Tinners' solder	Tin, 1½; lead, 1	R or Z	334°
5	Tinners' fine solder	Tin, 2; lead, 1	R or Z	340°
6	Hard solder for copper, brass, iron	Copper, 2; zinc, 1	B	
7	Hard solder for copper, brass, iron	Good, tough brass, 5; zinc, 1.	B	
8	Hard solder for copper, brass, iron more fusible than 6 or 7	Copper, 1; zinc, 1	B	
9	Hard solder for copper, brass, iron	Good tough plate brass	B	
10	Silver solder for jewellers	Silver, 19; copper, 1; brass, 1	B	
11	Silver solder for plating	Silver, 2; brass, 1	B	
12	Silver solder for silver, brass, iron	Silver, 1; brass, 1	B	
13	Silver solder for steel joints	Silver, 19; copper, 1; brass, 1	B	
14	Silver solder more fusible	Silver, 5; brass, 5; zinc, 5	B	
15	Gold solder	Gold, 12; silver, 2; copper, 4	B	
16	Bismuth solder	Lead, 4; tin, 4; bismuth, 1	R or Z	320°
17	Bismuth solder	Lead, 3; tin, 3; bismuth, 1	R or Z	310°
18	Bismuth solder	Lead, 2; tin, 2; bismuth, 1	R or Z	292°
19	Bismuth solder	Lead, 2; tin, 1; bismuth, 2	R or Z	236°
20	Bismuth solder	Lead, 3; tin, 5; bismuth, 3	R or Z	202°
21	Pewterers' solder	Lead, 4; tin, 3; bismuth, 2	R or Z	

Abbreviations: R, resin; B, borax; Z, chloride of zinc.

* *Vide* Part I, § 196, p. 335, for lacquers and browning liquids for fire-arms, etc.

CHAPTER VIII.

STRENGTH, ELASTICITY AND DUCTILITY OF THE NON-FERROUS METALS.

146. **The Strength of Non-ferrous Metals** and other mechanical properties have not attracted as much attention as the engineer would desire. Investigations have been few in number, generally very incomplete, and as a rule unfruitful, in comparison with those relating to iron and steel.

In recording and discussing experimental work on the non-ferrous metals and their alloys, the system and nomenclature adopted will be that employed in the study of the strength of iron and steel. The following summary will here suffice.* Following it, will be given a statement of the results of experiments made upon the non-ferrous metals, succeeded by chapters describing investigations of the strength and elasticity of their alloys, and the conditions modifying strength.

147. **The Resistance of Metal** to rupture may be brought into play by either of several methods of stress, which have been thus divided by the Author:

Longitudinal............	Tensile: resisting pulling force. Compression: resisting crushing force.
Transverse..............	Shearing: resisting cutting across. Bending: resisting cross breaking. Torsional: resisting twisting stress.

* Abridged and adapted from Part II., Chapter IX. For the theory of the elasticity and strength of materials, consult "Wood's Resistance of Materials," published by J. Wiley & Sons, and Burr's work on the same subject issued by the same publishers.

When a load is applied to any part of a structure or of a machine it causes a change of form, which may be very slight, but which always takes place, however small the load. This change of form is resisted by the internal molecular forces of the piece, *i.e.*, by its cohesion. The change of form thus produced is called *strain*, and the acting force is a *stress*.

The *Ultimate Strength* of a piece is the maximum resistance under load—the greatest stress that can exist before rupture. The *Proof Strength* is the load applied to determine the value of the material tested when it is not intended that observable deformation shall take place. It is usually equal, or nearly so, to the maximum elastic resistance of the piece. It is sometimes said that this load, long continued, will produce fracture; but, as will be seen hereafter, this is not necessarily, even if ever, true.

The *Working Load* is that which the piece is proportioned to bear. It is the load carried in ordinary working, and is usually less than the proof load, and is always some fraction, determined by circumstances, of the ultimate strength.

A *Dead Load* is applied without shock, and, once applied, remains unchanged, as, *e.g.*, the weight of a bridge; it produces a uniform stress. A *Live Load* is applied suddenly, and may produce a variable stress, as, *e.g.*, by the passage of a railroad train over a bridge.

The *Distortion* of the strained piece is related to the load in a manner best indicated by strain diagrams. Its value as a factor of the measure of shock-resisting power, or of resilience, is exhibited in a later article. It also has importance as indicating the ductile qualities of the metal.

The *Reduction of Area of Section* under a breaking load is similarly indicative of the ductility of the material, and is to be noted in conjunction with the distortion.

E.g. A considerable reduction of section with a smaller proportional extension would indicate a lack of homogeneousness, and that the piece had broken at the soft part of the bar. The greater the extension in proportion to the reduction of area in tension, the more uniform the character of the metal.

148. Factors of Safety.—The ultimate strength, or maximum capacity for resisting stress, has a ratio to the maximum stress due to the working load, which, although less in metal than in wooden or stone structures, is, nevertheless, made of considerable magnitude in many cases. It is much greater under moving than under steady "dead" loads, and varies with the character of the material used. For machinery it is usually 6 or 8; for structures erected by the civil engineer, from 5 to 6. The following may be taken as minimum values of this "factor of safety for the non-ferrous metals:"

MATERIAL.	LOAD.		SHOCK.	
	Dead.	Live.		
Copper and other soft metals and alloys.............	5	8	10 +	Ratio of Ultimate Strength to Working Load.
The brittle metals and alloys.	4	7	10 to 15	

The Proof Strength usually exceeds the working load from 50 per cent., with tough metals, to 200 or 300 per cent. where brittle materials are used. It should usually be below the elastic limit of the material.

As this limit, with brittle materials, is often nearly equal to their ultimate strength, a set of factors of safety, based on the elastic limit, would differ much from those above given for ductile metals, but would be about the same for all brittle materials, thus:

MATERIAL.	LOAD.		SHOCK.	
	Dead.	Live.		
Soft metals................	2	4	6	Ratio of Elastic Resistance to Working Load.
Brittle metals and alloys....	3	6	8 to 12	

The figure given for shock is to be taken as approximate, but used only when it is not practicable to calculate the energy of impact and the resilience of the piece meeting it, and thus to make an exact calculation of proportions.

The factors of safety adopted for non-ferrous metals are higher than those usually adopted for construction in iron or steel in consequence of the fact that the elastic limit and the elastic resilience, or shock-resisting power, of the latter seem to increase with strain, up to a limit; while the former gradually yield under comparatively low stresses, as will be seen hereafter. In common practice, the factor of safety covers not only risks of injury by accidental excessive stresses, but deterioration with time, uncertainty as to the character of uninspected material, and sometimes equally great uncertainty as to the absolute correctness of the formulas and the constants used in the calculations. As inspection becomes more efficient and trustworthy; as our knowledge of the effect of prolonged and of intermittent stress becomes more certain and complete; as our formulas are improved and rationalized, and as their empirically determined constants are more exactly obtained, the factor of safety is gradually reduced, and will finally become a minimum when the engineer acquires the ability to assume with confidence the conditions to be estimated upon, and to say with precision how his materials will continuously carry their loads.

A characteristic distinction between the ductile non-ferrous metals and ductile iron or steel, is that the former have usually, as purchased, no true elastic limit, but yield to small stresses without recovery of form and their permanent set equals their maximum distortion. Where brittle, they are often very elastic, however, and recover fully. In such cases, the elastic limit coincides with their ultimate resistance to fracture, as is the case with glass, hard cast iron, and often with hardened steel.

In the table above it is assumed that an elastic limit occurs at the point at which the elongation becomes 0.0010 of the total length of the piece stretched.

In some cases it is advisable to design some minor part, or element, of a train with a lower factor of safety, to insure that when a breakdown does occur it shall be certain to take place where it will do least harm.

149. The Measure of Resistance to *strain* is determined, in form, by the character of the *stress*. By stress is here understood the force exerted, and by strain the change of form produced by it.

Tenacity is resistance to a pulling stress, and is measured by the resistance of a section, one unit in area, as in pounds or tons on the square inch, or in kilogrammes per square centimetre or square millimetre. Then, if T represents the tenacity and K is the section resisting rupture, the total load that can be sustained is, as a maximum,

$$P=TK \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Compression is similarly measured, and if C be the maximum resistance to crushing per unit of area, and K the section, the maximum load will be

$$P=CK \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Shearing is resisted by forces expressed in the same way, and the maximum shearing stress borne by any section is

$$P=SK \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Bending Stresses are measured by moments expressed by the product of the bending effort into its lever-arm about the section strained, and if P is the resultant load, l the lever-arm and M the moment of resistance of the section considered,

$$Pl=M \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Torsional Stresses are also measured by the moment of the stress exerted, and the quantity of attacking and resisting moments is expressed as in the last case.

Elasticity is measured by the longitudinal force, which, acting on a unit of area of the resisting section, if elasticity were to remain unimpaired, would extend the piece to double its original length. Within the limit at which elasticity is unimpaired, the variation of length is proportional to the force acting, and if E is the "*Modulus of Elasticity*," or "Young's Modulus," l the length, and e the extension, P being the total load, and K the section:

$$E = \frac{Pl}{eK} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$e = \frac{Pl}{EK} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The Coefficients entering into these several expressions for resistance of materials are often called *Moduli*, and the forms of the expressions in which they appear are deduced by the Theory of the Resistance of Materials, and the processes are given in detail in works on that subject.

These moduli, or coefficients, as will be seen, have values which are rarely the same in any two cases; but vary not only with the kind of material, but with every variation, in the same substance, of structure, size, form, age, chemical composition or physical character, with every change of temperature, and even with the rate of distortion and method of action of the distorting force. Values for each familiar material, for a wide range of conditions, will be given in the following pages.

150. **Method of Resistance to Stress.**—When a piece of metal is subjected to stress exceeding its power of resistance for the moment, and gradually increasing up to the limit at which rupture takes place, it yields and becomes distorted at a rate which has a definitely variable relation to the magnitude of the distorting force; this relation, although very similar for all metals of any one kind, differs greatly for different metals, and is subject to observable alteration by every measurable difference in chemical composition or in physical structure.

Thus, in Fig. 2, let this operation be represented by the several curves, *a*, *b*, *c*, *d*, etc., the elevation of any point on the curve above the axis of abscissas, OX, being made proportional to the resistance to distortion of the piece, and to the equivalent distorting stress, at the instant when its distance from the left side of the diagram, or the axis of ordinates, *OY*, measures the coincident distortion. As drawn, the strain-diagram, *a a'*, is such as would be made by a soft metal like tin or lead; *b b'* represents a harder, and *c c'* a still harder and stronger metal, as zinc and rolled copper. If the smallest divisions measure the per cent. of extension horizontally, and 10,000 pounds per square inch (703 kilogrammes per square centimetre) vertically, *d d'*, would fairly represent a hard iron, or a puddled or a "mild" steel; while *f f'* and *g g'* would be strain diagrams of hard, and of very hard tool steels, respectively.

The points marked *e*, *e'*, *e''*, etc., are the so-called "*elastic*

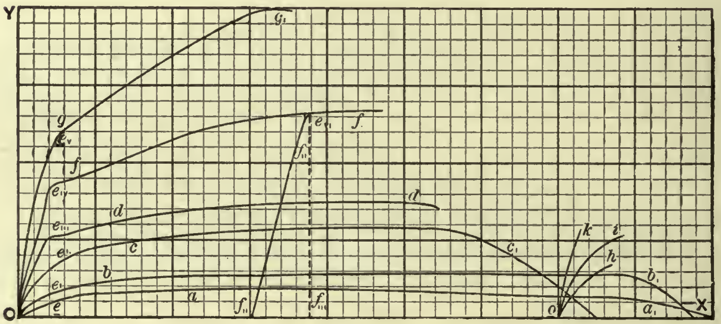


Fig. 2.—Strain-Diagrams.

limits," at which the rate of distortion more or less suddenly changes, and the elevation becomes more nearly equal to the permanent change of form, and at these points the resistance to further change increases much more slowly than before. This change of rate of increase in resistance continues until a maximum is reached, and, passing that point, the piece either breaks, as at *f'* and *g'*, or yields more and more easily until distortion ceases, or until fracture takes place, and it becomes zero at the base line, as at *X*.

Such curves have been called by the Author "Strain-diagrams."

151. Equations of Curves of Resistance or Strain-diagrams.—These curves are, at the start, often nearly parabolic, and the strain-diagrams of cast iron, h, i, k, having their origin at o, are usually capable of being quite accurately expressed by an equation of the parabolic form, as

$$P = A\frac{e}{l} - B\frac{e^2}{l^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

in which the Author found the constants for copper in tension to be

$$A = 10{,}000{,}000\,; \quad B = 100{,}000{,}000,$$

and where $\frac{e}{l}$ is the ratio of elongation to the length of the piece, and P, the load, is measured for tension, in pounds on the square inch of resisting section.

For bronze of fair quality, the Author has, in some experiments, obtained:

$$A = 12{,}000{,}000\,; \quad B = 50{,}000{,}000.$$

For brass, he obtained nearly:

$$A = 12{,}000{,}000\,; \quad B = 50{,}000{,}000.$$

The coefficient A, above, is the modulus of elasticity. Reducing the above quantities to metric measure—kilogrammes on the square centimetre—we have:

	A.	B.
For copper	703,000	7,030,000
For bronze	843,600	3,515,000
For brass	843,600	3,515.000

152. **The Series of Elastic Limits.**—If, at any moment, the stress producing distortion is relaxed, the piece recoils and continues this reversed distortion until, all load being taken off, the recoil ceases and the piece takes its "permanent set." This change is shown in the figure at $f'' f''$, the gradual reduction of load and coincident partial restoration of shape being represented by a succession of points forming the line $f'' f''$, each of which points has a position which is determined by the elastic resistance of the piece as

now altered by the strain to which it has been subjected. The distance $O f''$ measures the permanent set, and the distance $f'' f'''$ measures the recoil.

The piece now has qualities which are quite different from those which distinguished it originally, and it may be regarded as a new specimen and as quite a different metal. Its strain-diagram now has its origin at f'', and the piece being once more strained, its behavior will be represented by the curve $f'' f'' e^{vi} f'$, a curve which often bears little resemblance to the original diagram O, f, f'. The new diagram shows an elastic limit at e^{v}, and very much higher than the original limit e^{iv}. Had this experiment been performed at any other point along the line $f f'$, the same result would have followed. It thus becomes evident that the strain-diagram is a curve of elastic limits, each point being at once representative of the resistance of the piece in a certain condition of distortion, and of its elastic limit as then strained.

The ductile, non-ferrous metals, and iron and steel, and the truly elastic substances, have this in common—that the effect of strain is to produce a change in the mode of resistance to stress, which results, in the latter, in the production of a new and elevated elastic limit, and in the former in the introduction of such a limit where none was observable before.

It becomes necessary to distinguish these elastic limits in describing the behavior of strained metals, and, as will be seen subsequently, the elastic limits here described are, under some conditions, altered by strain, and we thus have another form of elastic limit to be defined by a special term.

In this work the original elastic limit of the piece in its ordinary state, as at e, e', e'', etc., will be called either the *Original*, or the *Primitive*, *Elastic Limit*, and the elastic limit corresponding to any point in the strain-diagram produced by gradual, unintermitted strain, will be called the *Normal Elastic Limit* for the given strain. It is seen that the diagram representing this kind of strain is a *Curve of Normal Elastic Limits.*

The elastic limit is often said to be that point at which a permanent set takes place. As will be seen on studying actual strain-diagrams to be hereafter given, and which exhibit accurately the behavior of the metal under stress, there is no such point. The elastic limit referred to ordinarily, when the term is used, is that point within which *recoil*, on removal of load, is approximately equal to the elongation attained and beyond which *set* becomes nearly equal to total elongation.

It is seen that, within the elastic limit, sets and elongations are similarly proportional to the loads, that the same is true on any elastic line, and that loads and elongations are nearly proportional everywhere beyond the elastic limit, within a moderate range, although the total distortion then bears a far higher ratio to the load, while the sets become nearly equal to the total elongations.

153. Effect of Shock or Impact; Resilience.—The behavior of metals, under moving, or "live," load and under shock, is not the same as when gradually and steadily strained by a slowly applied or static stress. In the latter case, the metal undergoes the changes illustrated by the strain diagrams, until a point is reached at which equilibrium occurs between the applied load and resisting forces, and the body rests indefinitely, as under a permanent load, without other change occurring than such settlement of parts as will bring the whole structural resistance into play.

When a freely moving body strikes upon the resisting piece, on the other hand, it only comes to rest when all its kinetic energy is taken up by the resisting piece; there is then an equality of *vis viva* expended and work done, which is expressed thus:

$$\frac{WV^2}{2g} = \int_0^s p\,dx = p_m s;$$

in which expression W is the weight of the striking body, V its velocity, p the resisting force at any instant, p_m the mean resistance up to the point at which equilibrium occurs, and s is the distance through which resistance is met.

As has been seen, the resistance may usually be taken as varying approximately with the ordinates of a parabola, the abscissas representing extensions. The mean resistance is, therefore, nearly two-thirds the maximum, and

$$\frac{WV^2}{2g} = \int_0^s p\,dx = p_m s = \tfrac{2}{3}\,et = ae^2, \text{ nearly} \quad . \quad . \quad (8)$$

where e is the extension, and t the maximum resistance at that extension, and a a constant. Brittle materials, like hard bronzes and brasses, have a straight line for their strain-diagrams, and the coefficient becomes ½ instead of ⅔, and

$$\frac{WV^2}{2g} = ae^2 = \tfrac{1}{2}\,et = \tfrac{1}{2}\,\frac{t^2}{E} \quad . \quad . \quad . \quad . \quad (9)$$

154. **Resilience, or Spring,** is the work of resistance up to the elastic limit. This will be called *Elastic Resilience.* The modulus of elasticity being known, the Modulus of Elastic Resilience is obtained by dividing half the square of the maximum elastic resistance by the modulus of elasticity, E, as above, and the work done to the "primitive elastic limit" is obtained by multiplying this modulus of resilience by the volume of the bar.*

The total area of the diagram, measuring the total work done up to rupture, will be called a measure of *Total* or *Ultimate Resilience.* Mallett's Coefficient of Total Resilience is the half product of maximum resistance into total extension. It is correct for brittle substances and all cases in which the primitive elastic limit is found at the point of rupture. With tough materials, the coefficient is more nearly two-thirds—and may be even greater where the metal is very ductile, as, *e.g.*, pure copper, tin, or lead. Unity of length and of section

* Rankine and some other writers take this modulus as $\frac{t^2}{E}$, instead of $\frac{1}{2}\frac{t^2}{E}$.

being taken, this coefficient is here called the Modulus of Resilience.

When the energy of a striking body exceeds the total resilience of the material, the piece will be broken. When the energy expended is less, the piece will be strained until the work done in resistance equals that energy, when the striking body will be brought to rest.

As the resistance is partly due to the *inertia* of the particles of the piece attacked, the strain-diagram area is always less than the real work of resistance, and, at high velocities, may be very considerably less, the difference being expended in the local deformation of that part of the piece at which the blow is received. In predicting the effect of a shock it is, therefore, necessary to know not only the energy stored in the moving mass and the method of variation of the resistance, but also the striking velocity. To meet a shock successfully it is seen that resilience must be secured sufficient to take up the shock without rupture, or, if possible, without serious deformation. It is, in most cases, necessary to make the *elastic* resilience greater than the maximum energy of any attacking body.

Moving Loads produce an effect intermediate between that due to static stress and that due to the shock of a freely moving body acting by its inertia wholly; these cases are, therefore, met in design by the use of a high factor of safety, as above.

As is seen by a glance at the strain-diagram, ff (Fig. 2), the piece once strained has a higher elastic resilience than at first, and it is therefore safer against permanent distortion by moderate shocks, while the approach of permanent extension to a limit renders it less secure against shocks of such great intensity as to endanger the piece.

When the shock is completely taken up, the piece recoils, as at $e^{vi}f''f''$, until it settles at such a point on that line—assuming the shock to have extended the piece to the point e^{vi}—that the static resistance just equilibrates the static load. This point is usually reached after a series of vibrations on either side of it has occurred. With perfect elasticity, this point is at one-half the maximum resistance, or elongation, attained. Thus we have

$$\int_0^s p\,dx = \frac{WV^2}{2g} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

but p varies as x within the elastic limit, which limit has now risen to some new point along the line of normal elastic limits, as e^{vi}. Taking the origin at the foot of $f''f''$, since the variations of length along the line Ox are equal to the elongations and to the distances traversed as the load falls, and as stresses are now proportional to elongations,

$$p=ax;\ Wh=Ws;\ \text{and}\ W=P \quad . \quad . \quad . \quad (11)$$

when the resisting force is p, the elongations x, while h and s are maximum fall and elongation, and P is the maximum resistance to the load at rest. Then

$$\int_0^s p\,dx = a\int_0^s x\,dx = \frac{a}{2}s^2 = Ws \therefore s = \frac{2W}{a} \quad . \quad . \quad (12)$$

For a static load, if s' is the elongation,

$$W = P = as' \therefore s' = \frac{W}{a}.$$

Hence, $$\frac{s'}{s} = ½ \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

and the extension and the corresponding stress due to the sudden application of a load are double those produced by a static load.

Where the applied load is a pressure and not a weight, *i.e.*, where considerable energy in a moving body is not to be absorbed, as in the action of steam in a steam engine, the only increase of strain produced by a suddenly applied load is that produced by the inertia of such of those parts of the mass attacked as may have taken up motion and energy.

155. **Proportioning to Resist Shock.**—The problem of proportioning parts to resist shock is thus seen to involve a determination of the energy, or "living force," of the load at impact, and an adjustment of proportion of section and shape of piece attacked such that its work of elastic or of ultimate resilience, whichever is taken as the limit, shall exceed that energy in a proportion measured by the factor of safety adopted. For ordinary live loads and moderate impact, requiring no specially detailed consideration, the factors of safety already given (Art. 148), as based upon ultimate strength simply, are considered sufficient; in all cases of doubt, or when heavy shock is anticipated, calculations of energy and resilience are necessary, and these demand a complete knowledge of the character, chemical, physical, and structural, of every piece involved, of its resilience and method of yielding under stress, and of every condition influencing the application of the attacking force—in other words, a complete knowledge of the material used, of the members constructed of it, and of the circumstances likely to bring about its failure.

The form of such parts should usually be determined on the assumption that deformation may some time occur, and such expedients as that of Hodgkinson in enlarging the section on the weaker side, as well as the adoption of a larger factor of safety based on ultimate strength, are advisable.

156. **The Methods of Testing** and the construction of the machines used are fully described in Part II. of this work. The form of test-piece advisable, and standard formulas, and many facts relating to this part of the subject may be there studied, or in works on the strength of materials.

157. **Compression.**—*Resistance to Compression* is measured by the same process as in testing by tension. This form of resistance is, however, governed in many cases by different laws, and is often modified by the size and shape of the piece tested to even greater extent than is resistance to tensile stress. The method of rupture is not only different for different materials, but it is different with pieces of the same metal for every difference in size, shape, or proportion. Thus, a

piece of copper or lead is soft and tough, and, in the form of a short cylindrical column, will gradually yield by crushing until it assumes the form of a cheese, or a button; the same metal in longer cylinders will yield similarly, until, reaching a certain limit, as in long columns, it will yield by bending laterally, and under a comparatively small load. A piece of speculum metal, or of other brittle metal or alloy, will break by crushing into fragments, and will break up the more completely as it is harder and more brittle. Extremely hard metals and alloys exhibit no sign of yielding until their limit of resistance is reached, when they suddenly fly to pieces with great violence.

In all cases, resistance increases up to a limit beyond which the piece usually gives way suddenly, if the metal be hard or brittle; while ductile and malleable metals often offer constantly increasing resistance, the limit being reached only when the pressure becomes so great as to cause the metal to flow steadily, as is illustrated in the manufacture of lead pipe.

In consequence of these variations due to form and size, it is even more necessary than when testing by tension to have a standard form of test-piece, as proposed in Part II., and to report all observations as made upon such standard.

158. **The Structure of the Piece and its Chemical Composition** determine the compressive resistance of metals and alloys. With pure, well-worked metal, the resistance follows pretty closely a law peculiar to and characteristic of each metal. Within the elastic limit, the behavior of the piece may be taken as the same, whether under tension or compression; beyond that limit, the compressive strength usually exceeds the tensile in a proportion which varies greatly. Copper and other non-ferrous metals are rarely used in the form of columns. Should it be necessary to so use them, the formulas given in Part II. and in special works on strength of materials may be used, substituting the proper value, C, of the modulus for compression.

159. **The Transverse Strength**, or the resistance of any piece to bending, is determined by the longitudinal strength

of the metal, both in tension and compression, by the form of the piece, and by its absolute dimensions. When this method of stress affects a bar of metal, there is called into action at every section a set of forces resisting flexure, each acting about a "neutral line" at which the forces change sign. If a bar is placed in the testing machine, and if, while supporting it at each end, the machine is made to apply a depressing force at the middle of the piece, the upper part of the bar is compressed, and the lower extended; while between these portions of strained metal is a plane of unstrained material, whose trace on the vertical plane is the neutral line. The moments of the forces by which the bar resists compression above and extension below this plane, together produce the measured resistance to flexure. The position of the neutral plane is determined by the relation existing between the magnitudes of the two forms of resistance; it may be considered as always at the middle of the section, within the elastic limit, while beyond that limit it approaches that side at which resistance is greatest at the moment. The total resistance to flexure, then, is measured by the sum of these two moments of resistance, which are themselves measured each by the product of the mean resistance of the strained parts of the most severely loaded cross section affected by it into its own lever arm.

By the ordinary theory, and its resulting equations, the resistances of particles to compression and to extension are taken proportional to their distance from the neutral surface; this is correct up to that limit of flexure at which the exterior sets of particles on the one side or on the other are forced beyond the elastic limit. With absolutely non-ductile materials, or materials destitute of viscosity, fracture occurs at this point; but, with nearly all of the metals and alloys in common use, rupture does not then take place. The exterior portions of the mass are compressed on the one side, offering more and more resistance nearly, if not quite, up to the point of actual breaking, which breaking may only occur long after passing the elastic limit; on the other side, similar sets of particles are drawn apart, passing the elastic limit for tension, and then resisting the stress with a more nearly constant force, "flow" occurring until the limit of that flow is reached, and rupture takes place.

No expressions have yet been derived by analysis, and constants determined by experiment, which enable the engineer to express by an equation the actual method of variation of internal resistances with variation of load and of deflection, for all materials; but sufficient accuracy is usually obtained for practical purposes by treating the case in the simplest manner.

160. Methods of Distribution of Resistances, in cases of flexure, are exhibited in the accompanying figures.

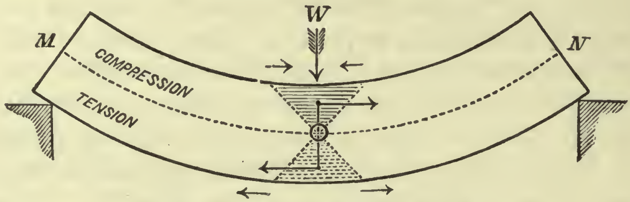


FIG. 3.—FLEXED ELASTIC BEAM.

In *MN*, the material being perfectly elastic up to the limit of flexure, the stress at any point is proportional to the area of the element strained, to the maximum elastic resistance of the material, and to the distance x of the element from the neutral plane *MON*. The resistance to flexure within the range of perfect elasticity is, therefore, in this case, as when the beam is ruptured, at that limit proportional to the breadth of the piece and to the square of the depth, where the section is rectangular.

Where a metallic beam is strained beyond the elastic limit at any part of its section, the stress outside that part is more nearly constant, and may become equal to the maximum resistance of the material, or nearly so. Thus, in Fig. 4, the law of resistance changes at *a* and is no longer proportional to the distance of the

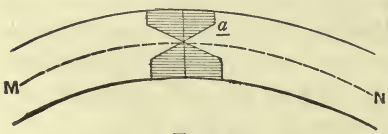


FIG. 4.

strained particles from the neutral plane, but has the maximum possible value. This change may occur abruptly, as shown, or gradually, making the shaded parts exhibiting the magnitude of the stress a pair of parabolas placed vertex to vertex. Finally, with all perfectly ductile materials, all parts of the section become equally strained, nearly as in Fig. 5.

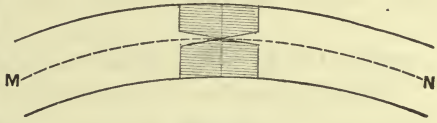


FIG. 5.

161. Theory of Rupture.*—In the usual case, in which the resistance to distortion varies from a maximum, R, at the outer surface to zero on the neutral plane, as in brittle materials, we have for the elementary area $dy\ dx$, for the resistance $\frac{R}{d_1}y$ per unit of area, and $\frac{R}{d_1}y\ dy\ dx$ on the area $dy\ dx$; while the moment of resistance, M, on that part of the whole section which lies on one side the neutral plane is obtained by integration from that line to the most strained fibre on that side, at a distance d_1, R being the "Modulus of Rupture":

$$\frac{R}{d_1}\int_0^b\int_0^{d_1} y^2\ dy\ dx = M,$$

i.e., the quotient of the modulus of rupture by the distance of the most strained fibre from the neutral line, multiplied by the moment of inertia of the section considered.

When the resistance, after passing the elastic limit, becomes throughout equal to the maximum R, we have per unit of area, a resistance $R\ dy\ dx$, and for the moment

$$R\int_0^b\int_0^{d_1} y\ dy\ dx = M'.$$

For rectangular beams, when the neutral line may be taken at the middle of the section, as with non-ductile materials generally for the first, and for copper, tin, lead and

* See Wood's "Resistance of Materials" for the Theory of Resistance.

other substances having nearly equal values of T and C, for the second case, we get, for the two cases respectively:

$$(a)\ M = \tfrac{1}{6} Rbd^2; \qquad (b)\ M^1 = \tfrac{1}{4} Rbd^2;$$

b being the breadth, and $d = 2d_1$ the total depth of section.

Thus, assuming the same value for ultimate resistance of cohesion, the ductile substance offers one-half greater resistance than the non-ductile, and one-half greater resistance just beyond than just within the elastic limit. Hence, also, it can only be expected that the value of R will coincide with the resistance to direct tension or direct compression in rare cases. It is evident that the actual value of R may be compared with the values of T and C, to determine to what extent the case approaches that giving the second of these equations.

The first of these cases is that which it has been customary to assume as applicable in all cases. Its solution evidently gives results differing from the truth on the right side.

Examining the equation, it is seen that the moment of resistance, M, is measured by the product of the "modulus" of rupture, R, into the quantity $\iint y^2\,dy\,dx$ divided by the depth d_1 to the neutral line, or as, shown by M. Navier, to the axis through the centre of gravity. The quantity $\iint y^2\,dy\,dx$, which is always a factor in this expression, is the "moment of inertia."

The data to be here given are experimentally obtained figures, derived from tests of pieces of rectangular section; other forms will be considered later.

162. **Formulas for Transverse Loading** are deduced in all works on resistance of materials. For cases of rupture, when the beam is supported at the ends and loaded in the middle, for rectangular bars,

$$M = \frac{1}{4} Pl = \frac{1}{6} Rbd^2; \text{ and } R = \frac{3Pl}{2bd^2},$$

for non-ductile materials, and it may be assumed, in all cases in the engineer's practice, that the material tested is in practice either sufficiently elastic and rigid to justify the use of this formula, or is to be loaded only within its elastic limit. Then the formulas for other cases become:

(1.) Beam fixed at one end, load at the other:

$$Pl = \frac{1}{6} Rbd^2; \qquad P = \frac{1}{6} R \frac{bd^2}{l}.$$

(2.) Same, with load distributed uniformly:

$$\frac{1}{2} Wl = M; \qquad W = \frac{1}{3} R \frac{bd^2}{l}.$$

(3.) Beam supported at ends, loaded at middle:

$$\frac{1}{4} Pl = M; \qquad P = \frac{2}{3} R \frac{bd^2}{l}.$$

(4.) Same, uniformly loaded:

$$\frac{1}{8} Wl = M; \qquad W = \frac{4}{3} R \frac{bd^2}{l}.$$

(5.) Beam firmly fixed at ends, loaded at middle:

$$\frac{1}{8} Pl = M; \qquad P = \frac{4}{3} R \frac{bd^2}{l}.$$

Same determined by Barlow's experiments:

$$\frac{1}{6} Pl = M; \qquad P = R \frac{bd^2}{l}.$$

(6.) Same uniformly loaded:

$$\frac{1}{12} Wl = M; \qquad W = 2 R \frac{bd^2}{l}.$$

(7.) Fixed at one end, supported at the other, load at the middle:

$$\frac{1}{8}Pl = M; \qquad P = \frac{4}{3}R\frac{bd^2}{l}.$$

All of these equations are, of course, "homogeneous."

Replacing bd^2 by $0.59d^3$, transforms these quotations so as to apply very exactly to circular sections.

163. **The Modulus of Rupture,** R, being obtained by experiment and inserted in these formulas, the maximum load that a beam will support, when of similar shape and of that material, becomes calculable.

The value of the modulus of rupture is readily determined by experiment from the formula:

$$R = \frac{3}{2}\frac{l}{bd^2}\left(P + \tfrac{1}{2} W\right),$$

when the weight of the beam, W, is taken into account. When the dimensions all become unity, we have, neglecting W,

$$R = \frac{3}{2}P;$$

that is to say, the modulus of rupture is one and a half times the load which would break a bar unity in length, breadth and depth, supported at the ends and loaded in the middle. For British measures, it is 18 times the weight that would break a bar so loaded if one foot long, and one inch square in section.

Very ductile bars bend without breaking. The correct modulus of rupture in these cases, therefore, cannot be determined, and it is necessary to assume a given amount of bending as equivalent to breaking the bar or rendering it useless, and the modulus of rupture is calculated from the load causing this maximum deflection, to afford a means of comparing the transverse strengths of all bars which were tested.

164. The Theory of Elastic Resistance, as generally accepted, is as follows:

In figure 6, which represents a longitudinal section through a loaded beam, let EF be the neutral line extending throughout its length. Let AB and CD be consecutive transverse sections separated by the distance dx; $C'D'$ is the position of C when swung out of its original place by the action of the load W, and its intersection with the plane AB is found at R. Then, ab being the original length of any fibre at a distance $Ob = y_1$ from the neutral axis, $bc = \lambda$ will be its elongation, and if the radius of curvature, OR, is called ρ, we have

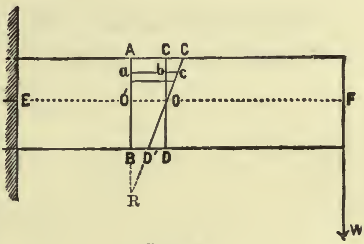


Fig. 6.

$$\lambda = \frac{y\,dx}{\rho};$$

and the stress on any fibre of the area, $a = dy\,dz$, since $\frac{p}{a} : E :: \lambda : dx$, will be

$$p = Ea\frac{\lambda}{dx} = \frac{E}{\rho} y\,dy\,dz,$$

and the moment about the intersection with the neutral line is

$$py = \frac{E}{\rho} y^2\,dy\,dz,$$

accordingly as the fibre is above or below that line.

The total moment will be

$$M = \frac{E}{\rho}\int_0^b \int_0^{d_1} y^2\,dy\,dz + \frac{E}{\rho}\int_0^b \int_0^{d_2} y^2\,dy\,dz.$$

For cases in which the section is symmetrical about the neutral line

$$M = \frac{EI}{\rho} = \frac{E}{\rho}\int_0^b \int_{-\frac{1}{2}d}^{+\frac{1}{2}d} y^2\,dy\,dz,$$

in which integrals b is the breadth of section, d_1 and d_2 are the depth of the half sections above and below EF, and d is the total depth. Also,

$$M = \frac{EI}{\rho}.$$

The value of ρ, the radius of curvature, is shown in works on the differential calculus to be

$$\rho = \pm \frac{\left(1 + \frac{dy^2}{dx^2}\right)^{\frac{3}{2}}}{\frac{d^2y}{dx^2}};$$

which value reduces the equation for $M = Pl$, as in Fig. 6, to

$$Pl = M = EI\frac{d^2y}{dx^2},$$

when $\frac{dy^2}{dx^2}$ may, as is probably usually the case, be neglected.

Inserting the value of M in terms of x, we have, for example, with the "cantilever," or beam fixed at one end, loaded at the other, origin at the fixed end:

$$(l - x)\,P = EI\frac{d^2y}{dx^2},$$

which, being integrated once, gives

$$\frac{dy}{dx} = \frac{P}{2EI}(2lx - x^2) + C,$$

where $x = 0$, $\frac{dy}{dx} = 0$, and $C = 0$.

Again integrating, and

$$y = \frac{P}{6EI}(3lx^2 - x^3) + C,$$

in which, where $x = 0, y = 0$ and $C = 0$, and the value for deflection at $x = l$, for this case is

$$D = \frac{1}{3}\frac{Pl^3}{EI},$$

as already given.

For uniform loading,

$$\frac{d^2y}{dx^2} = \frac{w}{2EI}(l - x)^2,$$

and

$$D = \frac{wl^4}{8EI}; \text{ etc.}$$

All usual cases are developed in treatises on the theory of the resistance of materials.

The elastic resistance to flexure is of greater importance in very many cases than the ultimate transverse strength, as pieces are in machinery almost invariably, and in other structures usually, rendered useless when the change of form exceeds a limit which is generally intended to be well within the elastic range.

In some of the tables, the figures in the column headed "Modulus of Elasticity," are those which are considered the *most probable* moduli within the elastic limit, or which most nearly represent the relation between the stresses and the distortions within that limit.

In a few instances the apparent modulus at the beginning of the test is much smaller than it soon afterward becomes; and this indicates either a possible error or the existence of internal stress at this part of the test.

In general, we have, within the elastic limit,

$$D = \frac{1}{3}\frac{Pl^3}{EI}; \quad P = \frac{3DEI}{l^3}$$

for the case of a beam fixed at one end and loaded at the other.

When uniformly loaded,

$$D = \frac{1}{8}\frac{Wl^3}{EI}; \quad W = \frac{8DEI}{l^3}.$$

For beams supported at the ends, these equations for single and distributed loads are

$$D = \frac{1}{48}\frac{Pl^3}{EI}; \quad P = \frac{48DEI}{l^3};$$

$$D = \frac{1}{75}\frac{Wl^3}{EI}, \text{ nearly}; \quad W = \frac{75DEI}{l^3}.$$

For beams fixed at the ends, we have

$$D = \frac{1}{200}\frac{Pl^3}{EI}, \text{ nearly}; \quad P = \frac{200DEI}{l^3}.$$

$$D = \frac{1}{400}\frac{Wl^3}{EI}, \text{ nearly}; \quad W = \frac{400DEI}{l^3}.$$

For rectangular beams,

$$I = \tfrac{1}{12} bd^3,$$

and we may write the simplified formula for a beam supported at the ends and loaded in the middle,

$$D = \frac{aPl^3}{bd^3}.$$

For a beam fixed at one end and loaded at the other,

$$D = \frac{16aPl^3}{bd_3};$$

and, when uniformly loaded, the t o cases give

$$D = \frac{5}{8}\frac{aWl^3}{bd^3},$$

and

$$D = \frac{6aWl^3}{bd^3}.$$

Where the length is measured in inches,

$$a = \frac{1}{4E}, \text{ and when in feet, } a = \frac{1728}{4E}.$$

165. **The Torsional Strength** and elasticity of iron and steel have been less thoroughly investigated than either of the other forms of resistance.

The moment of the applied force, as measured by the product of the magnitude of that force into the length of its lever-arm, at each instant equilibrates the resistance, and the formula for elastic resistance becomes:

$$Fl = M = \frac{2\pi s}{r_1}\int_{r_0}^{r_1} r^3\,dr.$$

For solid cylinders,

$$Fl = M = 1.5708 s r_1^3 = 0.2 s d^3.$$

For hollow cylinders,

$$Fl = M = 1.5708 s \left(\frac{r_1^4 - r_0^4}{r_1}\right) = 0.2 s \,.\, \frac{d_1^4 - d_0^4}{d_1};$$

where F is the applied force, l its lever-arm, M its moment, s the resistance of the material on the unit of area, or the maximum stress, r_0 and r_1 are the radii of the shaft, internal and external, and d_0 and d_1 are the diameters.

The *angle of torsion* is proportional to the length of the part twisted and to the torsional moment. The formula giving its value is

$$\alpha = \frac{2Mx}{C\pi r_1^4} = \frac{32M}{\pi d_1^4}\cdot\frac{x}{C} = 10.2\,\frac{Flx}{Cd_1^4},$$

x being the length of the part twisted;

$$Fl = M = \alpha C\frac{\pi d_1^4}{32x} = 0.098 C\,\frac{d_1^4\alpha}{x},$$

in which formulas C is the coefficient of elasticity of torsion.

166. The Strength of a Metal Shaft depends not only on the magnitude of the ultimate resistance of the material, but upon the method of its action. With brittle materials, fracture must occur when the limit of resistance of the outer layers is reached ; with ductile metals, capable of flow, fracture may not take place until all, or nearly all, parts of the cross section have been highly strained, the outer portions yielding by flow until the inner parts have been strained to their maximum.

For the first case, we have for the area of each elementary ring, $2\pi r\, dr$, for the stress upon it $s = \frac{s_1 r}{r_1}$, and for its lever-arm, r.

Then

$$Fl = M = \frac{2\pi s_1}{r_1}\int_{r_0}^{r_1} r^3\, dr = \frac{1}{2}\frac{\pi s_1}{r_1}(r_1^4 - r_0^4) = \frac{1}{16}\pi\frac{s_1}{d_1}(d_1^4 - d_0^4)$$

for hollow shafts, and when $r_0 = 0$, $d_0 = 0$, as for solid shafts,

$$Fl = M = 1.5708\, s^1 r_1^3 = 0.196\, s_1 d^3.$$

To obtain the diameter, we have:

For solid shafts,

$$d_1 = \sqrt[3]{\frac{5.1\, Fl}{s_1}}.$$

For hollow shafts,

$$d_1 = \sqrt[3]{\frac{5.1\, Fl}{s_1\left(1 - \frac{d_0^4}{d_1^4}\right)}}.$$

In these formulas, the ultimate resistance may be taken as already given for tension, and the factor of safety should usually be large.

When the material is capable of flow to such an extent that the whole section resists with maximum effect, we have the elementary area as before—$2\pi r\,dr$, its lever-arm r, and the value of s becomes constant and equal to s_1.

Then

$$Fl = 2\pi s_1 \int_{r_0}^{r_1} r^2 dr = \frac{2}{3}\pi s^1 (r_1^3 - r_0^3) = 0.26 s_1 (d_1 - d_0),$$

and when $r_0 = 0$,

$$Fl = 0.26 s_1 d_1^3 = 2.2 s_1 r_1^3.$$

In such cases, therefore, the strength of the shaft is increased one-third by the ductility of the metal.* It is uncertain to what extent this action occurs, and it is still more uncertain to what extent the action here occurring is a true shearing action. The last set of formulas, above deduced, are rarely used by the engineer.

When the section is square, the resistance is increased about 40 per cent. above that of a circular section having a diameter equal to the side of the square.

The real condition of the metal under stress is undoubtedly always intermediate between the two cases above taken, the metal near the centre resisting as a solid shaft strained within the elastic limit at its outer bounding surface, while the external portion acts as a hollow shaft strained throughout beyond that limit. Assuming the latter to be strained to the maximum throughout, and taking r_1 r_2 as the radii of the two parts, the total resistance would be

$$Fl = M = \frac{\pi}{2} s_1 r_1^3 + \frac{2\pi}{3} s_1 (r_2^3 - r_1^3)$$

$$= 0.528 s_1 (4r_2^3 - r_1^3).$$

* First shown by Prof. Jos. Thomson (*Cam. and Dub. Math. Jour.*, Nov., 1848; Ency. Brit., Art. Elasticity, pp. 798–9, 1883); his paper was not discovered by the Author until he had himself determined the facts experimentally, had reconstructed the theory as above, and had applied it, further, to the case of bent beams, as in Art. 161, and in Part II., Arts. 262–3, 277.

If α_e and α_r are the angles of torsion at the elastic limit of the piece and at the beginning of rupture or of flow,

$$r_1 = \frac{\alpha_e}{\alpha_r} r_2,$$

and

$$Pl = M = \frac{1}{6} \pi s r_2^3 \left(4 - \frac{\alpha_e^3}{\alpha_r^3}\right).$$

If $\alpha_e = \alpha_r$, $M = \frac{1}{2}\pi s r^3$, as already shown for brittle substances. When $\alpha_e = 0$, as in absolutely inelastic materials, did such exist, or when $\alpha_r = \infty$, as with perfectly ductile substances, $M = \frac{2}{3}\pi s r^3$, as already deduced for substances capable of unlimited flow.

When the torsional moment is given, the diameter of a shaft in inches is given by Molesworth as

$$d = \sqrt[3]{\frac{Pl}{K}},$$

in which

d = diameter in inches.
l = lever-arm in inches.
P = twisting effort in pounds.

VALUES OF K.

Wrought iron	1,700	Gun bronze	460
Copper	380	Brass	425
Tin	220	Lead	170

167. **The Tenacity of Copper** varies very greatly with physical and chemical modifications of structure and composition. In the ingot, if pure, it is generally stronger than in masses re-cast, as it is peculiarly liable to injury by the absorption of oxygen, the production of "blow-holes," and the formation of oxide. Rolled and forged copper are

stronger than ingot metal. They are made from well-fluxed ingots and are strengthened, like all rolled or forged metals, by working. Drawn copper is still stronger, and its strength increases as the wire is smaller.

Major Wade * found the tenacity of Lake Superior *cast* copper to range from 22,000 to nearly 28,000 pounds per square inch (1,547 to 1,968 kilog. per sq. cm.), averaging above 24,000 pounds (1,705 kilogs.). Egleston gives the tenacity of both Lake Superior and Ore Knob (N. C.) copper as above, 30,000 pounds per square inch (2,109 kgs. per sq. cm.).

Anderson † gives the figures for the tenacity of copper, which, in round numbers, are as below—ordinary copper is compared with that fluxed with phosphorus:

TABLE XXXIV.

TENACITY OF COPPER.

	PHOS.	TENACITY, T.	
		Lbs. per sq. in.	Kilog. per sq. cm.
Copper, forged	....	34,000	2,390
" cast	....	19,000	1,336
" "	....	25,000	1,758
" forged	0.015	38,000	2,671
" "	0.02	45,000	3,164
" "	0.03	48,000	3,374
" "	0.04	50,000	3,515

The effect of fluxing with phosphorus is here very plainly shown and amounts to an average increase of tenacity of 4,000 pounds per square inch (2,812 kilogs. per sq. cm.) for each one per cent. added up to four per cent.

168. Cast Copper.—The following are the records of tests, made by the Author, of ingot copper and of copper castings made direct from re-melted ingot:

* Metals for Cannon, 1856.

† Strength of Materials.

TABLE XXXV.

TESTS OF INGOT COPPER.

No. 654 *a* ; length 5″, diameter 0.798″ ; sound.

LOAD ; LBS.	EXTENSION, INCH.	LOAD ; LBS.	EXTENSION, INCH.
500	0.0009	7,000	0.627
1,000	0.0038	8,000	0.941
2,000	0.0089	120	0.0964
3,000	0.0137	9,000	0.1507
4,000	0.0205	10,000	0.2122
120	0.0089	120	0.2009
5,000	0.0279	12,000	0.3686
6,000	0.0324	120	0.3551
120	0.402	13,000	broke.

Tenacity 26,000 lbs. per sq. inch, original area.
" 1,828 kilogs. " " cm. " "
" 30,398 lbs. " " inch, fractured.
" 2,137 kilogs. " " cm. "

No. 654 *b*, same as above.

LOAD.	EXTENSION, INCH.	LOAD.	EXTENSION, INCH.
500	0.0004	10,000	0.1388
1,000	0.0032	120	0.1317
4,000	0.0201	12,000	0.3020
120	0.0037	120	0.2933
7,000	0.0485	14,910	broke.

Tenacity 29,820 lbs. per sq. inch, original area.
" 2,096 kilogs. " " cm. " "
" 36,217 lbs. " " inch, fractured.
" 2,546 kilogs. " " cm. "

169. **Tests of Copper.**—The methods of test adopted by the Author in testing these materials are also illustrated in the table of results which follow. The figures given exceed those obtained from similar metal by Major Wade.

These records are taken from the records of tests made for the Committee on Alloys of the U. S. Board.

The tests were made on bars cast from re-melted ingot copper.

TABLE XXXVI.

TESTS OF CAST COPPER.

No. 30 A.—Material: Lake Superior copper, cast in iron mould.—**Dimensions:** Length, 5″ (12.7 cm.); diameter, 0.798″ (2 cm.).

LOAD.	LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	ELONGATION IN PARTS OF ORIGINAL LENGTH.	LOAD.	LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	ELONGATION IN PARTS OF ORIGINAL LENGTH.
Pounds.	*Pounds.*	*Inch.*		*Pounds.*	*Pounds.*	*Inch.*	
400	800	0.0004	.00008	11,000	22,000	0.1605	.03210
1,000	2,000	0.0011	.00022	12,200	24,400	0.2191	.04382
2,000	4,000	0.0022	.00044	14,000	28,000	0.3258	.06516
4,000	8,000	0.0027	.00054	270	540	Set 0.3155	....
6,000	12,000	0.0032	.00064	14,400	28,800	0.3448	.06896
6,400	12,800	0.0052	.00104	14,600	29,200	0.3760	.07520
6,800	13,600	0.0083	.00166	Broke just as reading was taken ¼ inch from			
7,200	14,400	0.0132	.00264	A end. Fractured section distorted from cir-			
8,000	16,000	0.0358	.00716	cular form. Three diameters measured 0.737			
8,800	17,600	0.0642	.01284	inch, 0.725 inch, and 0.732 inch.			
9,600	19,200	0.0942	.01884	Tenacity per square inch original section,			
9,800	19,600	0.1073	.02146	29,200 pounds (2,053 kilogs. per sq. cm).			
250	500	Set 0.0951	....	Tenacity per square inch fractured section,			
10,200	20,400	0.1218	02436	34,790 pounds (2,446 kilogs. per sq. cm.).			

No. 525 *a*; length, 6″; diameter, 0.798″; sound casting.

NO. LBS.; LOAD.	EXTENSION, INCH.	NO. LBS.; LOAD.	EXTENSION, INCH.
3,470	0.01	5,900	0.07
4,240	0.02	6,780	0.12
4,920	0.03	7,220	0.16
5,350	0.04	7,270	broke.

Tenacity 14,540 lbs. per sq. inch.
" 1,022 kilogs. " " cm.

No. 525 *b*; size as above; sound.

NO. LBS.; LOAD.	EXTENSION, INCH.	NO. LBS.; LOAD.	EXTENSION, INCH.
4,000	0.01	8,100	0.23
4,900	0.02	9,000	0.30
5,100	0.03	10,000	0.40
6,200	0.11	10,220	broke.
7,550	0.17		

Tenacity, 20,646 lbs. per sq. inch.
" 1,451 kilogs. " " cm.

No. 57 B.—Material: Copper cast in iron mould.—Dimensions: Length, 5″ (12.7 cm.); diameter, 0.798″ (2 cm.).

LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	SET.	ELONGATION IN PARTS OF ORIGINAL LENGTH.	LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	SET.	ELONGATION IN PARTS OF ORIGINAL LENGTH.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
1,000	0.0004	......	.0001	17,000	0.0779	......	.0156
2,000	0.0032	......	.0006	18,000	0.0951	......	.0190
3,000	0.0064	......	.0013	19,000	0.1142	......	.0228
4,000	0.0093	......	.0019	20,000	0.1388	......	.0278
5,000	0.0116	......	.0023	240	......	0.1317	.....
6,000	0.0144	......	.0029	21,000	0.1702	......	.0340
7,000	0.0170	......	.0034	22,000	0.2028	......	.0406
8,000	0.0201	......	.0040	23,000	0.2444	......	.0489
240	......	0.0037	.....	24,000	0.3020	......	.0604
9,000	0.0227	......	.0045	240	......	0.2933	.....
10,000	0.0263	......	.0053	25,000	0.3585	......	.0717
11,000	0.0321	......	.0064	26,000	Measuring apparatus slipped.		
12,000	0.0371	......	.0074	29,820	Broke 2 inches from B end.		
240	......	0.0253	.....				
13,000	0.0428	......	.0086				
14,000	0.0485	......	.0097				
15,000	0.0554	......	.0111				
16,000	0.0652	......	.0130				
240	......	0.0583	.....				

Diameter of fractured section, 0.724 inch.
Tenacity per square inch, original section, 29,820 pounds (2,096 kilogs. per sq. cm.).
Tenacity per square inch, fractured section, 36,217 pounds (2,546 kilogs. per sq. cm.).

Records of tests of cast copper, as here given above, exhibit the variable quality of this material, due to its absorption of oxygen.

These tables illustrate the method of variation of resistance with deformation and with increasing load, and exhibit the figures obtained in a form which admits of the production of a strain-diagram.

The method of variation of the diameter of a test-piece, in tension, along the stretched portion is seen in the following record of test of copper fluxed with fluor-spar, a flux which was expected to give much better results than were in this case actually obtained.

TABLE XXXVII.

TEST OF CAST COPPER (FLUXED WITH FLUOR-SPAR).

No. 51 B.—Material: Copper, cast in hot iron mould, fluxed with fluor-spar.—Dimensions: Length, 6.19″ (15.5 cm.); diameter, 0.798″ (2 cm.).

LOAD PER SQUARE INCH.	ELONGATION IN 6.19 INCHES.	SET.	ELONGATION IN PARTS OF ORIGINAL LENGTH.
Pounds.	*Inch.*	*Inch.*	
8,000	0.01	....	.0016
9,800	0.02	....	.0032
10,000	0.03	....	.0048
11,400	0.07	....	.0113
12,400	0.11	....	.0173
15,100	0.17	....	.0275
16,200	0.23	....	.0372
17,040	0.26	....	.0258
18,000	0.30	....	.0485
19,400	0.36	....	.0581
20,000	0.40	....	.0646
0	....	0.40	....
20,400	0.44	....	.0710
20,440	0.46	....	.0743

Broke at D end.

Diameter of fractured section, 0.763 inch.

Tenacity per square inch, original section, 20,440 pounds (1,437 kilogs. per sq. cm.).

Tenacity per square inch, fractured section, 22,353 pounds (1571 kilogs, per sq. cm.).

The following measurements were made of the diameter of the piece after breaking:

	Inch.
At fractured section	0.763
½ inch from fractured section	0.765
1 inch from fractured section	0.766
2 inches from fractured section	0.766
3 inches from fractured section	0.765
4 inches from fractured section	0.766
4½ inches from fractured section	0.767
5 inches from fractured section	0.768
6 inches from fractured section	0.768
6½ inches from fractured section	0.774

The importance of effective fluxing and of skill and care in melting and casting copper, are well shown by a comparison of the figures given above for ingot copper with those obtained for the several re-cast samples, and even better by contrasting the figures obtained for the latter with those to be given for rolled and drawn copper, which may be taken to represent the most perfect attainable soundness.

Rolled Copper as tested by the Author, in bars purchased in the market, had a tenacity of 32,000 pounds per square inch and reduced in section 40 per cent. Two samples from the same bar gave the same figure. Rolled copper has been tested by a committee of the Franklin Institute * who

**Journal of the Franklin Institute*, 1837.

found that the mean of over 60 experiments gave a tenacity of very nearly 33,000 pounds per square inch (2,399 kilogs. per sq. cm.), the variations amounting to from 2 to 5 per cent.

Rolled copper, tested by Bauschinger, exhibited tenacities varying from 29,000 to 32,000 pounds per square inch (2,663 to 2250 kilogs. per sq. cm.), with a reduction of section, at fracture, of 30 to 45 per cent.

Several authorities agree on nearly the following figures for various commercial forms of copper:

TABLE XXXVIII.

TENACITY OF COMMERCIAL FORMS OF COPPER.

	LBS. PER SQ. INCH.	KILOGS. PER SQ. CM.
Copper cast	24,000	1,434
" forged	34,000	2,137
" bolt	36,000	2,151
" sheet	36,000	2,151
" wire	62,000	4,232

Major Wade found the tenacity of " L. S." copper used in making U. S. ordnance to be from 24,000 to 25,000 pounds per square inch (1,688 to 1,758 kilogs. per sq. cm.), and that of other brands to be between 20,000 and 21,000 (1,463 kilogs.), increasing a little with hammering. The density varied between 8.523 and 8.757, the higher figures accompanying, usually, high values of T.

According to Trautwine, the strength of cast copper varies from 18,000 to 30,000 pounds (1,265 to 2,109 kilogs.), a range fully confirmed, as above, by the experiments of the Author. Bolt copper ranges from 25,000 to 40,000 pounds per square inch (1,758 to 2,812 kilogs. per sq. cm.), and wire is the stronger as it is drawn finer and harder, to an extent not yet well settled by experiment.

Wertheim obtained for the tenacity of hard wire 4,100 kilogs. per square centimetre of section (58,250 pounds per sq. in.), with an elongation of 0.0033, and for the same wire, annealed, 3,160 kilogs. (44,900 pounds), with an extension of 0.003.

Copper steam pipes are sometimes given a thickness

$$t = 0.00148\ n\ d + 0.16,\text{* nearly;}$$

or, according to some authorities,†

$$t = 0.0001\ d p + 0.125,$$

when t is the thickness in inches, n the number of atmospheres pressure, d the inner diameter, and p the pressure in pounds per square inch. Feed pipes are a little heavier.

170. Shearing Stresses for Copper and sheet brass are given by the Ordnance Bureau of the United States War Department ‡ as below:

TABLE XXXIX.

SHEARING OF COPPER AND BRASS.

Punching.

DIAMETER OF PUNCH.	PRESSURES.			THICKNESS OF SHEET.	PRESSURES. Circ. hole 1 in. diam.		IRON.	
	Brass, .05 inch thick.	Copper, .15 inch thick.	Iron, .105 inch thick.		Copper.	Brass.	Thickness.	Pressure, Circ. hole 1 in. diam.
In.	Lbs.	Lbs.	Lbs.	In.	Lbs.	Lbs.	In.	Lbs.
1.5	8,475	15,996	23,273	.3	21,248	......	.615	82,871
1.375	7,723	14,570	21,445	.205	15,542	......	.565	76,962
1.25	6,980	13.275	19,682	.150	11,088	......	.510	69,984
1.0	5,450	11,073	16,535	.100	8,461	......	.445	62,591
.9	5,092	9,788	14,778	......	......	......	.404	57,623
.8	4,332	8,580	12,602	.050	3,646	......	.358	51,382
.7	3,772	7,827	11,468	.045	3,362	5,448	.283	40,486
.6	3,267	6,706	9,772	.041	.....	4,997	.245	35,712
.5	2,635	5,507	7,916	.034	2,538	3,730	.183	27,978
.4	2,183	4,585	6,660	.032	2,212	3,540	.145	22,213
.3	1,673	3,435	4,970	.028	......	2,964	.104	16,533
.2	1,110	2,240	3,333	.022	1,544	2,448	.057	9,452

* Ordnance Manual. † Seaton on Marine Engineering.
‡ Ordnance Manual.

SHEARING.

Angle formed by shear-blades, 3 degrees.

Sheet Metals.

IRON.		COPPER.		BRASS.		STEEL, PUDDLED.	
Thickness.	Pressure.	Thickness.	Pressure.	Thickness.	Pressure.	Thickness.	Pressure.
In.	Lbs.	In.	Lbs.	In.	Lbs.	In.	Lbs.
1.0*	144,000	.207	11,196	.05	540	.24	14,020†
.615	53,440	.238	6,007	.042	423	.24	14,930‡
.510	39,150	.204	4,820	.035	333	...	....
.404	25,970	.150	3,676	.025	220	...	....
.283	15,715	.09	2,200	.024	200	...	....
.183	10,390	.064	1,006	....	...	...	....
.104	4,200	.05	552	....	...	...	....
.057	2.180	.02	113	....	...	...	....

Bolts.

IRON.				COPPER.		BRASS.	
Diameter.	Pressure.	Diameter.	Pressure.	Diameter.	Pressure.	Diameter.	Pressure.
In.	Lbs.	In.	Lbs.	In.	Lbs.	In.	Lbs.
1.142	35,410	.697	13,979	.943	18,460	1.110	29,790
1.040	30,707	.585	10,593	.906	13,872	.905	22,386
.945	24,057	.447	5,543	.775	11,310	.779	17,976
.812	19,688	.320	3,093	.635	8,218	.648	11,648

The shearing resistance of copper is usually given in office hand-books as from 22,000 to 30,000 pounds per square inch (1,420 to 2,109 kilogs. per sq. cm.). Its value may be taken as the same as in tension and as subject to the same variations.

The work done in shearing copper is, according to Haswell, measured, for punched holes, by

$$W = 96,000\, d\, t,$$

in which W is the work in foot-pounds, d the diameter of the hole, and t the thickness of the sheet in inches.

171. Resistance to Compression varies with copper, as with all ductile and malleable metals, more with variation of form of test-piece and method of application of the stress than with the ordinary modifications of composition and of form produced in manufacture, as ingots, sheets, rods, bolts,

* The cutters were parallel ; the bar 3 inches wide.

† With oil. ‡ Without oil.

etc. The application of a crushing force to a test-piece of standard size and proportions first reduces it to the barrel-form, then to that of a flat cheese-shaped mass, and finally to a sheet of which the *total* resistance to compression increases indefinitely as its area becomes greater by flow. The compression stress thus increases from about that required to produce rupture by tension to that demanded to produce free flow when the *intensity* of the stress is a maximum; and its total amount is limited only by the area of the sheet produced. The intensity, C, of resistance to compression is usually incorrectly stated, without limitation, as about 100,000 pounds per square inch (7,030 kilogs. per sq. cm.) for rolled or forged, and 120,000 pounds (8,436 kilogs.) for cast copper. The results of experiments of the Author, presently to be given, indicate that good cast copper, in cylinders of three diameters length, will exhibit a resistance which may usually be reckoned up to a compression of one-half or more, as

$$C = 145{,}000 \sqrt[3]{e}, \text{ nearly,}$$

$$C_m = 10{,}000 \sqrt[3]{e}, \text{ nearly,}$$

where C and C_m are the resistance to compression in British and metric measures, and e is the compression in unity of length, the resistance being reckoned per unit of original section. But the volume of the piece remaining practically unaltered, the section is increased very nearly in proportion to the compression, and the resistance will thus become

$$C^1 = 72{,}000 \sqrt[3]{e}, \text{ nearly,}$$

$$C_m = 5{,}000 \sqrt[3]{e}, \text{ nearly,}$$

when reckoned per unit of area of section actually, at the moment, under compression. Thus, for good cast copper, the intensity of pressure producing flow may be taken as not far from 75,000 pounds per square inch (5,270 kilogs. per sq. cm.).

Cast copper under compression gives the detailed results exhibited in the next tables, as obtained by the Author for the U. S. Board.

TABLE XL.

TESTS BY COMPRESSIVE STRESS.

Cast Copper.

No. 30.—Material: Lake Superior copper, cast in iron mould.—Dimensions: Length, 2″ (5.08 cm.); diameter, 0.625″ (1.6 cm.).

LOAD.	COMPRESSION.	LOAD PER SQUARE INCH.	COMPRESSION IN PARTS OF ORIGINAL LENGTH.	LOAD.	COMPRESSION.	LOAD PER SQUARE INCH.	COMPRESSION IN PARTS OF ORIGINAL LENGTH.
Pounds.	*Inch.*	*Pounds.*		*Pounds.*	*Inch.*	*Pounds.*	
500	0.003	1,630	.0015	12,000	0.162	39,114	.0810
1,000	0.005	3,259	.0025	13,000	0.205	42,373	.1025
2,000	0.008	6,519	.0040	14,000	0.251	45,633	.1255
3,000	0.011	9,778	.0055	15,000	0.294	48,892	.1470
4,000	0.014	13,038	.0070	16,000	0.337	52,152	.1685
5,000	0.018	16,297	.0090	18,000	0.422	58,671	.2110
6,000	0.021	19,557	.0105	20,000	0.510	65,190	.2550
7,000	0.026	22,816	.0130	21,000	0.559	68,449	.2795
8,000	0.035	26,076	.0175	22,000	0.642	71,709	.3210
9,000	0.051	29,335	.0255	Piece removed slightly bent. Surface wrinkled.			
10,000	0.080	32,595	.0400				
11,000	0.119	35,854	.0595				

No. 51 B.—Material: Cast copper.

LOAD.	COMPRESSION.	LOAD PER SQUARE INCH.	COMPRESSION IN PARTS OF ORIGINAL LENGTH.	LOAD.	COMPRESSION.	LOAD PER SQUARE INCH.	COMPRESSION IN PARTS OF ORIGINAL LENGTH.
Pounds.	*Inch.*	*Pounds.*		*Pounds.*	*Inch.*	*Pounds.*	
150	.0000	.....	.....	20,000	.6461	65,188	.3230
4,000	.0006	13,038	.0033	22,000	.7295	71,709	.3647
6,000	.0089	19,557	.0044	24,000	.7936	78,228	.3968
8,000	.0573	26,075	.0286	26,000	.8619	84,747	.4309
10,000	.1560	32,595	.0780	28,000	.9258	91,266	.4679
12,000	.2568	39,114	.1284	30,000	.9783	97,785	.4891
14,000	.3602	45,633	.1801	32,000	1.0308	104,303	.5154
16,000	.4489	52,152	.2244	Specimen did not show any cracks, but merely flattened down.			
18,000	.5511	58,671	.2756				

Both are tests of cast copper, and their difference illustrates well its variability in quality as ordinarily cast. With proper fluxing and protection from oxidation and absorption of air, the metal should give a uniform and maximum resistance.

Rolled Copper, according to Trautwine, is compressed 1/8th by a load of 103,000 pounds per square inch (7,241 kilogs. per sq. cm.). Its maximum strength in this direction is not far from that of cast copper, as above, although its resistance rises more rapidly as pressure is applied and compression produced.

172. **The Compression of Rolled Copper by Impact** has been determined by the Author while investigating the efficiency of "drop-presses," such as are used in making "drop-forgings."

Two drop-hammers of each of two kinds were used in making the comparison, weighing with dies about nine hundred and about three hundred pounds respectively, plain. They were adjusted to fall twenty-eight inches. The lost work was from 10 to 30 per cent.

The gauges used in measuring the work done by the hammers were cylinders of pure merchant copper, prepared for the purpose. They measured:

Size No. 1	2½ inches long	....	1¼ inches	diameter.
" " 2	2 "	"	1 "	"
" " 3	1¼ "	"	5/8 "	"

Of these, a considerable number were prepared and divided into three sets; one for use with each kind of hammer, and one for testing and standardizing in the testing machine. The work done by crushing the standards in the testing machine, to the same extent that companion specimens were crushed under the hammers, gave a measure of the action of the latter, and permitted a fair comparison to be made. The amount of work done in the slowly-acting testing machine, in producing a given compression, is somewhat less than where the same effect is suddenly produced, as by a falling weight; but this difference is not great and, if it could be determined and introduced, would increase the figure here given for efficiency.

The results of the experiments thus made are exhibited in the accompanying table, and are also shown in the diagram, Fig. 7. The final results are given in foot-pounds of work per pound of hammer, and the unavoidable differences in size are thus eliminated. The modulus of resistance to compression is also given.

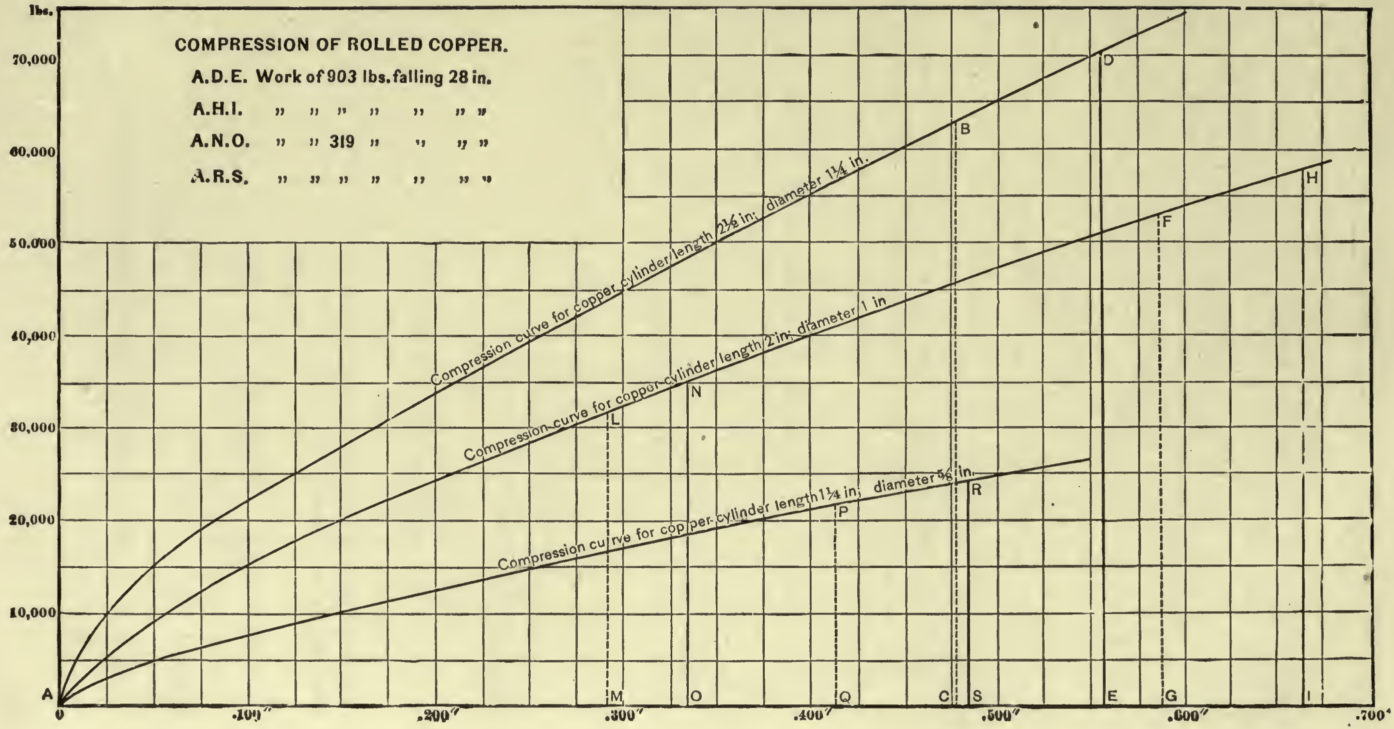
TABLE XLI.

TESTS OF COPPER BY IMPACT.

	WORK OF THE DROP-HAMMER.			
WEIGHT OF DROP.	903 lbs.		319 lbs.	
SIZE OF COPPER CYLINDER.	2½" x 1¼" diam. No. 1.	1" x 2" No. 2.	1" x 2" No. 2.	⅝" x 1¼" No. 3.
Area in square inches under compression curves. (See plate.)	A D E 45.23	A H I 45.26	A N O 13.75	A R S 13.76
	Average, 45.34.		Average, 13.75½.	
Reduced to work done, or inch pounds.	22,715	22,630	6,875	6,880
	Average, 22,672.		Average, 6,877.	
Ditto in foot pounds....	Average, 1,884.		Average, 576.	
Work done per pound of drop in inch pounds.	Average, 25.10		Average, 21.56	
Ditto in foot pounds....	Average, 2.09		Average, 1.8	
Final resistance to compression.	70,000 lbs. 31,751 kilogs.		35,000 lbs. 15,876 kilogs.	

The final resistance to compression in the testing machine was very nearly 25,000 pounds per square inch (1,760 kilogs. per sq. cm.). The method of variation of resistance is well shown in the accompanying diagram, in which the compression, in inches, is measured by abscissas, and the total corresponding load in pounds, by ordinates. The curves are nearly cubic parabolas.

Fig 7.—Compression of Copper.



The effect of impact on the tough metals having no definite limit of elasticity is modified by the velocity of the striking mass, and by the inertia of the piece attacked, to an extent, as yet, not fully determined. The experiments of Kick indicate a considerable increase of total work of resistance, when the piece is deformed in this manner, over that noted when the compression is produced slowly by steady pressure. The experiments of the Author also indicate that this work is the greater, with soft and malleable metals, as the velocity of action is increased. The real efficiency of the press, as above, is thus probably somewhat greater than the figures obtained would indicate.

In the preceding figure, the areas cut off under the curves by the ordinates in full lines are measures of the work of the most efficient drop-hammers, while those cut off by the dotted ordinates give the work of less efficient machines.

173. Copper, Subjected to Transverse Stress, is probably always to be considered as belonging to the second class of materials treated of in Art. 161, and as more correctly represented by the equation *b*. (p. 260) of Art. 166, than the usually adopted equations preceding them, *i.e.*

$$M^1 = R^1 \int_o^b \int_o^{d_1} y\, dy\, dx, \text{ and } Fl = 2\, \pi\, s_1 \int_{r_0}^{r_1} r^2\, dr,$$

instead of

$$M = \frac{R}{d_1} \int_o^b \int_o^{d_1} y^2\, dy\, dx, \text{ and } Fl = \frac{2\, \pi\, s_1}{r_1} \int_{r_0}^{r_1} r^3\, dr,$$

the former of which, for rectangular bearers and solid shafts, would become, were $T = C$,

$$M^1 = \frac{1}{4} R^1 \frac{b\, d^2}{l}; \qquad Fl = 2.2\, s_1\, r^3,$$

instead of

$$M = \frac{1}{6} R \frac{b\, d^2}{l}; \qquad Fl = 1.6\, s_1\, r_1^3.$$

The values of T and C are not, however, the same, and the differential expression must be integrated for the two sides of the bar separately.

Cast copper, tested by transverse stress, when of fair quality should give figures equal to, or exceeding, those obtained in the record which follows:

TABLE XLII.

TEST OF BAR OF CAST COPPER.

No. 55.—Material: Copper, cast in iron mould.—Dimensions: Length between supports, $l = 22''$; breadth, $b = 0.985''$; depth, $d = 0.970.''$

LOAD.	DEFLECTION.	SET.	MOD. ELASTICITY.	LOAD.	DEFLECTION.	SET.	MOD. ELASTICITY.
20	0.0033	......	....	480	0.4088	......	....
40	0.0075	......	15,792,947	500	0.4855	......	....
80	0.0176	......	13,459,739	5	......	0.3619	....
100	0.0224	......	13,219,331	540	0.6343	......	....
5	......	0.0001	....	580	0.8378	......	....
140	0.0337	......	12,301,425	Ruptured.	......	......	....
180	0.0477	......	11,174,068	580	0.8653	......	....
200	0.0552	......	10,728,725	680	1.46	......	....
5	......	0.0095	....	720	1.74	......	....
240	0.0674	......	10,540,763	800	2.39	......	....
280	0.0910	......	9,111,146	840	2.85	......	....
320	0.1176	......	....	860	3.23	......	....
360	0.1553	......	....	Supports slid out. Bar bent.			
400	0.2057	......	....	Breaking load, P = 860 pounds.			
5	......	0.1114	....	Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 30,621.$			
440	0.2883	......	....				

The modulus of rupture for good cast copper should thus exceed 30,000 pounds per square inch (2,109 kilogs. per sq. cm.), but may be expected to vary between 20,000 and 40,000 (1,406 and 2,812 kilogs.) with variations in the soundness and quality of the metal.

Rolled Copper, as tested by the Author, when of good quality and sound, may give values of the modulus of rupture as high as $R = 60,000$ pounds per square inch (4,218 kilogs. per sq. cm.), and sometimes exceeds this figure, one test under the eye of the Author, having given $R = 60,900$ $R_m = 4,281$.

174. **The Modulus of Elasticity of Copper** is almost invariably obtained by calculation from the results of transverse tests, using the expressions,

$$E = \frac{Pl^3}{48SI}, \quad E = \frac{Pl^3}{4Sbd^3},$$

for the general case and for rectangular sections, respectively,* when the weight of the bar may be neglected, as is the case with metal test-pieces, usually. By reference to the records of tests of cast copper already described (Table XXXVI., Art. 168), it will be seen that this modulus may vary, with even the variation of light loads, from 10 to 15 million pounds per square inch (703,000 to 1,054,500 kilogs. per sq. cm.), and the same differences are observable as a consequence of varying quality. The higher values obtained in any one test are the most probably correct, and it may be assumed that the modulus of elasticity of copper approaches 15,000,000 pounds per square inch (1,054,500 kilogs. per sq. cm.), as the metal is obtained in a state approximating purity and soundness. Usual values are two-thirds to three-fourths these.

Some authorities give values exceeding the maximum, as above, by 20 per cent., but such figures are not to be expected in the ordinary work of the engineer.

Forged and wire-drawn copper, as tested by Wertheim, gave the following values of this modulus:

	KILOGS. PER SQ. CM.
Copper, hard-drawn	1,245,000
" "	1,254,000
" annealed	1,052,000
" "	1,254,000

or very nearly 18,000,000 pounds per square inch for hard-drawn, and 20 per cent. less, in some cases, for annealed wire.

* See Part II., p. 499, § 268.

175. **Copper Subjected to Torsion** is found to exhibit the same variation of resistance with quality and physical structure that has been seen in other methods of test. The experiments of the Author give values of s_1 in the equations for total resistance, Art. 166, ranging between 20,000 and 40,000 pounds per square inch (1,406 and 2,812 kilogs. per sq. cm.), the lower figure for cast copper of ordinary soundness, and the higher for good forged or rolled copper. Thus for the two cases, it may be assumed that copper shafts will break under load when

$$d_1 = \sqrt[3]{\frac{Fl}{4,000}}, \text{ or } d_1 = \sqrt[3]{\frac{Fl}{8,000}} \quad . \quad . \quad (14)$$

accordingly as they are made of cast or worked copper, when the units employed are inches and pounds, or

$$d_{1m} = \sqrt[3]{\frac{Fl}{300}}, \text{ or } d_{1m} = \sqrt[3]{\frac{Fl}{400}} \quad . \quad . \quad (15)$$

when the units are metric.

Copper is seldom subjected, however, to any other than tensile stresses. It would probably be more correct to use the expressions in Art. 166 for tough metals than the above, making the true value of $s_1 = 15,000$ to $30,000$ pounds.

176. **Results of all Tests of Cast Copper** made for the Committee on Alloys of the U. S. Board being collected, rejecting all tests of samples known to be defective, the following figures were obtained. It will be remembered that these experiments were made with ordinary commercial metals melted and cast in the usual way and purposely without other precaution than is usually taken in every-day foundry work. Much higher figures, as has been seen, may be attained.

TABLE XLIII.

AVERAGE OF TESTS OF COPPER.

	TRANSVERSE TESTS.				TENSILE TESTS.				TORSIONAL TESTS.			
	Breaking load.	Modulus of rupture.	Elastic limit—parts of breaking load.	Modulus of elasticity.	Elongation—parts of original length.	Tenacity per square inch of— Original section.	Tenacity per square inch of— Fractured section.	Elastic limit—parts of breaking load.	Maximum torsional moment.	Torsional moment at elastic limit.	Elastic limit—parts of breaking load.	Extension of exterior fibre.
Brit. Meas.	765	26,357	0.232	10,076,756	0.0628	23,118	26,817	0.491	118.06	41.79	0.354	0.2630
Metric	348	1,853	0.232	708,396	0.0628	1,625	1,885	0.491	16.4	5.8	0.354	0.263

The composition of these bars of copper was found to be:

ANALYSES OF TURNINGS FROM FOUR BARS OF COPPER.

	NO. 1.	NO. 30.	NO. 53.	NO. 57.
Metallic silver..................	0.035	0.014	0.015	0.063
Metallic iron..................	0.020	0.014	0.035	0.014
Metallic zinc..................	0.014	0.057	0.016	None.
Metallic lead..................	Trace.	Trace.	None.	Trace.
Metallic bismuth..............	None.	None.	None.	None.
Metallic arsenic................	None.	None.	None.	None.
Metallic antimony............	None.	None.	None.	None.
Suboxide of copper............	12.086	3.580	6.730	1.620
Metallic copper................	87.900	96.330	93.200	98.330
Insoluble matter................	....	....	....	0.005
Carbon..........................	None.	....	....	....
	100.055	99.995	99.996	100.032

177. **The Strength of Tin**, as obtained in the market, is variable with the brand, the purity, the soundness, and density of the metal, with the temperature and the velocity of distortion and rupture, and with other variable conditions, as

is the strength of copper, but in less degree so far as it depends upon the skill and care of the metallurgist. It is less subject to injury by the presence of deleterious elements, and is less liable to become unsound in melting and casting.

Mallet obtained a tenacity of 5,600 pounds per square inch (3,936 kilogs. per sq. cm.), Rennie about 5,000 pounds per square inch (3,515 kilogs. per sq. cm.), and the Author has obtained figures for the U. S. Board, and in other experiments, ranging from 2,000 to 6,000 pounds per square inch (1,406 to 4,218 kilogs. per sq. cm.) for Banca and Australian tin of the following composition:

COMPOSITION OF TIN OF COMMERCE.

	INGOT BANCA TIN.	INGOT QUEENSLAND TIN.
Metallic iron	0.035	0.035
Metallic zinc	None.	None.
Metallic silver	.....	.....
Metallic arsenic	None.	Trace.
Metallic antimony	None.	None.
Metallic cobalt	.....	None.
Metallic bismuth	None.	None.
Metallic nickel	.	None.
Metallic lead	None.	0.165
Metallic manganese	.....	0.006
Metallic molybdenum	None.	None.
Metallic tungsten	.....	None.
Metallic copper	None.	None.
Metallic tin	99.978	99.794
Suboxide of copper	.....	.....
Carbon	.....	.....
Matter insoluble in aqua regia	Trace.	.....
	100.013	100.000

In casting tin in iron moulds, a difficulty was met with in the formation of surface "cold-shuts," producing an irregular section in bars of otherwise sound condition. Tests made as above give data as follows:

TABLE XLIV.

TENSION TESTS OF TIN (*Banca*).

Nos. 29 A, and 29 B.

LOAD.	LOAD PER SQUARE INCH.	ELONGATION IN 6 INCHES.	ELONGATION IN PARTS OF ORIGINAL LENGTH.	
Pounds.	*Pounds.*	*Inches.*		
1,700	3,400	0.15	.025	Broke ⅛ inch from A end. Diameter of fractured section 0.490 inch (approximately). The section was very much distorted, and an exact measurement could not be obtained. Tenacity per square inch of original section, considering 1,400 pounds as the breaking load, 2,800 pounds (with gradual test) (1,462 kilogs. per sq. cm).
0	.....	Set 0.15	.025	
Reduced to—				
1,250	2,500	0.19	.0318	
In 2 m.	2,500	0.27	.045	
1,400	2,800	0.32	.0533	
In 10 m.	2,800	1.70	.2833	
975	1,950	0.01	.0017	Broke 2 inches from D end. Fractured section very irregular, and drawn out almost to a point. Estimated diameter of final section 0.300 inch. Tenacity per square inch of original section (*with rapid test*) 4,200 pounds (2,953 kilogs. per sq. cm.).
1,180	2,360	0.03	.0050	
1,290	2,580	0.09	.0150	
1,600	3,200	0.20	.0332	
2,000	4,000	0.58	.0963	
2,100	4,200	1.88	.3123	
Piece extending rapidly and strain reduced to—				
1,700	3,400	2.58	.4269	

TABLE XLV.

Summary.

NO.	DIAMETER.		Total elongation—parts of original length.	TENACITY PER SQUARE INCH.		Elastic limit—pounds per square inch.	REMARKS.
	Original section.	Fractured section.		Original section.	Fractured section.		
29 A ...	0.798	0.490	0.2833	2,800	....	......	Tenacity of fractured section doubtful.
29 B ...	0.798	0.300	0.4269	4,200	....	......	
Mean ..	.....	0.395	0.3551	3,505	....	......	

The strength per square inch of fractured section is not given for comparison, as it is not an indication of either the ultimate or the useful strength of the metals, except they have but a slight ductility and show no increase of elongation under continued stress. With ductile metals, the portion of the test-piece near the point of fracture gradually narrowed down as the breaking load was approached, and in most cases this narrowing, or "necking down," was very rapid just before fracture. In such cases the beam of the scale dropped before fracture took place, showing decrease of resistance and decrease of stress. The final rupture was caused by some load less than the maximum. In a few cases, it was possible to follow the decrease of resistance by balancing the scale-beam, nearly to the instant of rupture, but the actual load sustained by the piece at the instant of rupture could never be determined. The so-called "tenacity per square inch of fractured section," found by dividing the maximum load by the area of section measured after fracture, is no measure of the strength of the metal.

This peculiar method of drawing down at the part nearest the section ruptured is well shown in the figure, and may be taken as illustrative of this action in all tough, ductile materials. The influence of variation of velocity of distortion will be exhibited in a later chapter.

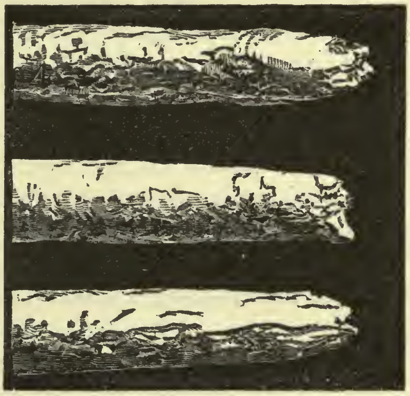


FIG. 8.—FRACTURE OF TIN.

Authorities give various values for the tenacity of other forms of tin, some of which are given above. Trautwine gives for block-tin 4,600 pounds, and for wire 7,000 pounds per square inch (2,854 and 4,921 kilogs. per sq. cm.).

Tests by Compression, made as above, gave values as in the succeeding record:

TABLE XLVI.

RESISTANCE TO COMPRESSION: CAST TIN.

No. 29 C.—Material: Banca tin, cast in iron mould.—Dimensions: Length, 2″; diameter 0.625″.

LOAD.	COMP.	C.	COMP. PER UNIT.	
1,250	0.003	4,074	.0015	At 1,850 pounds (110 kilogs. per sq. cm.), the piece was observed to be bulging out on all sides, but still remaining vertical. At the end of the test the piece had a slight bend in one direction, and was increased in diameter to 0.85 and 0.89 inch in different parts of the length.
1,500	0.012	4,889	.0060	
1,750	0.043	5,704	.0215	
1,850	0.097	6,030	.0485	
1,900	0 158	6,193	.0790	
2,000	0.265	6.519	.1325	
2,000	0.473	6,519	.2365	
2,200	0.612	7,171	.3060	
2.300	0.729	7,497	.3645	
2,300	0.899	7,497	.4445	

With tin, as with copper, and all ductile metals, the resistance to compression per unit of original section increases indefinitely with progressing distortion, and probably attains a maximum, as reckoned per unit of momentary sectional area, when the intensity of stress becomes equal to the resistance to the metal to continuous flow.

Elastic limits are even less well defined with tin than with copper, and the resistance rises rapidly, at the start, as distortion commences and progresses. Resistance to compression is stated by Trautwine and Haswell as above 15,000 pounds per square inch (1,054 kilogs. per sq. cm.).

178. **Tin under Transverse Test** behaves much like copper, but it has less strength and even less elasticity. It is the best representative of the viscous class of metals, and, as will be seen in the chapter on conditions modifying strength of the non-ferrous metals, is peculiarly susceptible to variation of time of loading and rapidity of distortion. Tests of cast tin made by the Author for the government, as above, gave data of which the following is fairly illustrative:

TABLE XLVII.

CAST TIN IN TRANSVERSE TEST.

No. 29.—Material: Banca tin, cast in iron mould.—Dimensions: Length between supports, 22″; breadth, 0.993″; depth, 1.002″.

LOAD.	DEFLECTION, Δ.	SET.	MODULUS OF ELASTICITY. $E=\frac{l^3}{4\Delta bd^3}(P+4)$	LOAD.	DEFLECTION, Δ.	SET.	MODULUS OF ELASTICITY. $E=\frac{l^3}{4\Delta bd^3}(P+4)$
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
3	0.0008	......	....	80h. in 5m	0.282	.....	.....
5	0.0032	......	....	5	.....	0.265	.....
10	0.0055	......	....	85	0.340	.....	.....
20	0.0095	......	6,734,838	In 10 m	0.840	.....	.....
0	......	0.0047	....	90	0.966	.....	.....
24	0.012	......	6,218,983	90h. 10m.	1.199	.....	.....
30	0.015	......	6,039,908	0	.....	1.155	.....
35	0.017	......	....	100	1.360	.....	.....
0	......	0.0055	....	In 5 m.	1.624	.....	.....
40	0.021	......	5,583,107	In 20 m.	2.124	.....	.....
0	......	0.0095	....	0	.....	2.065	.....
45	0.029	......	....	110	2.332	.....	.....
0	......	0.015.	....	In 10 m.	8.395	Bar bent and tray reached bottom of supports.	
50	0.041	......	3,517,648				
0	......	0.021.	....				
60	0.062	......	2,750,622				
0	......	0.043.	....				
70	0.104	......	....				
0	......	0.082.	....				
80	0.218	......	1,026,751				

Crack observed on under side of bar extending across half its breadth.

Breaking load, 110 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=3{,}750.$

R_m (metric), = 262.9

Tests of Queensland and Banca tin, compared, stood as follows:

TRANSVERSE TESTS OF TIN.

Number.	MATERIAL.	Length between supports.	Breadth, b.	Depth, d.	Breaking load, P.	Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}$	Total deflection, Δ.	Limit of elasticity. Load.	Limit of elasticity. Parts of break-load.	Modulus of elasticity.	REMARKS.
		Ins.	*Ins.*	*Ins.*	*Pds*		*Ins.*				
58	Queensland tin..	22	1.038	1.023	150	4,559	3. +	4	.267	5,635,593	Bent.
29	Banca tin.......	22	0.993	1.002	110	3,740	8. +	3	.273	6,734,838	Bent.
	Mean of 2 bars..	......	......	......	130	4,150	....	....	.270	6,185,210	

Queensland tin proved very good, showing a somewhat greater strength by transverse and torsional test than Banca tin, but a less strength by tension. The transverse strength probably appears higher than it should be, both on account of different methods of test, the Banca tin being tested by dead loads and the Queensland tin by platform-scale, and on account of a perceptible flaw in the centre of the Banca bar.

In the test of No. 29, as above, a load of 40 pounds produced a set of 0.0095 inch, and the elastic limit appeared to be reached at about 30 pounds. At 80 pounds a crack was observed on one of the edges on the under side of the bar, which gradually opened but did not increase in length. At 110 pounds the bar sank gradually, the deflection increasing more than 6 inches in ten minutes. The bar was finally broken by repeated bending, and showed that the crack above mentioned was produced by an imperfection in the casting, about one-fourth of the surface, or that portion in which the crack was observed, showing radiated lines of cooling and the remainder the close pasty appearance peculiar to tin ruptured by bending. The crack weakened the bar, and the final bending was resisted by but little more than three-fourths of the section.

Major Wade found the tenacity of Banca tin used in making U. S. Army ordnance to be 2,122 pounds per square inch (148 kilogs. per sq. cm.); its density was 7,297.

179. **The Modulus of Elasticity of Tin** is stated by Tredgold at 4,600,000 pounds per square inch (285,400 kilogs. per sq. cm.) for cast metal, by Molesworth at same figure nearly, and is found by the Author to vary up to nearly 7,000,000 pounds (492,000 kilogs., nearly). Some of the figures obtained are given in the records of transverse tests of cast tin already referred to.

No values have been found for other forms of this metal. Tin is, however, probably less affected by the form in which it enters the market than other common metals, and the moduli here given may be accepted for general use as substantially accurate.

180. **Tin in Torsion**, as tested by the Author, gives

figures of which the following, from the Report of the **U. S.** Board, may be taken as fairly representative :

TABLE XLVIII.

TORSIONAL TESTS OF TIN.

Averages of Results calculated from Autographic Strain-Diagram.

Number.	MATERIAL.	Area of diagram.	Angle of torsion.	Ordinates of diagram. Maximum.	Ordinates of diagram. At elastic limit.	Torsional moment. Maximum.	Torsional moment. At elastic limit.	Extension of exterior fibre.	Resilience.	No. of pieces averaged.
		Sq. ins.	*Degrees.*	*Ins.*	*Ins.*	*Ft.-lbs.*	*Ft.-lbs.*		*Ft.-lbs.*	
58	Queensland tin ..	42.78	691.0	0.73	0.22	13.15	4.36	2.9029	208.48	3
29	Banca tin	21.26	556.8	0.48	0.13	12.75	5.78	2.1975	105.45	4
	Mean (British) ...	32.02	623.9	0.61	0.18	12.95	5.07	2.5502	156.97	....
	Metric	20.6	623.9	1.6	0.46	1.8	0.7	......	......	....

The Queensland tin showed an extraordinary ductility in the torsional tests, one of the pieces twisting through an angle of 818 degrees, or more than 2¼ turns before breaking. This represents an elongation of a line of particles parallel to the axis on the surface of the cylindrical portion of the test-piece from one inch to 4.57 inches.

The average of all tests of tin is given in the following:

AVERAGE RESULTS OF TESTS OF TIN.

TRANSVERSE TESTS.				TENSILE TESTS.				TORSIONAL TESTS.				
Breaking load.	Modulus of rupture.	Elastic limit—parts of breaking load.	Modulus of elasticity.	Elongation—parts of original length.	Tenacity per square inch of— Original section.	Tenacity per square inch of— Fractured section.	Elastic limit—parts of breaking load.	Maximum torsional moment.	Torsional moment at elastic limit.	Elastic limit—parts of breaking load.	Extension of exterior fibre.	Resilience.
130	4,150	.270	6,185,210	.3551	3,130	.....	.476	12.95	5.07	.392	2.5502	156.97

181. The Strength of Zinc has been determined by but few investigators, and, like that of all other useful metals except iron and steel, is a subject of which comparatively little is known by the engineer.

Cast zinc is stated to have a tenacity of about 4,000 pounds per square inch (281.2 kilogs. per sq. cm.), and a resistance in compression of ten times that amount. Stoney states the tenacity at nearly 3,000 pounds (211 kilogs.) cast, and Trautwine gives for sheet-zinc and zinc wire 16,000 and 22,000 pounds per square inch (1,124.8 and 1,546.6 kilogs. per sq. cm.), respectively. The modulus of elasticity is given by Wertheim and by Tredgold at from 12,000,000 to nearly 14,000,000 pounds per square inch (843,600 to 984,200 kilogs. per sq. cm.), the value being higher for cast zinc. The Author has obtained much smaller figures.

Pure zinc, like pure tin, is never used alone, by the engineer, for purposes demanding strength and toughness. The values of the several moduli are given as of interest, however, and for comparison.

Samples of *cast zinc* tested by the Author show variable tenacity, the figures ranging between 4,500 and 6,500 pounds per square inch (2,847 to 4,253 kilogs. per sq. cm.), or considerably above those given by earlier investigators. All the zinc thus tested by the Author was very pure, and made from New Jersey calamine. The effects of varying time and rapidity of strain are observable in zinc, as in tin, and are the same in kind; they will be described later.

Zinc is much less ductile than tin.

The resistance of zinc to compression varies with the degree of reduction, and, as tested by the Author, was about 22,000 pounds per square inch (1,547 kilogs. per sq. cm.) when the compression amounted to one-tenth the original height of test-piece in pieces three diameters long, and one-half greater for a compression of one-third. Zinc is weaker under compression than any copper-zinc alloy.

Zinc has no defined elastic limit, but an apparent elastic limit in compression was recorded at 5,000 pounds per square inch (352 kilogs. per sq. cm.).

182. Records of Test of Zinc are given below, as reported to the U. S. Board.

TABLE XLIX.

TENACITY OF CAST ZINC.

Length, 5″; diameter, 0.798″.

LOAD.	TOTAL EXTENSION.	SET.	PER CENT. ELONGATION.	REMARKS.
800	0.0011	....	0.02	
1,200	0.0024	....	0.02	Diam. fractured.
1,600	0.0034	....	0.07	Section, 0.796″.
2,000	0.0051	....	0.10	Tenacity, 6,300 pounds
3,000	0.0097	....	0.19	per square inch (4,429
4,000	0.0157	....	0.31	kilogs. per sq. cm.).
200	.....	0.0096	....	
5,000	0.0206	....	0.41	
6,000	0.0240	....	0.48	
6,300	Broke.	....	....	

COMPRESSION OF CAST ZINC.

Length, 2″; diameter, 0.625″.

LOAD.		COMPRESSION.	LOAD.		COMPRESSION.
Total.	Per sq. in.	Per cent.	Total.	Per sq. in.	Per cent.
1,000	3,259	0.15	8,000	26,076	12.15
2,000	6,519	0.55	9,000	29,335	17.15
3,000	9,778	1.85	10,000	32,595	20.60
4,000	13,038	3.40	10,000	"	21.80
5,000	16,297	5.10	10,500*	34,225	24.40
6,000	19,557	7.20	Resistance fell to		
7,000	22,816	10.65	10,000	32,595	33.35

* Continued one minute.

CAST ZINC LOADED TRANSVERSELY.

LOAD.	DEF.	SET.	E.	REMARKS.
20	0.0101	...	....	
40	0.0171	...	6,698,725	
60	0.0246	...	6,927,556	Modulus of rupture,
80	0.0324	...	6,984,644	$R = 7,540$ pounds per
100	0.0424	...	6,655,180	sq. in. (5,300 kilogs.
120	0.0506	...	6,680.965	per sq. cm.).
140	0.0616	...	6,395,032	Most probable value
3	......	0.0	....	of E = 6,900,000
160	0.0753	...	5,973,588	$E_m = 428,130$.
180	0.0906	...	5,581,549	
200	0.1244	...	1,797,132	
Broke.	......	...	....	

TESTS OF CAST ZINC BY TORSION.

Length, 1″; diameter, 0.625″.

NO.	AREA DIAGRAM.	ANGLE.	MAX. ORDINATE.	MAX. MOMENT.	EXTEN. EXTER. FIBRE.
21 A	19.63	123°	2.15	37.83	0.2042
21 C	18.81	129	2.07	36.55	0.2227
21 D	17.24	151	1.95	34.42	0.2955
21 B	18.13	163	2.15	37.83	0.3380

183. Other Metals than those already described have been made the subject of very few experiments and the data obtainable are very unsatisfactory. The *alloys* of the three principal non-ferrous metals are made the subject of succeeding chapters.

Lead has a tenacity which is reported by Haswell as:

	LBS. PER SQ. IN.	KILOGS. PER SQ. CM.
Lead, cast..........................	1,800	116.5
" milled..........................	3,320	233.4
" wire..........................	2,580	181.4

In compression the resistance is stated to be 7,700 pounds per square inch (541 kilogs. per sq. cm.) and the modulus of elasticity is given as 720,000 lbs. (49,350 kilogs.). Wertheim, however, obtains a value of 21,500,000 pounds per square inch (175,750 kilogs. per sq. cm.). Trautwine gives, for tenacity:

	LBS. PER SQ. IN.	KILOGS. PER. SQ. CM.
Lead, cast	1,800 to 2,400	116.5 to 168.7
" pipe	1,700 to 2,240	119.5 to 157.5
" wire	1,600	112.5
" sheet	1,925	155.5

as collated from various older experiments, and a resistance to compression agreeing with Haswell.

The strength of lead pipe, as obtained in market, has, when tested, been found variable. The best results noted by the Author * indicate a tenacity of the metal exceeding one ton per square inch (2,240 lbs.; 157.5 kilogs. per sq. cm.). Comparing the results of a number of experiments to obtain a value of p in Clark's formula:

$$T = \frac{p}{\log R}; \qquad p = T \log R;$$

in which T is the tenacity, p the pressure, and R the ratio of external and internal radii, a mean value of T was found to be 1.4 tons per square inch (220.5 kilogs. per square cm.). The minimum value was three-fourths as great. It is probable that a much lower pressure, long continued, would have burst these pipes.

The thickness of lead pipe is frequently determined by the rule:

$$t = 0.0024\, n\, d + 0.2,$$

in which t is the thickness in inches, n the pressure in atmospheres and d the internal diameter in inches.

* Lond. Engineer; Nov. 16, 1883, p. 378.

Antimony has a tenacity of about 1,000 pounds per square inch (70 kilogs. per sq. cm.), and *bismuth* of three times that amount. *Gold* is a moderately strong metal, with a tenacity, cast, of 20,000 pounds per square inch, and of 30,000 in wire (1,406 to 2,109 kilogs. per sq. cm.). *Silver* is reported to be about equally strong (?) in the two forms, having a tenacity of 40,000 pounds per square inch (2,812 kilogs. per sq. cm.), according to Baudrimont. Platinum has a strength of from 30,000 to above 50,000 pounds (2,109 to 3,515 kilogs.). Nickel, tested by the Author, exhibited tenacities of from 50,000 to 54,000 pounds per square inch (3,515 to 3,543 kilogs. per sq. cm.), elongating about 10 per cent. Palladium, tested by Wertheim, had a tenacity equal to that of nickel. It is questionable whether any of these metals have a true elastic limit.

184. Wertheim on Elasticity.—Wertheim gives the following as the densities, atomic weights, and products of the two, and also the tenacities and sound-conductivity of several metals:

	S. G.	AT. WT.	S. G. × A. W.	RESISTANCE TO RUPTURE PER MILLIMETRE.		Coefficient of elasticity (Tredgold).	Rapidity of sound (Chladni).
				By extension (Guyt-Morveau).	By compression (Rennie).		
Lead	11.352	12.94498	0.8769	0.022	1.45	600	....
Tin	7.285	7.35294	0.9907	0.063	6.20	3.200	7.5
Gold	19.258	12.43013	1.5493	0.274	....	.....	....
Silver	10.542	6.75803	1.5599	0.341	....	.....	9.0
Zinc	6.861	4.03226	1.7015	0.199	....	9.600	....
Platinum	21.530	12.33499	1.7454	0.499	....	.....	....
Copper	8 850	3.95695	2.2365	0.550	38.55	.....	12.0
Iron	7.788	3.39205	2.2959	1.000	....	20.000	17.0

He infers a general variation of cohesion with change of intramolecular distances, and obtains his data from experiments upon fifty-four binary alloys and nine ternary alloys, among which are found also most of the alloys employed in the arts, such as brass, pinchbeck, gong-metal annealed and unannealed, bronze, packfong, type-metal, etc.

These experiments gave the following results:

1st. If we suppose all the molecules of an alloy to be the same distance from one another, we find that, in general, the smaller the mean distance, the greater is the coefficient of elasticity.

2d. The coefficient of elasticity of the alloys agrees sufficiently well with the mean of the coefficient of elasticity of the constituent metals, some alloys of zinc and copper being the only exceptions. The only condensations and expansions which occur during the formation of the alloy do not sensibly affect the coefficient. We can then calculate beforehand what should be the composition of an alloy in order that it may have a given elasticity, or that it may conduct sound with a given rapidity, provided that this elasticity or this velocity fall within the limits of the values of these same quantities for the known metals.

3d. Neither the tenacity, nor the limit of elasticity, nor the maximum elongation of an alloy can be determined *a priori* by means of the same quantities as determined for the metals which compose them.

4th. The alloys behave like the simple metals as to longitudinal and transverse vibrations, as well as elongation.

Wertheim,* experimentally determining the moduli of elasticity of various metals, under varying conditions, came to the following conclusions:

1st. The modulus of elasticity is not constant for the same metal; whatever augments the density increases it, and reciprocally.

2d. The longitudinal and transverse vibrations give the same modulus of elasticity.

3d. Vibration gives moduli of elasticity much greater than those obtained by elongation. This difference is due to the acceleration of movement produced by liberated heat.

4th. Consequently, sound in solid bodies is due to waves and condensation, and we may be able by means of the for-

* Comptes Rendus. Vol. 15, 1842.

mula of M. Duhamel to find the relation of specific heat under constant pressure to that at constant volume. This ratio is greater for annealed than for non-annealed metals.

5th. The modulus of elasticity diminishes with the elevation of the temperature at a more rapid rate than that which is due to the corresponding dilation.

6th. Magnetization does not sensibly change the elasticity of iron.

7th. The elongation of rods and bars by the application of loads affects their densities very slightly. The coefficient of elasticity should, therefore, vary as little in the different positions of equilibrium; and this is, in fact, what takes place, in so far as the loads do not become great enough to produce rupture. The law of Gerstner is therefore confirmed by all the metals of which the particles take a position of equilibrium after having passed their limit of elasticity.

8th. The permanent alloys are not found intermittently, but in a continuous manner. By suitably limiting the load and its duration of action, such permanent elongation as may be desired can be produced.

9th. No true limit of elasticity exists; and if no permanent elongation is observed for the first loads, it must be because they have not been allowed time to act, and because the rod submitted to the experiment is too short relatively to the delicacy of the measuring instrument.

The values of maximum elongation and of cohesion also depend much on the manner of operation. They become greater the more slowly the loads are increased. It may be seen from this how arbitrary is the determination of least and of greatest permanent elongation, and that we cannot found a law upon their values.

10th. The resistance to rupture is considerably diminished by annealing. The elevation of the temperature, even to 200° C., does not greatly diminish the cohesion of metals previously annealed.

Wertheim's values of the moduli for several metals are, in round numbers, as follow.*

* "Physique Mécanique."

TABLE L.

MODULI OF ELASTICITY OF METALS.

	LBS. PER SQ. IN.	KILOGS. PER SQ. CM.
Lead	2,500,000	176,000
Cadmium	7,700,000	492,000
Gold	11,500,000	808,500
Silver	10,000,000	703,000
Palladium	17,000,000	1,195,000
Platinum	24,000,000	1,687,000

Bischof's Method of Test to determine the purity and economic value of metals consists in making strips of a definite and standard size and subjecting them to repeated bending. The purer the metal, as a rule, the greater the number of changes of form required to produce fracture. Zinc, for example, was found to withstand 100, 54 or 19 bendings accordingly as it was pure zinc, best commercial spelter or the lowest quality. The ill effect of the introduction of 0.00001 tin, or of 0.0004 cadmium is perceivable even more certainly than by analysis.

Metals which do not alter by remelting, as tin or zinc, are melted in crucibles, with continual stirring and then cast in ingot moulds, 12 cm. long, 1.3 cm. square at the top and 0.3 cm. square at the bottom, 40 or 50 grammes being taken for a test, or 60 grammes for lead. The bars thus made are rolled to the desired thinness, annealed and tested. Metals, as brass, bronze or copper, which are liable to change in fusion, are rolled from the commercial form, with repeated annealing. The strips tested by Bischof were 13 cm. (4 inches) long, 0.7 cm. (2 inches) wide and of such thickness that they weigh as follows: Copper, 17; brass, 16; tin and zinc, 15; lead, 25; iron and steel, 12 grammes. They were tested in a "metallometer," in which they could be bent conveniently to any angle. Repeated flexure and reflexure through an angle of 67½ degrees was found best adapted to bring out the quality of the metal. Ten strips were tested simultaneously, and fifty tests were usually made of each metal, occupying from an hour to an hour and a half. The following are some of the results:

(1.) ZINC.—NUMBER OF BENDINGS OF CHEMICALLY PURE ZINC—100.

100 parts chemically pure zinc alloyed with	Tin.	Cadmium.	Lead.	Copper (precipitated in the galvanic way).	Iron.	Aluminium.
5.0 parts....	Could not be rolled.	Could not be rolled.	..	80	Could not be rolled.	..
4.0 "			..	76		..
3.0 "			93	73		..
2.0 "			..	77		..
1.0 "			95	61		..
0.5 "			91	54	52	..
0.25 "			100	61	59	95
0.10 "	53	29	..	64	64	89
0.05 "	57	35	..	69	62	97
0.025 "	57	41	..	83	60	..
0.0125 "	..	45	..	82	70	..
0.00625 "	63	..	..	85	75	..
0.003125 "	..	58	..	92	90	..
0.0015625 "	69	..	..	94	88	..
0.00078125 "	..	90	..	91	93	..
0.00039062 "	85	85	..	..	..	..
0.00019531 "	84	..	..	..	..	..
0.00004382 "	89	..	..	..	..	..
0.00001095 "	93	..	..	..	..	..

The numbers of bendings of about 25 different kinds of zinc from the market were found to lie between 54 and 19.

(2.) TIN.—NUMBER OF BENDINGS OF BANCA TIN—100.

100 PARTS OF BANCA TIN ALLOYED WITH	LEAD.	ANTIMONY.
5.0 parts....................................	20	30
2.5 "	29	46
1.0 "	35	64
0.1 "	72	..
0.05 "	84	..

The numbers of bendings of 4 kinds of Banca tin, obtained through different sources, were respectively 100, 101, 88, and 78.

(3.) LEAD.—NUMBER OF BENDINGS OF M M M MECHERNICH EXTRA—100.

100 PARTS OF M M M ALLOYED WITH	TIN.	ANTIMONY.
5.0 parts	51	95
2.5 "	54	95
1.0 "	84	71
0.5 "	87	74
0.1 "	91	100

The numbers of bendings of 4 different brands of lead from the market were found between 100 and 89.

185. Aluminium, according to Mr. A. E. Hunt,* gives the following:

FORM.	RED. OF AREA.	POUNDS PER SQUARE INCH.		
		Elastic Limit.	Tenacity.	Modulus Elasticity.
Cast	0.10	5,000	15,000	11,000,000
Thin sheet	.25	12,000	24,000	15,000,000
Small wire	.40	16,000 to 30,000	30,000 to 65,000	15,000,000
Bars	.20	10,000	28,000	15,000,000

In compression the elastic limit is found at about 3,500, the ultimate resistance at 12,000. The modulus of resilience is 0.16 to 0.22. In shearing it ranges from 12,000 to 16,000, about equal to pure copper. Specific gravity varies between 2.55 and 2 65. [See Appendix.]

Further, are given the following:

MATERIAL.	WEIGHT PER CU. FT.	TENACITY, LBS. PER SQ. IN.	LENGTH OF BAR, SUSTAINING ITSELF.
Cast iron	444	16,000	535 ft.
Gun bronze	525	31,000	9,893
Wrought iron	480	50,000	15,000
Al. sheet	165	26,000	23,000
cold rolled	168	55,000	39,615
cast	160	15,000	13,321
forged	165	20,000	17,700

Its conductivity is high, it is non-magnetic, sonorous, and exceedingly malleable. It has many valuable alloys, and is much used in iron and steel castings to confer soundness.

* Jour. Franklin Inst., Feb., 1891 ; May, 1892.

CHAPTER IX.

STRENGTH OF BRONZES AND OTHER COPPER-TIN ALLOYS.

186. **The Bronzes**—under which name are included the principal alloys of copper and tin, and a few special compositions—vary, in strength, elasticity, ductility and hardness, with variations of composition to such an extent that they find application in an immense number of the engineer's constructions, their character and chemical constitution being adjusted to his needs. The most common of these alloys is "gun-bronze," which consists, usually, of 90 parts copper, 10 of tin, or 89 copper, 11 tin. Such bronze has a strength which will depend greatly on the soundness of the castings and purity of the constituents of the alloy, but which often may exceed 50,000 pounds per square inch (3,515 kilogs. per sq. cm.) in tension.

Bronze used for journal-bearings in machinery is made harder or softer, according to pressure sustained, the composition approaching usually that of gun-bronze, and ranging from copper, 7; tin, 1; to copper, 11, tin, 1; *i.e.*, copper, 87.5; tin, 12.5, to copper, 91.67; tin, 8.33. A little zinc or lead added slightly softens it. Packing rings for steam engines are made of still softer and more ductile bronze—copper, 92, to copper, 96. These alloys have been very fully described elsewhere, and this chapter is devoted entirely to the consideration of their strength, ductility, elasticity and density.

187. **Gun-bronze,** according to the "Ordnance Manual," should have a tenacity of 42,000 pounds per square inch (2,826 kilogs. per sq. cm.), and a specific gravity of 8.7.

In Major Wade's report on "Experiments on Metals for Cannon," 1856, are given records of a number of tests of gun metal.

Specimens of metal from 83 "gun-heads" (the upper part of the casting is always deficient in strength) gave an average result of 29,655 pounds per square inch (2,085 kilogs. per sq. cm.), the highest figure being 35,484 and the lowest 23,529 pounds. This alloy was copper, 9; tin, 1.

Small bars made of gun metal gave higher figures. One set of 16 bars gave an average result of 42,754 pounds (3,006 kilogs. per sq. cm.), and another similar set an average of 41,284 pounds (2,902 kilogs. per sq. cm.), the lowest figure of the 32 specimens being 23,854 pounds and the highest 54,544 pounds. Five of the specimens gave more than 50,000 pounds (3,515 kilogs. per sq. cm.), and only three less than 30,000 pounds (2,109 kilogs. per sq. cm.).

The average of 12 gun-heads was one-half that obtained from the small sample bars cast with the guns.

A sample of very inferior quality fell below 18,000 pounds (1,265 kilogs. per sq. cm.).

Major Wade found the quality of bronze ordnance enormously irregular and uncertain, and considered it very important that a more reliable method of manufacture should be found.

The tenacity of gun-bronze thus depends greatly upon the method of manufacture, of casting, and of cooling. By careful handling it has been given a tenacity, in ordnance, exceeding, even, 60,000 pounds per square inch (4,218 kilogs. per sq. cm.), and the Author has obtained small bars still stronger. Bronze ordnance of large size has been made here and in Europe with success; it is, however, very liable to be irregular in composition and physical character, and the uncertainty always felt in regard to its condition is an element which enters into the question of its use for any purpose.

Continual use of ordnance is thought to lead to a separation of the tin from the copper, and to final destruction. The gases of powder sometimes corrode the metal badly.

The Modulus of Elasticity of gun-bronze is given by Tredgold at 10,000,000 pounds per square inch (703,000 kilogs. per sq. cm.), and this figure is confirmed by the experiments of the Author as given later, but it is subject to great variations with the condition of the metal.

Gun-bronze has less elastic resilience, and therefore less capacity for taking up shock without permanent deformation, than has good wrought iron, but more than gun-iron; it wears more seriously than iron, and the finished gun is considerably more expensive, nowithstanding the comparative ease with which bronze can be worked. It is, therefore, not used very extensively for ordnance, and is less generally used than formerly, when steel was less easily obtained for this purpose and was more costly than at present. The use of bronze ordnance will probably, in time, cease entirely.

188. Anderson's Experiments on copper-tin alloys, approximating to the composition of gun-bronze, give the following results, the tenacity being given to the nearest round numbers:

TABLE LI.

TENACITY OF ORDNANCE BRONZES.

	TENACITY, T.	
	LBS. PER SQ. IN.	KILOGS. PER SQ. CM.
Copper, 92; tin, 8	29,000	2,039
" 91.7; " 8.3	31,000	2,116
" 91; " 9	33,000	2,130
" 90; " 10	38,000	2,165

189. Bell-Metals.—Mallet, testing harder alloys, approaching bell-metal in character, obtained as results the tenacities given below:

TABLE LII.

TENACITY OF BELL-METAL.

	TENACITY, T.	
	LBS. PER SQ. IN.	KILOGS. PER SQ. CM.
Copper, 84.29; tin, 15.71	30,000	2,530
" 82.81; " 17.19	34,000	2,390
" 81.10; " 18.90	40,000	2,812
" 78.97; " 21.03	31,000	2,116

190. Gun-bronze in Compression was tested by the Author with the following results:

TEST OF GUN-BRONZE.

No. 1252.—Copper, 90; tin, 10; length, 2″; diameter, 0.769″.
Fluxed with mercury sulphate; sound.

LOAD; LBS.	COMPRESSION, INCH.	LOAD; LBS.	COMPRESSION, INCH.
30,000	0.6460	36,000	0.7914
32,000	0.6904	38,000	0.8115
34,000	0.7311		

Resistance, max. 123,860 lbs. per sq. inch, original area.
8,707 kilogs. " cm. " "
Compression, in per cent., 40.57.

No. 1252-2; as above.

LOAD; LBS.	COMPRESSION, INCHES.	LOAD; LBS.	COMPRESSION, INCHES.
10,000	0.0609	25,000	0.5092
15,000	0.2110	28,000	0.8062
20,000	0.3599	23,500	......

Max. resistance, 92,894 lbs. per sq. inch.
6,530 kilogs. " cm.
Compression, 40 per cent.

Gun-bronze under compression behaves as exhibited in the accompanying table.* The resistance at 10 per cent. compression averages about 40,000 pounds per square inch (2,812 kilogs. per sq. cm.); at 50 per cent. about 140,000 pounds (9,842 kilogs.).

* Construction of Artillery, Mallet.

TABLE LIII.

RESISTANCE OF BRONZE GUN-METAL TO COMPRESSION.

Specimen.	Specific Gravity.	The pressure is in lbs. and the compression in decimals of an inch.												
		Lbs. 2,500	Lbs. 5,000	Lbs. 7,500	Lbs. 10,000	Lbs. 12,500	Lbs. 15,000	Lbs. 17,500	Lbs. 20,000	Lbs. 22.500	Lbs. 25,000	Lbs. 27,500	Lbs. 30,000	Lbs. 32,500
No. 1. A.	8.3194	.025	.057	.12	.17	.22	.265	.30	.34	.38	.417	.455	.493	.540
No. 1. B.	8.2954	.03	.078	.15	.22	.272	.357	.47	.56	.586	.612	....	....	....
No. 1. C.	8.2827	.021	.061	.131	.191	.248	.280	.330	.371	.417	....	....	....	....
Mean	8.2992	.203	.065	.134	.194	.247	.301	.370	.424	.460	.514	....	....	....
No. 2. A.	8.6811	.01	.035	.100	.161	.219	....	....	....	....	....	....	....	....
No. 2. B.	8.3641	.005	.022	.078	.138	.200	.250	.315	....	....	....	....	....	....
No. 2. C.	8.3263	.01	.031	.08	.140	.210	.260	....	....	....	....	....	....	....
Mean	8.4572	.008	.029	.086	.136	[illegible]	.240	.315	....	....	....	....	....	....
No. 3. A.	7.9171	.005	.060	.130	.200	.252	.308	.359	.401	.450	.490	.530	.563	.592
No. 3. B.	7.9511	.013	.072	.145	.211	.270	.322	.370	.420	.460	.500	.540	.570	.610
No. 3. C.	8.1936	.01	.060	.135	.200	.259	.310	.370	.430	.489	....	....	....	....
Mean	8.0209	.009	.064	.137	.203	.260	.313	.366	.417	.466	.495	.535	.566	.601
No. 4. A.	8.7068	.005	.025	.100	.170	.223	.270	....	....	....	....	....	....	....
No. 4. B.	8.6723	.005	.029	.095	.152	.202	.250	.292	.348	.379	.420	.460	.495	.522
No. 4. C.	8.7077	.001	.058	.143	.192	.202	.288	.325	.365	.408	.450	.490	521	.550
Mean	8.6956	.004	.037	.113	.171	.209	.269	.308	.356	.393	.433	.475	.508	.536

These experiments were made by Col. Wilmot, R.A., at Woolwich Arsenal, at the request of Mallet, in 1856. Nos. 1, 2, and 3 were from the "runner" cast with a "24-pounder" howitzer. No. 4 was from the cascabel of a similar piece of ordnance. The test pieces were two diameters long, 0.5 inch by 1 inch (1.27 by 2.54 cm.).

191. Hardness of Bronzes.—Riche tested the hardness of copper and bronze with an apparatus producing an indentation by the blow of a drop or hammer falling upon a steel punch.

The hardness of bronze increases very rapidly with the proportion of tin, and the following is the average of many experiments with the apparatus above referred to:

	Impacts necessary in order to obtain a depression of—	
	4^{mm}.	1^{mm}.
Copper	19	7
Bronze of 97 parts copper	23	8 to 9
Bronze of 96 parts copper	27	10
Bronze of 95 parts copper	38	14
Bronze of 94 parts copper	40	15
Bronze of 90 parts copper	Did not succeed with 70 blows.	

After these experiments, medals were struck at the mint in Paris. The differences, which are unimportant for medals less than 35 millimeters, become more noticeable when the dimensions attain to 50 millimeters diameter. There are necessary in this latter case—

With pure copper	7 compressions.
With bronze of 97 parts copper	10 compressions.
With bronze of 96.5 parts copper	12 compressions.
With bronze of 96 parts copper	13 to 14 compressions.
With bronze of 95 parts copper	16 to 17 compressions.
Alloy of 95 copper, 4 tin, 1 zinc	14 compressions.
Alloy of 94 copper, 4 tin, 2 zinc	16 to 18 compressions.

From which he concludes that bronze of 96 and 97 per cent. copper may be employed to great advantage and with no serious inconvenience in the manufacture of medals. Its hardness does not much exceed that of copper; it possesses sonority and casts well, rolls evenly, and its color is more artistic than that of copper. The action of the press and of heat modifies its density but little.

The hardness and brittleness of speculum and bell-metals are such as to forbid the use of this method of testing them.

192. **"Phosphor Bronze"** exhibits much greater strength and ductility than the same metal cast without phosphorus. The following tables exhibit the data obtained by various experimenters and by several methods of test, as collated by Dick.* They show great strength and remarkable toughness.

TABLE LIV.

TENACITY OF PHOSPHOR-BRONZE—(*Kirkaldy*).

	PULLING STRESS PER SQUARE INCH.		ULTIMATE EXTENSION IN PER CT.	NUMBER OF TURNS IN 5 INCHES.	
	Hard.	Annealed.	Annealed.	Hard.	Annealed.
Copper	63,122 lbs.	37,002 lbs.	34.1	86.7	96
Brass	81,156 "	51,550 "	36.5	14.7	57
Charcoal iron	65,834 "	46,160 "	28	48	87
Coke iron	64,321 "	61,294 "	17	26	44
Steel	120,976 "	74,637 "	10.9	†	79
Phosphor-bronze No. 1.	159,515 "	58,853 "	46.6	13.3	66
do do No. 2.	151,119 "	64,569 "	42.8	15.8	60
do do No. 3.	139,141 "	54,111 "	44.9	17.3	53
do do No. 4.	120,950 "	53,381 "	42.4	13	124

	Elastic stress per square inch.	Ultimate stress per square inch.	Ultimate permanent extension in per cent.
	lbs.	lbs.	per cent.
Phosphor-bronze No. 1...	55,200	73,987	3.2
do do No. 2...	40,500	63,653	9.4
do do No. 3...	26,300	54,060	31.3

* Journal Franklin Institute, 1879.

† Of the 8 pieces of Steel tested, 3 stood from 40 to 45 turns and
5 " " 1½ " 4 "

TENACITY OF PHOSPHOR-BRONZE—(*Uchatius*).

Specimens.	Absolute resistance in kilogs. per square centimetre.	Elastic resistance in kilogs. per square centimetre.	Stretch in per cent.
	kilogs.	kilogs.	per ct.
Phosphor-bronze No. 0.	3,600	600	20.66
do do No. 00.	5,660	3.800	1.60
Krupp Cast Steel.......	5,000	1.000	11.00

TENACITY OF PHOSPHOR-BRONZE (*Wohler*).

Tests by Repeated Application of Direct Strain.

PHOSPHOR-BRONZE.			ORDINARY GUN METAL.		
	Tensile stress per square in.	Number of efforts until rupture.	No.	Tensile stress per square in.	Number of efforts until rupture.
1	10 Tons.	408,350	1	10 Tons.	Broke before total stress was applied.
2	12½ "	147,850	2	10 "	4,200
3	7½ "	3,100,000	3	7½ "	6,300

Tests by Repeated Bending in the same Direction.

PHOSPHOR-BRONZE.			ORDINARY GUN METAL.		
No.	Tensile stress per square in.	Number of bends until rupture.	No.	Tensile stress per square in.	Number of bends until rupture.
1	10 Tons.	862,980	1	10 Tons.	102,650
2	9 "	4 Million (not broken.)	2	9 "	150,000
3	7½ "	3 " (not broken.)	3	7½ "	837,760
4	6 "	2 " (not broken.)			

A bar of hammered phosphor-bronze, under 12 tons per square inch, without breaking, stood more than 2½ million turns, whilst according to Wohler's experiments, a bar of Krupp cast steel under 12 tons, broke after 879,700 turns, and another bar of the same under 13 tons, broke after 1,007,550 turns.

193. The Resistance to Abrasion of the Phosphor-Bronzes has been found such that Dr. Künzel has adopted them, with the addition of a little lead, for the " brasses " of railway axles. The liquation occurring often results in the production of two alloys, intermingled, the one a hard, tough, strong metal which acts as a sponge, retaining the softer alloy very uniformly diffused throughout its mass. Künzel considers that a good axle-bearing should not be homogeneous, but must consist of a tough metal skeleton, the hardness of which should nearly equal that of the axle, and which should resist any pressure or shock without changing its form ; the pores of this skeleton should be filled with soft alloy. The nearer the hardness of the skeleton bearing approaches the hardness of the axle, the better this skeleton will resist pressure ; and the softer the metal which fills the pores, the more excellent is the bearing. Such a bearing is obtained by using a compound of two or more metals of different tempers and melting points, and in such proportions that necessarily by cooling a separation of the metals into two parts or two different alloys of definite composition results. Bearings of phosphor-bronze alloyed with lead consist of a tough and homogeneous skeleton, the hardness of which may be regulated to nearly equal the hardness of the axle, whilst its pores are filled with a very soft alloy ; the wearing part of such bearings may, therefore, be considered as consisting of a great number of small bearings of soft metal, each of which is surrounded by metal of nearly the same temper as the axle ; Künzel's particles of soft alloy may be easily discerned. When this alloy is heated to a dull red, the soft alloy exudes, whilst a hard sponge-like mass forming the skeleton of the bearing remains. Herein consists the advantage of bearings of these alloys, the axle running partly on a very soft metal, whereby heating is obviated, whilst the harder part of the bearing—its skeleton —checks the wear of the softer metal. The following table* shows the result of a series of experiments on such bearings.

* *Polytech. Centralblatt*, Jan., 1874.

TABLE LV.

WEAR OF BEARINGS.—KUNZEL.

Kind of Bearings.	Composition of Alloy in 100 parts.	Cost of bearings per 100 kilometres, the melting expenses and loss of metal taken at 70s. per 100 kilometres.	1 kilogramme of bearing metal is worn out in		Wear per 1,000 kilometres by four bearings.	Cost of metal per 1,000 kilometres for four bearings.	Railroads where the bearings are in use.
			German miles.	Kilometres.	Grammes.	Pence.	
Gun metal..............	83 copper, 17 tin	$260\frac{2}{10}$	12,052	90,390	$11\frac{60}{100}$	0 301	Austrian State R. R.
"	82 " 18 "	$260\frac{8}{10}$	13,320	99,900	$10\frac{1}{100}$	0.260	Grand Central Belgium.
Gun metal on brake......	82 " 18 "	$260\frac{8}{10}$	1,218	9,134	$109\frac{43}{100}$	2.844	" "
White metal...........	3 " 90 " 7 antimony	$298\frac{68}{100}$	9,104	78,280	$14\frac{64}{100}$	0.395	Austrian State Railway.
"	5 copper, 85 tin 10 antimony	$293\frac{40}{100}$	11,750	88,145	$11\frac{35}{100}$	0.331	Niederschlesish-Markische.
Lead composition......	84 lead 16 antimony	$118\frac{56}{100}$	10,838	81,280	$12\frac{30}{100}$	0.145	Austrian State Ry. Bohn.
Phosphor-bronze with lead.	....	350	57.226	429 200	2 33	0 081	Grand Central, Belgium.
Phosphor-bronze on brake.	....	350	14,320	107,410	$9\frac{31}{100}$	0.325	" "

See *Railroad and Engineering Journal*, paper by Dr. Dudley. 1891–92, for valuable details of similar work.

194. **Manganese Bronze** is another valuable alloy. That used in the construction of torpedo boats for the British navy was supplied under a contract calling for a tenacity of 26 to 31 tons per square inch (4,094 to 4,882 kilogs per sq. cm.), and an elongation of 20 per cent.

This sheet bronze was from $\frac{1}{16}$th to $\frac{1}{8}$th inch (0.16 to 0.32 cm.) thick (No. 9 to No. 18 B. W. G.), and sustained 29 to 30 tons (4,567 to 4,725 kilogs.), stretching 25 to 35 per cent., and bending cold to a radius equal to their thickness.

Manganese bronze, tested at the Royal (British) Gun Factory at Woolwich, England, by tension, gave the following figures, as reported to the Admiralty:

TABLE LVI.

TENACITY OF MANGANESE BRONZE.

(Sheet Metal; Rods and Bolts.)

	NOS.	LOADS				ELONGATION.	
		Yielding.		Breaking.			
		Tons per sq. in.	Kgs. per sq. cm.	Tons per sq. in.	Kgs. per sq. cm.	Per cent.	
Bars and Rods.	4,766	14.0	2,204	24.3	3,817	8.7	Cast in metal mould.
	4,767	12.6	1,984	29.0	4,567	31.8	Ditto and forged.
	4,768	14.0	2,204	22.1	3,480	5.5	Ditto.
	4,769	13.2	2,079	28.8	4,535	35.3	Ditto and forged.
	4,770	16.8	2,645	23.6	3,717	3.8	Cast in metal mould, slight flaw in specimen.
	4,771	12.0	1,890	30.3	4,772	25.7	Cast in metal mould and forged.
							ROLLED RODS.
	6,536	11.0	1,732	29.0	4,567	44.6	Mild, for ships' bolts and rivets.
	6,545	16.6	2,615	30.7	4,835	20.7	High, for Engineers' bolts, pump rods, etc.
	6,546	14.6	2,299	30.0	4,725	26.2	Medium.
	6,547	34.4	5,417	39.6	6,237	11.6	Cold rolled.

AREA OF SPECIMENS, 0.133 INCH. LENGTH OF BREAKING PART, 2 INCHES.

Plates.	7,364	13.8	2,173	28.57	4,504	28.7	Pulled in direction of fibre.
	7,365	14.06	2,205	28.46	4,488	23.2	Across fibre.
	7,369	14.06	2,205	30.13	4,740	47.8	With fibre.
	7,372	14.8	2,331	30.78	4,850	34.1	Across fibre.
	7,374	16.7	2,630	30.1	4,740	28.8	With fibre.

Manganese bronze, tested by transverse stress, has been found to possess great strength, flexibility, and toughness. The following are figures given the Author by the inventor, as obtained by tests made in presence of the Inspector to the British Admiralty, January, 1881 :

TABLE LVII.

TRANSVERSE STRENGTH OF MANGANESE BRONZE.

[Length, 1 foot (0.3 m.); Section, 1 in. (2.54 cm.) square.]

	LOAD AT MIDDLE OF BAR.			
	Elastic Limit.		At Rupture.	
	Lbs.	Kgs.	Lbs.	Kgs.
Manganese Bronze	2,688	122	6,048	275
Gun (Copper-tin) Bronze	1,232	56	2,912	132

195. **Manganese Bronze tested by Impact,** resisted the blow as shown in the following table, furnished the Author by the inventor :

TABLE LVIII.

MANGANESE BRONZE BARS. IMPACT.

Weight, 50 lbs. (22.7 kilogs.); Fall, 5 feet (1.52 m.); Bars, 1 inch (2.54 cm.) square, 1 foot between supports (0.3 m.).

Deflection in Inches.

No. of Blows.	WROUGHT IRON.			GUN-METAL (COPPER-TIN).						MANGANESE BRONZE.					
	Staffordshire Rolled.			Cast in Sand.						Cast in Sand.				FORGED.	
	No. 1.	No. 2.	No. 3.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
1	1.12	.50	....	.82	.86	.90	.72	.73	.45	.66	.66	.65	.60	.59	.60
2	and broke half thro'	.97	.96	1.50	1.58	1.63	1.32	1.42	and broke	1.23	1.18	1.18	1.15	1.06	1.06
3		1.84	1.42	1.70	2.22	2.35	1.92	1.52	... .	1.73	1.63	1.67	1.60	1.44	1.44
4	....	2.30	1.87	and broke	and broke	2.86	1.94	and broke	....	2.16	2.06	2.12	2.07	1.80	1.81
5	....	2.74	2.33	....	....	and broke	and broke	....	....	2.62	2.48	2.55	2.52	2.12	2.10
6	....	3.20	2.80	....	....	....	....	....	....	3.05	2.88	2.98	2.97	2.45	2.48
7	....	3.74	3.27	....	....	....	....	....	....	3.47	3.60	3.40	3.39	2.77	2.75
8	....	4.20	3.80	....	....	....	....	....	....	3.92	and broke	and broke half-thro'	4.04	3.05	3.12
9	....	4.84	4.35	....	....	....	....	....	....	4.05	......		and broke half-thro'	3.33	3.40
10	....	not broken	not broken	....	....	....	....	....	....	not broken	......	......		not broken	3.78
11	....	....	....	....	....	....	....	....	....	....	......	......	....	....	4.10
12	....	....	....	....	....	....	....	....	....	....	......	......	....	....	4.40
13	....	....	....	....	....	....	....	....	....	....	......	slipped through supports			4.46

The wrought iron was of three grades; the gun-metal was partly (Nos. 1, 2, 3), of usual good quality, and partly (Nos. 4, 5) specially made for the test of copper, 16, tin, 2, and copper, 16, tin, 2½. The manganese was of several grades. No. 6 was annealed.

196. Copper and Iron, in the proportions varying from copper, 93.5, iron, 6.5, to copper, 96, iron, 4, was tested by M. Riche,* and the alloy compared with copper, as below,

TABLE LIX.

TENACITY OF FERROUS COPPER.

Elongations in millimetres corresponding to loads in kilogrammes.

	NAME OF METALS.	P. ct. Iron.	Area, sq. mm.	800	1,000	1,100	1,200	1,300	1,400	1,500	1,600	1,700
1	Copper of commerce, melted..	....	94	0	1	3	5	(†)	....	....	....	....
2	Copper of commerce, rolled...	....	95	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
3	Pure copper, melted...........	....	111	1.25	3.0	4.5	5.5	6.0	....	....	....	....
4	Pure copper, melted	....	98	2.5	5.0	(‡)	....	....	....	....	....	....
5	Copper and iron, melted	2	92	0.25	0.25	0.25	0.25	0.75	1.5	2.5	(§)	....
6	Copper and iron, melted	2	92	0.25	0.25	0.25	0.25	0.50	2.0	3.0	3.5	3.5
7	Copper and iron, melted	4.5	97	....	....	....	....	....	....	....	....	....
8	Copper and iron, melted	4.5	97	....	....	....	....	....	....	....	....	....
9	Pure copper, rolled...........	....	81.5	....	....	....	....	....	....	....	....	....
10	Pure copper, rolled...........	....	89	....	....	....	....	....	....	....	....	....
11	Copper and iron, rolled	4.5	88	....	....	....	....	....	....	....	....	....
12	Copper and iron, rolled	4.5	90	....	....	....	....	....	....	....	....	....

	NAME OF METALS.	P. ct. Iron.	1,800	1,900	2,000	2,100	2,200	2,300	2,400	2,500	2,600	2,700	2,800
1	Copper of commerce, melted................	....	....	....	....	....	....	....	....	....	....	....	....
2	Copper of commerce, rolled................	....	0.5	0.5	1.5	2.5	4.5	5.5	....	....	....	....	....
3	Pure copper, melted	....	....	....	....	....	....	....	....	....	....	....	....
4	Pure copper, melted	....	....	....	....	....	....	....	....	....	....	....	....
5	Copper and iron, melted.	2	....	....	....	....	....	....	....	....	....	....	....
6	Copper and iron, melted.	2	4.5	5.5	7.0	8.5	10.0	12.5	15.0	....	....	....	....
7	Copper and iron, melted.	4.5	....	0.25	2.5	(‖)	....	....	....	....	....	....	....
8	Copper and iron, melted.	4.5	....	....	....	....	....	0.25	1.0	1.20	1.75	2.5	4.0
9	Pure copper, rolled	....	0.25	0.25	2.0	4.0	8.75	12.0	....	....	....	....	....
10	Pure copper, rolled	....	0.5	1.5	3.0	4.5	8.0	16.00	....	....	....	....	....
11	Copper and iron, rolled ..	4.5	....	....	....	....	....	....	....	....	....	....	...
12	Copper and iron, rolled ..	4.5	....	....	....	....	....	....	....	....	....	....	....

* (*Ann. de Chim. et de Phys.*, 4 *série*, *t.* xxx., Nov., 1873, 26.)

† The test was arrested because a blowhole was formed in the sample.

‡ The broken section presents blowholes.

§ At 1,600 kilogrammes one lug of the piece was broken.

‖ The sample broke without the two pieces being entirely separated.

	NAME OF METALS.	Per ct.	2,900	3,000	3,100	3,200	3,300	3,400	3,500	3,600	Breaking load.	Strength per sq. mm.	Density.
											Kilog.	*Kilog.*	
1	Copper of commerce, melted	....	....	....	....	....	....	....	....	....	.. ...	......	.....
2	Copper of commerce, rolled	....	....	....	....	....	....	....	....	....	2,300	24.210	.....
3	Pure copper, melted	....	....	....	....	....	....	....	....	....	1,300	11.711	8.039
4	Pure copper, melted	....	....	....	....	....	....	....	....	....	1,000	10.204	.....
5	Copper and iron, melted	2	....	....	....	....	....	....	....	....	......	......	.....
6	Copper and iron, melted	2	....	....	....	....	....	....	....	....	2,400	26.086	.....
7	Copper and iron, melted	4.5	....	....	....	....	....	....	....	....	......	......	.....
8	Copper and iron, melted	4.5	....	....	....	....	....	....	....	....	2,800	28.865	8.879
9	Pure copper, rolled	....	....	....	....	....	....	....	....	....	2,300	28.220	8.904
10	Pure copper, rolled	....	....	....	....	....	....	....	....	....	2,300	25.842	.....
11	Copper and iron, rolled.	4.5	0.25	0.5	0.5	1.0	2.5	2.5	4.75	....	3,500	39.772	8.891
12	Copper and iron, rolled.	4.5	....	....	....	0.25	0.75	1.5	3.5	9.0	3,600	40.000	.....

OBSERVATION.—The melted copper (Nos. 1, 3, 4) contains blowholes which destroy its tenacity. It elongates under light loads, and breaks, also, under a small load. The copper acquires a certain tenacity by rolling. While the resistance of melted copper is from 10 to 12 kilograms per square millimetre, that of the same copper attains, by rolling, 25 to 28 kilograms. The ductility is less, and the elongation becomes no longer evident under loads of 1,800 kilograms.

finding a decided gain of strength and hardness with no loss of malleability. The same metals subjected to the action of a punch, were indented in the proportions, cast copper, 2.5; rolled copper, 1.5; with 0.03 iron, cast, 1.1; rolled, 0.9.

197. **The Copper-Tin Alloys,** which, as has been stated, furnish a very large number of the best bronzes and engineers' compositions, and which are extensively used in every department of construction and the arts, had never been systematically studied until the investigation was made by the U. S. Government Board upon a plan prepared, proposed, and carried out at the request of that Board, by the Author. Earlier investigations had been confined to a few familiar compositions, and it was only when appropriations made by the Congress of the United States could be applied to such a research that it became possible to determine the method of variation of strength, elasticity, and ductility, and of specific gravity, and other properties, with variation of composition throughout all the possible proportions of copper and tin alloys. In the research to be described the principal assistant employed by the Author was Mr. William Kent.

This investigation of the strength, ductility, and other properties of all alloys of copper with tin was made in the Mechanical Laboratory of the Stevens Institute of Technology, in the years 1875–1878, for the Committee on Alloys of the United States Board appointed to test the useful metals of the United States, and the facts and data here to be given are mainly condensed from the reports made to that board * and the notes taken by the Author. This work was supplemented by private investigations, of which an account will also be given.

The intention in the work here to be described was, not to determine the character of chemically pure metals, melted, cast, and cooled with special precaution, but to ascertain the practical value of commercial metals, as found in the markets of the United States, melted in the way that such alloys are prepared in every foundry for business purposes, and cast and otherwise treated in every respect as the brass-founder usually handles his work; and to determine what is the practical value, to the brass-founder and to the constructor, of commercial materials, treated in the ordinary manner and without any special precaution or any peculiar treatment.

The result was the complete exploration of a broad and most important field of which almost nothing was previously known.

The whole field having been explored the useful alloys are proven to occupy but a limited portion of its great extent, and it has been now shown that a comparatively narrow band, extending from ordnance-bronze, on the one side of this triangular territory, to Muntz metal, on the other, contains all of the best of the generally useful alloys. This small portion of valuable territory having been pointed out and defined, its more minute study was left for future investigators.

The reader should make a careful study of the graphical

* Executive Document 98, 45th Congress ; Ex. Doc. 23, 46th Congress, 2nd Sessions ; 1878–1881. In the text of the report will be found a statement of the more important facts determined, and the tables appended contain all the results of observation. The whole forms a collection of facts that will probably repay a vastly more complete analysis and more careful study than it has yet been possible to give them.

representation of the results of the research on the alloys, as presenting most completely and satisfactorily the characteristics of the metals used.

The researches consisted of an investigation of the properties of the alloys of copper and tin, cast in the form of bars about 28 inches (71.1 cm.) long and 1 inch (2.54 cm.) square in section, prepared from the commercial metals, only ordinary precautions being taken to secure good castings. It was desired to learn also the laws which connected these properties with the proportions of the component metals, and whether alloys mixed in simple proportions of the chemical equivalents of the component metals possessed advantages over other mixtures.

198. **The Metals used** were the best Lake Superior copper and Banca tin; they had the following compositions:

	INGOT LAKE SUPERIOR COPPER.	INGOT BANCA TIN.
Metallic iron	0.013	0.035
Metallic zinc	None.	None.
Metallic silver	0.014	......
Metallic arsenic	None.	None.
Metallic antimony	None.	None.
Metallic cobalt	......	......
Metallic bismuth	None.	None.
Metallic nickel	......	......
Metallic lead	Trace.	None.
Metallic manganese	......	......
Metallic molybdenum	......	None.
Metallic tungsten	......	......
Metallic copper	99.420	None.
Metallic tin	None.	99.978
Suboxide of copper	0.537	.....
Carbon	0.041	......
Matter insoluble in aqua regia	......	Trace.
	100.025	100.013

199. **Alloys Tested.**—The following table gives the composition of the alloys made, according to their atomic proportions and percentages of original mixture, and according to chemical analysis after test.

TABLE LX.

ALLOYS OF COPPER AND TIN.—FIRST SERIES.

Composition by Original Mixture and Analysis.

NUMBER.	ATOMIC PROPORTION.		PERCENTAGE BY ORIGINAL MIXTURE.		MEAN PERCENTAGE BY ANALYSIS.		MEAN SPECIFIC GRAVITY.
	Cu.	Sn.	Cu.	Sn.	Cu.	Sn.	
1	1	0	100	0	....	....	8.487
2	96	1	98.1	1.9	97.89	1.90	8.564
3	48	1	96.27	3.73	96.06	3.76	8.649
4	24	1	92.80	7 20	92.11	7.80	8.694
5	..	..	90.00	10.00	90.27	9.58	8.669
6	12	1	86.57	13.43	87.15	12.73	8.681
7	..	..	80.00	20.00	80.95	18.84	8.740
8	6	1	76.32	23.68	76.64	23.24	8.565
9	..	..	70.00	30.00	69.84	29.89	8.932
10	4	1	68.25	31.75	68.58	31.26	8.938
11	..	..	65.00	35.00	65.34	34.47	8.947
12	3	1	61.71	38.29	62.31	37.35	8.970
13	12	5	56.32	43.68	56.70	43.17	8.682
14	2	1	51.80	48.20	51.62	48.09	8.560
15	12	7	47.95	52.05	47.61	52.14	8.442
16	3	2	44.63	55.37	44.52	55.28	8.312
17	4	3	41.74	58.26	42.38	57.30	8.302
18	6	5	39.20	60.80	3[illegible].37	61.32	8.182
19	1	1	34.95	65.05	34.22	65.80	8.013
20	3	4	28.72	71.28	25.85	73.80	7.948
21	3	5	24.38	75.62	23.35	76.29	7.835
22	1	2	21.18	78.82	20.25	79 63	7.770
23	1	3	15.19	84.81	15.08	84.62	7.657
24	1	4	11.84	88.16	11.49	88.47	7.552
25	1	5	9.70	90.30	8.57	91.39	7.487
26	1	12	4.29	95.71	3.72	96.31	7.360
27	1	48	1.11	98.89	0.74	99.02	7.305
28	1	96	0.557	99.443	0.32	99.46	7.299
29	0	1	0	100	....	....	7.293

SECOND SERIES.

NUMBER.	COMPOSITION OF ORIGINAL MIXTURE.		MEAN COMPOSITION BY ANALYSIS.		MEAN SPECIFIC GRAVITY.
	Copper.	Tin.	Copper.	Tin.	
31	97.5	2.5	99.09	0.87	.....
32	92.5	7.5	94.10	5.43	8.684
33	87.5	12.5	88.40	11.59	8.647
34	82.5	17.5	82.72	17.33	8.792
35	77.5	22.5	77.56	22.25	8.917
36*	72.5	27.5	72.89	26.85	8.925
37	67.5	32.5	67.87	32.09	8.907
38	62.5	37.5	62.42	37.48	8.956
39	57.5	42.5	57.87	42.05	8.781
40	52.5	47.5	53.46	46 54	8.643
41	47.5	52.5	47.27	52.72	8.445
42	42.5	57.5	43.99	55.91	8.437
43	37.5	62.5	37.10	62.90	8.101
44	32.5	67.5	30.76	69.19	7.931
45	27.5	72.5	26.62	73.18	7.915
46	22.5	77.5	22.10	77.58	7.774
47	17.5	82.5	16.70	83.23	7.690
48	12.5	87.5	11.68	88.25	7.542
49	7.5	92 5	6.05	93.77	7.419
50	2.5	97.5	2.11	97.68	7.343

200. **Temperatures of Casting.**—The following are the temperatures at which some of these alloys were poured into the ingot-moulds. They vary irregularly, but show a general decrease from a maximum for alloys richest in copper to alloys containing most tin. These temperatures are evidently not those of fusion of the several alloys, but are somewhat above in all cases, and are several hundred degrees above the melting points, usually. The determination was made by pouring a small portion of molten alloy into a known weight of water, noting the rise in temperature of the latter, and, from it, calculating the loss of temperature of the alloy.

* Second casting; first broke in emery planer.

TABLE LXI.

ESTIMATED TEMPERATURES OF CASTING.

NUMBER.	COMPOSITION BY ORIGINAL MIXTURES.		WEIGHT OF WATER.	WEIGHT OF METAL.	TEMPERATURES OF WATER, CENTIGRADE SCALE.			ASSUMED SPECIFIC HEAT.	CALCULATED RELATIVE TEMPERATURE.	
	Copper.	Tin.			Initial.	Final.	Range.		Centigrade.	Fahrenheit.
			Gram.	*Gram.*						
31......	97.5	2.5	907	74	8.3	22.8	14.5	0.094177	1909.9	3469.8
32*.....	92.5	7.5	907	101	12.8	31.7	18.9	0.092231	1871.9	3401.4
33......	87.5	12.5	907	149	16.7	42.8	26.1	0.090285	1802.6	3276.6
34......	82.5	17.5	907	362	9.4	60.0	50.6	0.088339	1495.1	2723.0
35......	77.5	22.5	907	225	15.0	47.3	32.3	0.086393	1554.5	2829.2
36......	72.5	27.5	907	157	11.7	33.3	21.6	0.084447	1511.8	2751.8
37......	67.5	32.5	907	97	11.1	26.1	15.0	0.082501	1726.2	3148.8
38......	62.5	37 5	907	177	10.6	31.7	21.1	0.080555	1373.9	2503.4
39......	57.5	42.5	907	129	17.2	32.8	15.6	0.078609	1428.0	2602.4
40......	52.5	47.5	907	214	8.3	35.0	26.7	0.076663	1511.1	2751.8
41......	47.5	52.5	907	216	12.2	50.5	38.3	0.074717	2205.0	4001.0
42......	42.5	57.5	907	328	9.5	47.2	37.8	0.072771	1063.8	1945.4
43......	37.5	62.5	907	293	13.9	38.9	25.0	0.070825	1131.7	2067.8
44......	32.5	67.5	907	255	8.9	32.2	23.3	0.068879	1756.9	3192.8
45......	27.5	72.5	907	85	7.8	18.3	10.5	0.066933	1701.6	3093.8
46......	22.5	77.5	907	277	12.2	38.9	26.7	0.064987	1382.7	2519.6
47......	17.5	82.5	907	241	15.5	37.2	21.7	0.063041	1331.1	2427.8
48......	12.5	87.5	907	104	14.4	22.7	8.3	0.061095	1211.9	2211.8
49......	7.5	92.5	907	240	18.9	33.3	14.4	0.059149	956.5	1752.8
50......	2.5	97.5	907	154	20.5	27.2	6.7	0.057203	725.3	1337.0

The test-pieces were usually cast in iron moulds to secure rapid cooling.

201. External Appearance of the Bars.—The following were characteristic features of the bars after casting:

(1) A regular gradation in color took place from bar No. 1, all copper, down to No. 8, 76.64 copper, 23.24 tin, the polished surface of which was light golden yellow, and a regular gradation in hardness, No. 8 was filed with great difficulty.

* In casting bar No. 32 (94.10 copper, 5 43 tin), while pouring the metal into water for the temperature test, an explosion took place which broke the wooden vessel holding the water, and threw water and metal about with great violence.

No. 30 was cast at a dazzling white heat. On pouring a small portion into water to obtain the temperature, a severe explosion took place, and this was repeated every time that even a drop of the molten metal touched the water. After the metal remaining in the crucible had cooled considerably, it could be poured into water without causing explosions.

It might be supposed that the result of casting at high temperature would be to make No. 30 a bad bar, as this seems to be indicated by the experiments of Major Wade on gun-metal. The result, however, showed the contrary, as it proved to be equal to any bars cast.

(2) A sudden change of all properties took place at bar No. 9—69.84 copper, 29.89 tin. This bar was silver-white in color, and could not be scratched with a file. Pieces broken off showed a conchoidal fracture. No. 10—68.58 copper, 31.26 tin—was similar to No. 9, and No. 11—65.34 copper, 34.47 tin—but little different.

(3) Another change of color and properties occurred at No. 12—62.31 copper, 37.35 tin—which bar was of a dark bluish-gray color, and the fracture similar to that of granite or other hard rock. This was the most dense alloy of the series. No. 13—56.70 copper, 43.17 tin—was similar to No. 12, but lighter in color and a little softer.

(4) Bar No. 14—51.62 copper, 48.09 tin—was peculiar in showing a marked difference in the two ends of the bar. The upper end was like bar No. 12, while the bottom was of a lighter color, granular fracture, and so soft that it could be cut with a knife like a piece of chalk.

(5) A change between bars No. 14 and No. 20—25.85 copper, 73.80 tin—occurred gradually, the bars becoming whiter and softer, and the appearance of fracture changing from rough and stony to crystalline or granular. No. 20 could be cut with a knife, giving a short chip which had slight cohesion. From No. 20 to No. 29 (all tin) the softness increased gradually, No. 21 giving a malleable chip on being cut. From No. 24 to No. 29 the appearance of all bars was much the same, differing slightly in hardness, and scarcely at all in color.

No. 1 to No. 8 were likely to prove of value where strength was required, and bars No. 9 to No. 18, inclusive, were deficient in ductility as well as in strength, and for all practical purposes (except, perhaps, extremely limited use for special purposes, as speculum metal) worthless.

Nearly all of the bars appeared to be good castings.

202. The Behavior of the Alloys under test was carefully observed and a journal kept. Thus when tested by transverse stress:

Bar No. 7 (80.95 copper, 18.84 tin), the strongest of the series, showed little ductility, breaking after a deflection of half an inch. From No. 8 to No. 13 (23.24 to 43.17 tin) inclusive, there was a regular and rapid decrease, both in strength and ductility, the latter being the weakest bar of the series, showing only about $\frac{1}{27}$th of the strength of No. 7 and a deflection of only 0.0103 inch. This bar gave trouble in casting by breaking in the mould. Bar No. 9 (69.84 copper, 29.89 tin), which, in appearance, differed remarkably from No. 8 (76.64 copper, 23.24 tin), had less than $\frac{2}{5}$ths of its strength and less than $\frac{1}{4}$th of the strength of No. 7, which latter differed only 10 per cent. from it in composition by original mixture, or 11 per cent. by analysis. Bars No. 14 to No. 20 (48.09 to 73.80 tin) inclusive, showed irregular variation in strength and ductility, but all of them were worthless, the best having only about $\frac{1}{7}$th of the strength of the maximum, and a deflection of only 0.123 inch before breaking. Bar No. 21 (23.35 copper, 76.29 tin) showed considerably greater strength and ductility than any of the series between No. 8 and No. 20, and greater strength than any from No. 8 to No. 29 (all tin), giving what may be called a second maximum point of strength in the series. This bar had a cavity extending throughout nearly its whole length.

No. 21 to No. 24 (76.29 to 88.47 tin) had higher strength than those above and below them in series, showing that the second maximum point of strength is approached by bars having a difference of over 10 per cent. in composition. From No. 25 to No. 29 (91.39 to 100 tin) there was a somewhat irregular decrease of strength but a great increase of ductility, bar No. 29 (all tin) showing the maximum ductility of the series and a second minimum in strength. Bars No. 26 to No. 29, inclusive, bent without breaking, as did those from No. 2 to No. 6 (1.90 to 12.73 tin) at the other end of the series.

With reference to the relation of the elastic limit to the ultimate transverse resistance from bar No. 1 to No. 7 inclusive, the apparent elastic limit occurred at from 35 to 65 per cent. of the ultimate resistance. At No. 8 this limit approached nearly, if not quite, the ultimate resistance; and from No. 9 to No. 18 (29.89 to 61.32 tin) inclusive the two coincided, *i.e.*, the elastic limit was not reached till the bar broke. From No. 19 (34.22 copper, 65.80 tin) to the end of the series (all tin) the elastic limit was again reached before fracture, the ratio decreasing to No. 22 (20.25 copper, 79.63 tin), and then remaining appreciably constant at from 20 to 30 per cent. to the end of the series.

The relation which the composition bears to the mechanical properties of strength, ductility, and elastic resistance is thus defined with tolerable exactness.

Bars from No. 1 to No. 8, inclusive, had considerable strength, and all the rest were worthless for all purposes where strength is required. The dividing line between the strong and the brittle alloys is precisely that at which the color changes from golden yellow to silver white, viz., at a composition containing between 24 and 30 per cent. of tin; alloys containing more than 24 per cent. tin are comparatively valueless.

The journals of other tests give very similar records to those just quoted, and confirm, generally, the deductions which are made from transverse tests. Of the two bars of copper, No. 1 was spongy and weak, as it was cast in sand; No. 30 was strong and ductile.

In tests by compression, many pieces were compressed to less than one-half of their original lengths, the resistance to further compression always increasing. When bending took place, the piece would, in some cases, take such a position as to gradually diminish in resistance, the pressure-plates touching only on the edges of the upper and lower surfaces of the piece.

The actual "crushing strengths" of the ductile metals, therefore, cannot be stated; but, for purposes of comparison, the crushing strength is assumed to be that which corresponds to a compression of one-tenth of the original length. In the table, therefore, the figures in the column headed "crushing strength" represent, in the cases of ductile metals, the loads per square inch necessary to produce compressions of 10 per cent. of the original lengths.

All brittle alloys, and some possessing limited ductility, No. 8 (76.64 copper, 23.24 tin) to No. 18 (38.37 copper, 61.32

tin) inclusive, broke suddenly when their maximum resistances were reached, and the figures for crushing strengths are, therefore, actual values. In these, the "total compressions produced by maximum load" are the calculated compressions at the instants of breaking. In other cases, the figures are total compressions actually given the pieces without breaking them and include the shortening of the piece by bending; they are not the total amounts of compression which might have been produced had the test been continued further.

By inspection and comparing the results with those of transverse, tensile, and torsional tests, some important facts are observed. Assuming that the crushing strength of a ductile metal is the load necessary to produce a compression of one-tenth, and that of a brittle metal the load actually causing fracture, it is noted that the maximum and minimum strengths are not found in the compositions which exhibited maximum and minimum strengths by the other methods of test. It has been observed that the relative strengths of the alloys, as shown by the other three methods of test, are similar. This is not the case with compressive tests.

The maximum crushing strength is given by No. 9 (69,84 copper, 29.89 tin), which gave results nearer the minimum under the other tests. The minimum strength is found in tin, which was superior to several of the brittle alloys in other methods of test, which alloys greatly surpassed it in tests by compression.

The compression pieces, No. 1 (all copper) to No. 5 (90.27 copper, 9.58 tin), and No. 30 (all copper), give results nearly alike. From No. 6 (87.15 copper, 18.84 tin) to No. 9 (69.84 copper, 29.89 tin), is a rapid increase. From this point a decrease takes place to No. 29 (all tin). This decrease is somewhat irregular. It would be necessary to make a number of tests before attempting to explain this irregularity, but it may be a peculiarity of these compositions, since No. 12 was different in color from both No. 11 and No. 15, and had the highest density of the series.

Nos. 1 to 8 (all copper to 76.64 copper, 23.24 tin), inclusive, were turned in the lathe without difficulty, a gradually increasing hardness being noticed, the last named giving a short chip, and requiring frequent sharpening of the tool. The turned surface was perfectly smooth. The color varied from copper-red to light golden-yellow, gradually becoming lighter with increase of percentage of tin.

Nos. 36 to 42 (43.99 copper, 55.91 tin) inclusive, were tested with their original section unaltered, as they were too brittle to be turned. All gave trouble in setting in the tension machine, their brittleness and hardness being so great that the grips of the machine would not firmly hold them. They usually broke in the grips, and the figures representing strength are in many cases too low.

203. **Surfaces of Fracture.**—After the tests by transverse stress, pieces were cut from each bar showing the fracture. These pieces were examined by Prof. A. R. Leeds, who made the following report.

No. 1 (all copper).—Color, copper-red, altering by exposure to air into purple by film of suboxide, and into black by film of oxide of copper.

Surface in part large vesicular, in part curvilinear fibrous. Maximum diameter of vesicles, 7 mm.; maximum breadth of fibres, 1.5 mm.; length, 8 mm.

No. 2 (97.89 copper, 1.90 tin).—Color, red, slightly oxidized by exposure. Large and coarse vesicular; maximum diameter of vesicles, 5 mm.

No. 3 (96.06 copper, 3.76 tin).—Color, bright reddish-yellow, with faint traces of black oxide from exposure. Surface, small and finely vesicular.

No. 4 (92.11 copper, 7.80 tin).—Color, dull reddish-yellow. Homogeneous. Surface, finely arborescent.

No. 5 (90.27 copper, 9.58 tin).—Color, reddish-yellow, with spots of dark red and bright yellow. Surface, not homogeneous, in part vesicular, in part finely fibrous.

No. 6 (87.15 copper, 12.73 tin).—Color, brass-yellow in part, in part bluish-white. Surface, not homogeneous, finely vesicular. Fracture, hackly.

No. 7 (80.95 copper, 18.84 tin).—Color, reddish-gray, with brass-yellow spots. Surface, reticulated fibrous.

No. 8 (76.64 copper, 23.24 tin).—Color, reddish-gray. Surface, faintly vesicular; interior of vesicles brass-yellow. Fracture, irregularly curved. Lustre, dull.

No. 9 (69.84 copper, 29.89 tin).—Color, grayish-white. Surface, crystallization prismatic, diverging from centre. Fracture, of large curvature. Lustre, glistening.

No. 10 (68.58 copper, 31.26 tin).—Color, grayish-white, more white than the preceding. Surface, crystalline prismatic, diverging from the centre. Fracture, of large curvature. Lustre, glistening.

No. 11 (65.34 copper, 34.47 tin).—Color, bluish-gray, showing yellowish spots in some lights. Surface, interruptedly crystalline. Fracture, coarsely rounded. Lustre, splendent.

No. 12 (62.31 copper, 37.35 tin).—Color, dark bluish-gray. Surface, laminated. Fracture, coarse hackly. Lustre, splendent.

No. 13 (56.70 copper, 43.17 tin).—Color, bluish-white. Surface, crystallization eminent; crystals prismatic and diverging from centre. Lustre, splendent.

No. 14 (51.62 copper, 48.09 tin).—Color, bluish-white. Surface, crystallized, but not readily apparent. Fracture, coarse angular. Lustre, splendent.

No. 15 (47.61 copper, 52.14 tin).—Color, grayish-white. Surface, finely granular. Fracture, waved. Lustre, glistening.

No. 16 (44.52 copper, 55.28 tin).—Color, grayish-white. Surface, laminated granular. Fracture, coarsely waved. Lustre, glistening.

No. 17 (42.38 copper, 57.30 tin).—Color, grayish-white. Surface, crystallization finely reticulated. Fracture, uneven. Lustre, glistening.

No. 18 (38.37 copper, 61.32 tin).—Color, grayish-white. Surface, crystallized, but not readily apparent. Fracture, coarse hackly. Lustre, bright.

No. 19 (34.22 copper, 65.80 tin).—Color, grayish-white. Surface, crystallization eminent, prismatic, and diverging from centre. Prismatic angle, 130°. Sides of prism doubly striated, one set of striæ parallel to edge of prism, the other at an angle of 47° with the former. Lustre, splendent.

No. 20 (25.85 copper, 73.80 tin).—Color, grayish-white. Surface, crystallization eminent, prismatic. Lustre, splendent.

No. 21 (23.35 copper, 76.29 tin).—Color, grayish-white. Surface, crystallized, but not readily apparent. Fracture, hackly. Lustre, bright.

No. 22 (20.25 copper, 79.63 tin).—Color, grayish-white. Surface, crystallization not large but eminent; prismatic diverging from centre. Prismatic angle, 107°. Lustre, splendent.

No. 23 (15.08 copper, 84.62 tin).—Color, grayish-white. Surface, crystallization, coarse with prismatic faces, divergent. Fracture, jagged. Lustre, splendent.

No. 24 (11.49 copper, 88.47 tin).—Color, grayish-white. Surface, crystallization finely reticulated. Fracture, hackly. Lustre, dull with bright reflections from scattered crystalline faces. Section, distorted.

No. 25 (8.57 copper, 91.39 tin).—Color, grayish-white. Surface, granular. Lustre, dull, with glistening points. Section, distorted with curved edges.

No. 26 (3.72 copper, 96,31 tin).—Color, grayish-white. Surface, rounded granular. Lustre, dull.

No. 27 (0.74 copper, 99,02 tin).—Color, grayish-white. Surface, usually crystallization feeble with undefined prismatic faces. Lustre, bright.

No. 28 (0.32 copper, 99.46 tin).—Color, grayish-white. Surface, irregularly waved. Lustre, dull.

No. 29 (All tin).—Color, bluish or grayish-white. Surface, slightly vesicular at centre, prismatic at edges. Section, much distorted. Lustre, bright.

The following description of the fractures by tensile stress was also recorded :

No. 1 B (all copper).—Color, copper-red, with a purple film of sub-oxide ; surface, in part large vesicular, in part crystalline, radiating toward edge.

No. 2 A (97.95 copper, 1.88 tin).—Color, copper-red ; surface deeply vesicular ; fracture, uneven ; lustre, dull, with bright points.

Bar No. 2 B (97.83 copper, 1.92 tin).—Color, copper-red, inclining toward yellow; surface, finely vesicular; fracture, uneven; lustre, dull, with fine bright points.

Bar No. 3 B (95.96 copper, 3.80 tin).—Color, reddish-yellow; surface, finely vesicular, the curved surfaces interrupting; lustre, dull.

Bar No. 4 B (92.07 copper, 7.76 tin).—Color, yellowish-red in part, in part reddish-yellow; surface, vesicular; lustre, dull.

Bar No. 5 A (90.11 copper, 9.66 tin).—Color, yellowish-red; surface, crystallization, fibrous, radiate, finely vesicular on faces; lustre, dull.

Bar No. 5 B (90.43 copper, 9.50 tin).—Color, grayish-yelow; surface, coarse vesicular; fracture, jagged; lustre, dull.

Bar No. 6 A (87.15 copper, 12,69 tin).—Color, bluish-white with bright yellow spots; surface, confusedly vesicular; fracture, hackly; lustre, dull.

Bar No. 6 B (87.15 copper, 12.77 tin).—Color, reddish-yellow, with bluish-gray points, producing a general impression of orange; surface, broadly crystalline, with surfaces of prismatic faces finely vesicular; lustre, dull, with minute bright points.

Bar No. 7 A (80.99 copper, 18.92 tin).—Color, grayish-white with yellow points; surface, not apparently crystalline; fracture, coarse hackly; lustre, dull.

Bar No. 8 B (76.60 copper, 23.23 tin).—Color, yellowish-gray; surface, vesicular, with smooth intervening faces; fracture, even; lustre, shining.

Bar No. 9 A (69.90 copper, 29.85 tin).—Color, yellowish-gray to bluish-gray in different lights; surface, broadly-bladed prismatic, and diverging from centre; fracture, smooth; lustre, splendent.

Bar No. 10 A (68.58 copper, 31.26 tin).—Color, yellow to bluish-gray; surface, broadly-bladed prismatic and diverging from centre; fracture, smooth; lustre splendent.

Bar No. 11 A (65.31 copper, 34.47 tin).—Color, yellow to bluish-gray; surface, crystallized, but not readily apparent; fracture, coarsely waved; lustre, splendent.

Bar No. 12 B (62.79 copper, 36.96 tin).—Color, blue; surface, coarsely waved and pitted; lustre, splendent.

Bar No. 13 A (56.28 copper, 43.11 tin).—Color, bluish; surface, crystallization eminent, prismatic blades diverging from centre; fracture, uneven; lustre, splendent.

Bar No. 14 A (62.27 copper, 37.58 tin).—Color, bluish-gray in part, in part reddish-gray; surface, crystallized but not readily apparent; fracture, uneven; lustre, dull.

Bar No. 14 B (38.41 copper, 61.04 tin).—Color, bluish-gray; surface, crystallized but not readily apparent; fracture, coarsely waved; lustre, splendent.

Bar No. 15 B (47.49 copper, 52.29 tin).—Color, bluish-gray to grayish white; surface, waved; fracture, irregular; lustre, glistening.

Bar No. 16 B (44.42 copper, 55.41 tin).—Color, grayish-white; surface, crystallized but not readily apparent, waved and feebly vesicular; lustre, glistening.

Bar No. 17 B (38.83 copper, 60.79 tin).—Color, grayish-white; surface, finely waved vesicular; lustre, shining, with bright points.

Bar No. 18 A (43.37 copper, 56.37 tin).—Color, grayish-white; surface, crystallization prismatic, with waved lines on prismatic faces; lustre, splendent.

Bar No. 18 B (43.36 copper, 56.40 tin).—Color, grayish-white; surface, crystallized but not readily apparent, feebly vesicular; fracture, irregular; lustre, glistening, bright lines of reflection from crystalline faces.

Bar No. 19 A (40.32 copper, 59.46 tin).—Color, grayish-white; surface, crystallization eminent, prismatic; the prismatic faces large and striated: prismatic angle, 91°; lustre, splendent.

Bar No. 19 B (40.24 copper, 59.44 tin).—Color, grayish-white; surface, crystallization eminent, prismatic; lustre, splendent.

Bar No. 20 A (26.57 copper, 73.08 tin).—Color, grayish-white; surface, crystallization eminent, the faces in part prismatic, in part having an octahedral aspect; lustre, splendent.

Bar No. 20 B (25.12 copper, 74.51 tin).—Color, grayish-white; surface, crystallized but not readily apparent, waved and feebly vesicular fracture, rough ; lustre, glistening, with bright surfaces of reflection.

Bar No. 21 B (33 89 copper, 75.68 tin).—Color, grayish-white ; surface, feebly crystalline and vesicular ; fracture, hackly ; lustre, glistening, with bright points.

Bar No. 22 A (20.28 copper, 79.63 tin).—Color, grayish-white ; surface, crystallization eminent, prismatic faces irregular ; lustre, splendent.

Bar No. 22 B (20.21 copper, 79.62 tin).—Color, grayish-white ; surface, confusedly crystalline, with prismatic faces ; lustre, splendent.

Bar No. 23 A (15.12 copper, 84.58 tin).—Color, grayish-white, in part with yellow tarnish ; surface, crystallization eminent, broad prismatic faces, radiate ; lustre, splendent.

Bar No. 24 B (11.48 copper, 88.50 tin).—Color, grayish-white ; surface, crystallized fibrous ; fracture, hackly ; lustre, glistening, with bright lines of reflection from edges of crystals.

Bar No. 25 A (8.82 copper, 91.12 tin).—Color, grayish-white ; surface, irregular and feebly vesicular ; lustre, dull.

Bar No. 26 B (3.74 copper, 96.32 tin).—Color, grayish-white ; surface, fibrous, in part slightly vesicular ; lustre, dull.

Bar No. 27 A (0.75 copper, 98.98 tin).—Color, grayish-white ; surface, fibrous ; fracture, jagged ; lustre, dull.

204. **Records illustrating the Methods and Results** of this research are given on the following pages, in tabular form, selected from the mass of data recorded in the reports of the U. S. Board, to which reference may be made for other details. Those here given are representative of the work done on some of the best alloys discovered during the investigation, but do not by any means include all the useful compositions, the data from which are included in the table of summaries of all methods of test there given. These tables of records cover the range from good bearing metal to bell-metal, and the figures given are fair averages for such alloys ; they fall considerably below figures attainable in larger work performed by trained workmen.

TABLE LXII.

TESTS BY TENSILE STRESS.

No. 4 A.—Material: Alloy.—Original Mixture: 92.8 Cu. 7.2 Sn.—Analysis, 92.14 Cu, 7.84 Sn. —Dimensions: Length, 5″; Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.	Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inch.*		*Pounds.*	*Pounds.*	*Inch.*	
5,100	10,200	0.01	.0020	14,610	29,220	0.37	.0740
8,000	16,000	0.02	.0040	14,650	29,300	0.39	.0780
10,000	20,000	0.03	.0060				
10,760	21,520	0.05	.0100				
11,410	22,820	0.09	.0180				
0	......	Set 0.08	.....				
11,900	23,800	0.11	.0220				
12,800	25,600	0.14	.0280				
13,140	26,280	0.21	.0420				
14,000	28,000	0.27	.0540				

Broke 1¼ inches from C end.
Diameter of fractured section, 0.730 inch.
No blowholes.
Tenacity per square inch of original section, 29,300 pounds (2,090 kgs. per sq. cm.).
Tenacity per square inch in fractured section, 35,000 pounds (2,451 kgs. per sq. cm.).

No. 7 A.—Material: Alloy.—Original mixture: 80 Cu, 20 Sn.—Analysis: 80.99 Cu, 18.92 Sn. —Dimensions: Length, 6″; Diameter, 0.798″.

9,850	19,700	0.01	.002
14,000	28,000	0.02	.004
16,800	33,600	Broke in middle.	

Diameter of fractured section, 0.798 inches.
One blowhole, irregular-shaped, about 0.10 inch diameter.

Tenacity per square inch original section, 33,600 pounds (2,362 kgs. per sq. cm.).
Tenacity per square inch, deducting blowhole, 34,139 pounds (2,400 kgs. per sq. cm.).

No. 33 B.—Material: Alloy.—Original mixture: 87.5 Cu, 12.5 Sn.—Dimensions: Length, 5″; Diameter, 0.798″.

1,200	0.0025	......	.0005	24,000	0.0905	......	.0191
2,000	0.0052	......	.0010	200	......	0.0665	.....
3,000	0.0097	......	.0019	26,000	0.1040	......	.0208
4,000	0.0139	......	.0028	28,000	0.1271	......	.0254
6,000	0.0206	......	.0041	200	......	0.1063	.....
8,000	0.0275	......	.0055	30,000	0.1561	......	.0312
200	......	—0.0008 (?)	.....	32,000	0.2007	......	.0401
10,000	0 0330	......	.0066	200	......	0.1811	.....
12,000	0.0396	......	.0079	33,000	0.2270	......	.0454
200	......	0.0049	.. ..	33,200	0.2432	......	.0485
14,000	0.0473	......	.0094				
16,000	0.0541	......	.0108				
200	......	0.0200	.....				
18,000	0.0623	......	.0125				
20,000	0.0709	......	.0142				
200	......	0.0421	.....				
22,000	0.0793	......	.0159				

Broke in middle.
Diameter of fractured section, 0.770 inch.
Tenacity per square inch, original section, 33,200 pounds (2,334 kgs. per sq. cm.).
Tenacity per square inch, fractured section, 35,648 pounds (2,508 kgs. per sq. cm.).

TABLE LXIII.

TESTS BY COMPRESSIVE STRESS.

No. 31.—Material: Alloy.—Original mixture: 97.5 Cu, 2.5 Sn.—Analysis: 99.09 Cu, 0.87 Sn. —Dimensions: Length, 2″; Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inch.*	*Pounds.*		*Pounds.*	*Inch.*	*Pounds.*	
150	.0000	......	.....	16,000	.3951	52,152	.1975
2,000	.0018	6,519	.0009	18,000	.5176	58,671	.2588
4,000	.0093	13,038	.0046	20,000	.6156	65,188	.3078
6,000	.0302	19,557	.0151	22,000	.7266	71,709	.3683
8,000	.0609	26,075	.0305	24,000	.8483	78,228	.4242
10,000	.1077	32,595	.0539	25,000	.8801*	81,485	.4100
12,000	.1662	39,114	.0831				
14,000	.2601	45,633	.1300				

* Wedge cracked off at the top.

No. 32.—Material: Alloy.—Original mixture: 92.5 Cu, 7.5 Sn.—Analysis: 94.11 Cu, 5.43 Sn. Dimensions: Length, 2″; Diameter, 0.625″.

150	.0000	......	.....	22,000	.4584	71,709	.2292
2,000	.0000	6,519	.....	24,000	.5151	78,228	.2575
4,000	.0000	13,038	.....	26,000	.5778	84,747	.2889
6,000	.0002	19,557	.0001	28,000	.6393	91,266	.3197
8,000	.0108	26,075	.0054	30,000	.7000	97,780	.3500
10,000	.0511	32,595	.0255	32,000	.7499	104,303	.3749
12,000	.1219	39,114	.0609	34,000	.8033	110,822	.4016
14,000	.1937	45,633	.0968	36,000	.8447	117,341	.4223
16,000	.2648	52,152	.1324	38,000	.8918	123,860	.4459
18,000	.3310	58,671	.1655	40,000	.9330	130,379	.4665
20,000	.3951	65,188	.1975				

No. 33.—Material: Alloy.—Original mixture: 87.5 Cu, 12.5 Sn.—Analysis: 88.40 Cu, 11.59 Sn.—Dimensions: Length, 2″; Diameter, 0.625″.

150	.0000	......	.....	24,000	.3234	78,228	.1617
4,000	.0014	13,038	.0007	26,000	.3575	84,747	.1783
6,000	.0058	19,557	.0029	28,000	.4019	91,266	.2009
8,000	.0170	26,075	.0085	30,000	.4412	97,785	.2206
10,000	.0374	32,595	.0187	32,000	.4815	104,303	.2407
12,000	.0711	39,114	.0355	34,000	.5171	110,822	.2585
14,000	.1166	45,633	.0583	36,000	.5534	117,341	.2767
16,000	.1636	52,152	.0818	38,000	.5905	123,860	.2952
18,000	.2102	58,671	.1051	40,000	.6234	130,379	.3117
20,000	.2564	65,188	.1282	42,000	.6611	136,898	.3305
22,000	.2991	71,709	.1495	44,000	.6911	143,417	.3455

TABLE LXIV.

TESTS BY TRANVERSE STRESS.

No. 4.—Material: Alloy.—Original mixture: 92.8 Cu, 7.2 Sn.—Dimensions: Length between supports, 22″; Breadth, 0.997″; Depth, 1.012″.

Load.	Deflection, Δ.	Set.	Modulus of elasticity. $E=\frac{l^3}{4\,\Delta\, bd^3}(P+4)$	Load.	Deflection, Δ.	Set.	Modulus of elasticity. $E=\frac{l^3}{4\,\Delta\, bd^3}(P+4)$
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
6	0.0008	......	....	0	.....	0.020	....
10	0.0016	......	....	750	0.173	.....	....
20	0.0039	......	....	800	0.199	.....	10,408,413
30	0.007	......	....	0	.....	0.049	....
40	0.010	......	....	850	0.232	.....	....
60	0.013	......	....	900	0.287	.....	8,114,620
80	0.017	......	....	0	.....	0.116	....
100	0.020	......	13,396,305	950	0.348	.....	....
0	......	0.000	....	In 5 m.	0.429	.....	....
125	0.024	......	....	1,000	0.491	.....	5,267,855
150	0.029	......	13,680,575	In 5 m.	0.584	.....	....
175	0.034	......	....	0	.....	0.379	....
200	0.041	......	12,818,227	1,050	0.620	.....	....
0	......	0.000	....	In 10 m.	0.781	.....	....
225	0.045	......	....	1,100	0.858	.....	3,314,847
250	0.052	......	12,583,801	In 10 m.	1.031	.....	....
0	......	0.0008	....	0	.....	0.807	....
275	0.057	......	....	1,100	1.053	.....	....
300	0.059	......	13,274,439	1,150	1.155	.....	....
0	......	0.000	....	In 3 m.	1.289	.....	....
325	0.063	......	....	1,200	1.384	.....	2,240,640
350	0.066	......	13,817,863	In 10 m.	1.824	.....	....
375	0.072	......	....	0	.....	1.549	....
400	0.075	......	13,877,197	1,200	1.824	.....	....
0	......	0.000	....	1,250	1.935	.....	....
425	0.079	......	....	In 10 m.	2.178	.....	....
450	0.082	......	14,263,420	In 30 m.	2.281	.....	....
475	0.087	......	....	$15^h\ 30^m$	2.637	.....	....
0	......	0.0016	....	0	.....	2.343	....
500	0.095	......	13,677,484	1,250	2.638	.....	....
0	......	0.0024	....	1,300	2.746	.....	1,223,372
525	0.102	......	....	In 10 m.	2.911	.....	....
550	0.106	......	13,464,355	In 30 m.	2.966	.....	....
0	......	0.0032	....	1,350	3.226	.....	....
575	0.112	......	....	In 30 m.	6.706	Tray reached bottom of supports.	
0	......	0.0055	....				
600	0.124	......	12,548,648				
0	......	0.0095	....				
650	0.137	......	....				
0	......	0.013	....				
700	0.153	......	11,853,945				

Breaking load, $P=1{,}350$ pounds.

Modulus of rupture,

$$R=\frac{3l}{2bd^2}(P+3)=48{,}731.$$

$$R_m=3{,}074.$$

TABLE LXIV.—*Continued.*

No 32.—Material: Alloy.—Original mixture: 92.5 Cu, 7.5 Sn.—Dimensions: Length between supports, $l = 22''$; Breadth, $b = 0.956''$; Depth, $d = 0.982''$.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $E = \frac{Pl^3}{4 \Delta bd^3}$	Load.	Deflection. Δ	Set.	Modulus of elasticity. $E = \frac{Pl^3}{4 \Delta bd^3}$
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inches.*	*Inches.*	
10	0.0060	......	....	3	......	0.0655	....
20	0.0104	......	....	600	0.2095	......	....
40	0.0185	......	6,357,759	640	0.2365	......	7,957,281
80	0.0278	......	8,461,765	680	0.2867	......	....
120	0.0376	......	9,384,450	720	0.3511	......	6,030,003
160	0.0472	......	9,967,673	760	0.4609	......	....
200	0.0572	......	10,281,341	800	0.6031	......	3,900,466
3	......	0.0035	....	3	......	0.0413	....
240	0.0668	......	10,564,538	800	0.6202	......	....
280	0.0769	......	10,706,500	840	0.7792	......	....
320	0.0880	......	10,692,594	880	0.0427	......	....
360	0.0983	......	10,768,738	920	1.3217	......	....
400	0.1105	......	10,644,211	960	1.74	......	....
3	......	0.0145	....	1,000	2.13	......	1,380,404
440	0.1232	Beam sinks	10,501,656	1,040	2.63	......	....
480	0.1389	......	10,161,429	1,080	3.78	......	840,132
520	0.1535	......	9,961,177	3	......	3.40	....
560	0.1719	......	9,579,171				
600	0.1963	......	8,987,663				
3	......	0.0577	....				
600	0.2065	......	....				

Resistance decreased in 2^m to 586 pounds.
Resistance decreased in $1^h\ 48^m$ to 562 pounds.

Bar bent to a deflection of 8″ without breaking. Breaking load (or the load causing deflection of $3\frac{1}{2}''$) 1,080 pounds.

Modulus of rupture, $R = \frac{3Pl}{2bd^2} = 38,659.$

$Rm = 2,718.$

No. 7.—Material: Alloy.—Original mixture: 80 Cu, 20 Sn.—Analysis: 80.95 Cu, 18.84 Sn.—Dimensions: Length between supports, 22″; Breadth, 0.998″; Depth, 1.011.

100	0.025	......	10,737,827	900	0.184	......	12,681,589
125	0.028	......	11,891,996	0	.....	0.0103	....
150	0.033	......	12,045,639	950	0.192	......	....
175	0.037	......	12,487,468	1,000	0.201	......	12,893,200
200	0.043	......	12,245,726	0	.....	0.012	....
0	.....	0.0024	....	1,050	0.209	......	....
225	0.045	......	....	0	.....	0 013	....
250	0.051	......	12,855,428	1,100	0.219	......	13,012,118
275	0.057	......	....	1,200	0.256	......	12,139,743
300	0.063	......	12,455,356	0	.....	0.026	....
3	.....	0.0039	....	1,300	0.285	......	11,810,161
325	0.069	......	....	0	.....	0.039	....
350	0.073	......	12,517,091	1,400	0.320	......	11,325,050
375	0.077	......	....	0	.....	0.055	....
400	0.081	......	12,874,176	1,500	0.360	......	10,783,714
0	.....	0.0047	....	0	.....	0.075	....
425	0.083	......	....	1,600	0.415	......	9,976,527
450	0.087	......	....	0	.....	0.099	....
475	0.094	......	....	1,700	0.470	......	9,355,254
500	0.098	......	13,274,787	0	.....	0.126	....
0	.....	0.0063	....	1,650	0.510	......	9,202,114
525	0.103	......	....	In 15 h	0.537	......	....
550	0.105	......	....	0	.....	0.169	....
575	0.114	......	....	1,520	0.469	......	....
600	0.122	......	12,779,097	1,750	Broke 10 seconds after putting on the last pound of the weight.		
0	.....	0.0063	....				
625	0.128	......	....				
650	0.132	......	....				
700	0.140	......	12,979,791				
0	.....	0.0039	....				
750	0.155	......	....				
800	0.167	......	12.426,896				
0	.....	0.0063	....				
850	0.172	......	....				

Breaking load, 1,750 pounds.

Modulus of rupture,

$$R = \frac{3l}{2bd^2}(P+3) = 56,715.$$

$Rm = 3,987.$

TABLE LXIV.—*Continued.*

No. 33.—Material: Alloy.—Original mixture: 87.5 Cu, 12.5 Sn.—Dimensions: Length between supports, 22″; Breadth, 0.973″; Depth, 0.977″.

Load.	Deflection. Δ	Set.	Modulus of elasticity, $E=\frac{Pl^3}{4\Delta bd^3}$	Load.	Deflection. Δ	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
10	0.0042	....	....	1,000	0.3245	....	....
20	0.0075	....	....	3	......	0.0910	....
40	0.0125	....	9,387,752	1,040	0.3611	....	....
80	0.0236	....	9,969,873	1,080	0.3959	....	8,002,946
120	0.0322	....	10,603,633	1,200	0.4493	....	....
160	0.0409	....	11,478,087	1,160	0.5122	....	....
200	0.0508	....	11,549,891	1,200	0.5727	....	6,147,034
3	......	0.0049	....	3	......	0.2827	....
240	0.0606	....	11,618,503	1,200	0.5892	....	....
280	0.0701	....	11,717,949	1,240	0.6475	....	....
320	0.0793	....	11,838,275	1,280	0.7485	....	....
360	0.0890	....	11,869,273	1,300	0.8111	....	....
400	0.0980	....	11,974,171	1,320	0.8701	....	....
3	......	0.0036 (?)	....	1,360	0.9892	....	....
440	0.1071	....	12,052,435	1,400	1.1419	....	3,596,760
480	0.1168	....	....	1,440	1.3032	....	....
520	0.1255	....	12,155,454	1,480	1.4878	....	....
560	0.1355	....	12,127,844	1,520	1.6700	....	....
600	0.1461	....	12,047,936	1,560	1.8500	....	....
3	......	0.0112	....	1,600	2.1000	....	2,235,179
640	0.1568	....	....	1,640	2.4500	....	....
680	0.1678	....	11,888,540	1,680	3.1000	....	....
720	0.1800	Beam sinks slowly.		1,700	3.5000	....	1,424,927
760	0.1933	....	....	3	......	2.81	....
800	0.2074	....	11,315,997	1,700	......	....	....
3	......	0.0284	....				
840	0.2269	....	....				
880	0.2475	....	....				
920	0.2716	....	9,937,327				
960	0.2964	....	....				

Bar broke after a deflection of about 4″.
Breaking load, 1,700 pounds.

Modulus of rupture, $R=\frac{3Pl}{2bd^2}=60{,}403$ lbs.

$Rm=4{,}246$.

No. 34.—Material: Alloy.—Original mixture: 82.5 Cu, 17.5 Sn.—Dimensions: Length between supports, 22″; Breadth, 0.950″; Depth, 0.970″.

120	0.0316	....	11,659,056	1,000	0.2060	....	14,903,838
160	0.0405	....	12,129,260	10	......	0.0098	....
200	0.0481	....	12,765,982	1,040	0.2157	....	14,802,137
10	......	0.0035	....	1,080	0.2264	....	....
240	0.0560	....	13,158,079	1,120	0.2377	....	14,466,320
280	0.0646	....	13,307,417	1,160	0.2472	....	....
320	0.0729	....	13,476,957	1,200	0.2614	....	....
360	0.0804	....	13,747,250	1,240	0.2728	....	....
400	0.0881	....	13,939,699	1,280	0.2852	....	....
10	......	0.0035	....	1,320	0.3003	....	13,495,466
440	0.0940	....	14,371,235	1,360	0.3175	....	....
480	0.1027	....	14,349,611	1,400	0.3330	....	....
520	0.1099	....	14,526,967	10	......	0.0436	....
560	0.1174	....	14,644,993	1,520	0.3880	....	12,055,389
600	0.1265	....	14,562,305	1,600	0.4393	....	....
10	......	0.0028	....	10	......	0.0935	....
640	0.1340	....	14,663,731	1,720	0.5247	....	10,064,370
680	0.1409	....	14,817,235	1,800	0.5757	....	....
720	0.1473	....	15,007,180	1,840	0.6125	....	9,223,187
760	0.1549	....	15,063,694				
800	0.1631	....	15,059,318				
Resistance decreased in $19^h\ 45^m$ to 788 pounds.							
10	......	0.0047	....				
840	0.1702	....	15,152,664				
880	0.1790	....	15,093,815				
920	0.1873	....	15,080,625				
960	0.1959	....	15,045,481				

Broke suddenly with a ringing sound about 30 seconds after putting on the strain, and just after reading the deflection.
Breaking load, 1,840 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=67{,}930$.

$Rm=4{,}675$.

205. Final Results.—The following table exhibits the results of the whole investigation in a compact form which permits ready comparison of data.

The average results obtained by test of the copper-tin alloys, enable the engineer to reach tolerably definite conclusions relative to their value in construction. The results are given as obtained by the four principal methods of stress. They are very variable, and this variability is due not only to the variation of composition of the alloys, but also to their differences of physical structure, and is, therefore, to some extent, accidental.

General conclusions may, nevertheless, be deduced and the principal facts revealed by test, and these conclusions are also most unmistakably exhibited by the diagrams presented in this and preceding articles.

The figures given by the tests have been plotted in the form of curves having for their ordinate the resistance observed and for their abscissas the distortion of the given test-piece. These curves exhibit the method of variation of resistance with progressing change of form, and constitute "strain diagrams" which exhibit to the eye every important quality of the material.

TABLE LXV.

ALLOYS OF COPPER AND TIN.

Summary of Average Results.

NUMBER.	ATOMIC PROPORTION.	COMPOSITION OF ORIGINAL MIXTURE. Copper.	COMPOSITION OF ORIGINAL MIXTURE. Tin.	MEAN COMPOSITION BY ANALYSIS. Copper.	MEAN COMPOSITION BY ANALYSIS. Tin.	MEAN SPECIFIC GRAVITY.	TESTS BY TRANSVERSE STRESS. Modulus of rupture.	TESTS BY TRANSVERSE STRESS. Elastic limit, in parts, of breaking load.	TESTS BY TRANSVERSE STRESS. Total deflection before breaking.	TESTS BY TRANSVERSE STRESS. Resilience within a deflection of 3½ inches.	TESTS BY TRANSVERSE STRESS. Modulus of elasticity.	TESTS BY TENSILE STRESS. Tensile strength per square inch of— Original section.	TESTS BY TENSILE STRESS. Tensile strength per square inch of— Fractured section.	TESTS BY TENSILE STRESS. Elastic limit, percentages of breaking load.	TESTS BY TENSILE STRESS. Total elongation, in parts of original length.	TESTS BY TENSILE STRESS. Diameter of fractured section, percentages of original.	COMPRESSION TESTS. Crushing strength, pounds per square inch.	COMPRESSION TESTS. Amount of compression, percentages of original length.	TESTS BY TORSIONAL STRESS. Torsional moment. Maximum.	TESTS BY TORSIONAL STRESS. Torsional moment. Elastic limit, percentages of maximum.	TESTS BY TORSIONAL STRESS. Ductility. Angle of torsion.	TESTS BY TORSIONAL STRESS. Ductility. Extension of exterior fibre.	TESTS BY TORSIONAL STRESS. Resilience.
									In's.	*Ft. lbs.*		*Lbs.*	*Lbs.*						*Foot lbs.*				
1*	Cu......	100.00	0.00	.....	.....	‡8.487	21,251	.346	2.306	114.8	13,986,605	12,260	12,987	.862	.0047	.96	39,000	.10+	65.66	.505	40.50	0.0255	37.71
30	Cu......	100.00	0.00	.....	.....	8.791	29,848	.140	Bent	191.25	10,203,205	27,800	32,496	.518	.0647	.92	42,000	.10+	143.24	.353	153.00	0.3084	320.35
2	$SnCu_{96}$..	98.10	1.90	97.89	1.90	8.564	......	.....	.....	......	....	......	......	.....	.....	....	34,000	.10+	150.46	.248	317.50	1.0006	572.51
31*	....	97.50	2.50	99.09	0.87	8.511	......	.....	.....	......	....	......	......	.....	.....	....	....	.....	......	.....	......	....	......
3	$SnCu_{48}$..	96.27	3.73	96.06	3.76	8.649	33,232	.350	Bent	239.68	13,739,654	32,000	42,692	.500	.1429	.86	42,000	.10+	156.93	.338	247.40	0.7031	599.96
4	$SnCu_{34}$..	92.80	7.20	92.11	7.80	8.694	43,731	.426	Bent	310.58	14,263,420	28,540	33,780	.666	.0553	.92	42,000	.10+	160.01	.383	125.60	0.2189	277.22
32	....	92.59	7.50	94.11	5.43	8.684	38,659	.370	Bent	264.20	13,581,817	27,900	34,383	.502	.0743	.88	....	.....	156.63	.333	187.25	0.4318	368.33
5	....	90.00	10.00	90.27	9.58	8.669	49,400	.400	Bent	345.01	14,012,135	26,860	30,205	.586	.0366	.93	38,000	.10+	175.28	.414	114.50	0.1795	274.60
33	....	87.50	12.50	88.41	11.59	8.648	60,403	.353	4.000	415.14	12,472,655	31,100	33,153	.675	.0356	.97	....	.....	178.05	.385	70.75	0.0730	175.23
6†	$SnCu_{12}$..	86.57	13.43	87.15	12.73	‡8.681	......	.....	2.291	155.70	....	29,430	30,680	.680	.0333	.98	53,000	.10+	182.32	.446	100.00	0.1391	253.61
34	....	82.50	17.50	82.70	17.34	8.792	67,930	.565	0.625	57.75	15,152,664	36,200	36,346	.....	.0071	1.00	....	.....	198.06	.516	14.00	0.0032	35.85
7	....	80.00	20.00	80.95	18.84	8.740	56,715	.657	0.492	44.30	13,304,198	32,980	32,980	.....	.0040	1.00	78,000	.10+	190.15	.623	16.30	0.0040	35.59
35	....	77.50	22.50	77.56	22.25	8.917	29,926	1.00	0.161	5.62	15,149,535	24,650	24,650	1.00	.0054	1.00	....	....	153.96	.714	4.38	0.0003	6.46
8	$SnCu_8$ ..	76.32	23.68	76.64	23.24	8.565	32,210	1.00	0.191	8.17	13,495,122	22,010	22.010	1.00	.....	1.00	114,081	.0905	122.13	1.00	3.40	0.0002	3.72
36	....	72.50	27.50	72.89	26.85	8.925	9,512	1.00	0.048	0.57	16,387,041	6,493	6,493	1.00	.....	1.00	....	.....	35.54	1.00	1.00	0.00003	0.89
9	....	70.00	30.00	69.84	29.89	8.932	12,076	1.00	0.062	0.97	15,321,736	5,585	5,585	1.00	.....	1.00	146,676	.0350	17.58	1.00	1.50	0.00008	0.63
10	$SnCu_4$ ..	68.25	31.75	68.58	31.26	8.938	9,192	1.00	0.043	0.58	15,694,556	1,620	1,620	1.00	.....	1.00	....	.....	......	.....	.....	....	.....

37	....	67.50	32.50	67.87	32.10	8.907	9,477	1.00	0.052	0.58	14,896,691	2,536	2,586	1.00	.....	1.00	....	.....	26.13	1.00	1.65	0.00009	1.08
11	....	65.00	35.00	65.34	34.47	8.947	4,770	1.00	0.020	0.12	19,344,368	2,201	2,201	1.00	.....	1.00	84,747	.0285	16.44	1.00	0.75	0.00002	0.36
38	....	62.50	37.50	62.42	37.48	8.956	2,907	1.00	0.019	0.17	....	1,561	1,561	1.00	.....	1.00	....	.....	19.20	1.00	0.50	0.00001	0.15
12	$SnCu_3$ ..	61.71	38.29	62.31	37.35	8.970	2,761	1.00	0.032	0.12	9,603,989	688	688	1.00	.....	1.00	39,114	.0175	7.06	1.00	1.00	0.00003	0.25
39	....	57.50	42.59	57.88	42.05	8.781	3,732	1.00	0.021	0.12	....	1,377	1,377	1.00	.....	1.00	....	.....	8.60	1.00	0.50	0.00001	0.16
13	Sn_5Cu_{12}	56.32	43.68	56.70	43.17	8.682	2,126	1.00	0.010	0.01	14,693,513	1,455	1,455	1.00	.....	1.00	....	.....	8.94	1.00	1.00	0.00003	0.41
40	....	52.50	47.50	53.46	46.55	8.643	1,995	1.00	0.008	0.05	....	......	......	.....	.....	....	....	.....	7.77	1.00	0.40	0.00001	0.08
14	$SnCu_2$ ..	51.80	48.20	51.62	48.09	8.560	3,877	1.00	0.040	0.23	....	2,555	2,555	1.00	.....	1.00	....	.....	13.54	1.00	1.00	0.00003	0.19
15	Sn_7Cu_{12}.	47.95	52.05	47.61	52.14	8.442	3,600	1.00	0.019	0.07	17,039,130	1,525	1,525	1.00	.....	1.00	84,747	.0215	14.87	1.00	1.00	0.00003	0.28
41	....	47.50	52.50	47.27	52.72	8.446	5,601	1.00	0.019	0.18	....	2,407	2,407	1.00	.....	1.00	....	.....	17.96	1.00	1.00	0.00003	0.34
16	Sn_2Cu_3..	44.63	55.37	44.52	55.28	8.312	4,776	1.00	0.026	0.15	16,823,869	3,010	3,010	1.00	.....	1.00	35,854	.0066	23.35	1.00	0.92	0.00003	0.53
42	....	42.50	57.50	43.99	55.91	8.437	6,084	1.00	0.036	0.33	§9,824,600	2,098	2,098	1.00	.....	1.00	....	.....	16.23	1.00	1.33	0.00006	0.60
17	Sn_3Cu_4..	41.74	58.26	42.38	57.30	8.302	7,172	1.00	0.042	0.25	23,238,907	3,910	3,910	1.00	.....	1.00	39,114	.0205	28.11	1.00	1.65	0.00007	0.60
18	Sn_5Cu_6..	39.20	60.86	38.37	61.32	8.182	8,400	1.00	0.060	0.46	12,302,353	2,820	2,820	1.00	.....	1.00	29,335	.0145	23.46	1.00	1.70	0.00005	0.42
43	....	37.50	62.50	37.10	62.90	8.101	6,942	.500	0.080	0.76	10,672,961	2,400	2,400	.....	.....	1.00	....	.....	12.70	1.000	1.50	0.00004	0.20
19	$SnCu$....	34.95	65.05	34.22	65.80	8.013	5,384	.625	0.043	0.25	11,041,901	3,371	3,371	.....	.....	1.00	19,557	.0555	16.56	1.000	1.87	0.00005	0.31
44	....	32.50	67.50	30.76	69.19	7.931	7,178	.476	0.112	1.28	6,984,987	2,322	2,322	.....	.....	1.00	....	.....	17.32	.977	2.63	0.00014	0.73
20	Sn_4Cu_3..	28.72	71.28	25.85	73.80	7.948	8,067	.583	0.121	1.53	9,982,832	1,648	1,648	.....	.....	1.00	17,927	.10+	20.97	1.000	2.34	0.00011	0.76
45	....	27.50	72.50	26.63	73.17	7.915	11,128	.438	0.220	3.69	7,803,107	4,380	4,380	.....	.....	1.00	....	.....	25.50	.985	3.17	0.00018	1.06
21	Sn_5Cu_3..	24.38	75.62	23.35	76.29	7.835	12,408	.378	0.269	5.33	11,520,262	6,775	6,775	.....	.....	1.00	....	.....	41.50	.979	4.50	0.0003	2.25
46	....	22.50	77.50	22.10	77.58	7.774	13,687	.300	0.405	8.78	8,474,849	5,000	5,014	.....	.0022	1.09	....	.....	27.80	.951	7.38	0.0012	3.31
22	Sn_2Cu ..	21.18	78.82	20.25	79.63	7.770	10,019	.333	0.345	5.35	9,743,644	4,337	4,337	.....	.....	1.00	16,297	.10+	22.93	.930	5.69	0.0006	2.07
47	....	17.50	82.50	16.70	83.23	7.690	10,288	.267	0.533	11.51	7,356,258	2,816	2,822	.....	.....	1.00	....	.....	24.39	.784	10.62	0.0020	3.96
23	Sn_3Cu ..	15.19	84.81	15.08	84.62	7.657	9,063	.222	0.858	12.89	7,032,130	6,520	6,520	.844	.0067	1.00	6,519	.10+	22.80	.753	24.83	0.0092	9.05
48	....	12.50	87.50	11.69	88.24	7.543	10,254	.200	1.076	21.42	7,901,458	3,798	3,825	.527	.0055	.99	....	.....	24.86	.779	56.50	0.0471	22.93
24	Sn_4Cu ..	11.84	88.16	11.49	88.47	7.552	10,706	.250	Bent	76.72	10,403,101	6,380	6,627	.549	.0410	.98	10,104	.10+	23.24	.653	61.75	0.0703	23.45
25	Sn_5Cu ..	9.70	90.30	8.57	91.39	7.484	5,305	.250	Bent	43.72	7,965,988	6,450	7,594	.543	.0687	.92	....	.....	22.98	.631	131.75	0.2347	43.85
49	....	7.50	92.50	6.05	93.77	7.417	9,764	.207	Bent	73.79	7,969,719	6,096	8,121	.427	.2022	.87	....	....	19.83	.556	178.00	0.4006	50.66
26	$Sn_{12}Cu$..	4.29	95.71	3.72	96.31	7.360	6,925	.190	Bent	39.75	8,613,200	4,780	6,804	.575	.1232	.84	....	.....	22.83	.514	220.50	0.5677	76.28
50	....	2.50	97.50	2.11	97.68	7.342	8,374	.240	Bent	63.64	6,692,585	5,600	12,397	.214	.4000	.68	....	.....	15.75	.474	362.00	1.2189	80.15
27	$Sn_{48}Cu$..	1.11	98.89	0.74	99.02	7.305	3,964	.333	Bent	33.16	6,771,517	3,650	7,867	.....	.2279	.70	....	.....	18.29	.448	387.50	1.3388	90.40
28	$Sn_{98}Cu$..	0.55	99.43	0.32	99.46	7.290	4,438	.300	Bent	29.94	9,398,659	4,475	13,223	.559	.3544	.58	....	.....	16.47	.418	535.30	2.0879	125.99
29	Sn	0.	100	.....	.....	7.293	3,740	.273	Bent	29.79	6,734,838	3,500	......	.476	.3551	.50	6,400	.10+	12.75	.453	556.75	2.1975	105.45

* Defective bar. † Defective transverse bar.

‡ Specific gravity of turnings of ingot-copper, 8.874; specific gravity of turnings of No. 6 A, 8,943.

§ Short bar.

206. **Strain-Diagrams,** obtained from tests determining tenacity of the bronzes, are given in the accompanying figure as derived from experiments upon the first series of copper-tin alloys, No. 1, pure copper, to 29, pure tin, inclusive. The curves marked A are from the upper end of the bar and B from the lower end.

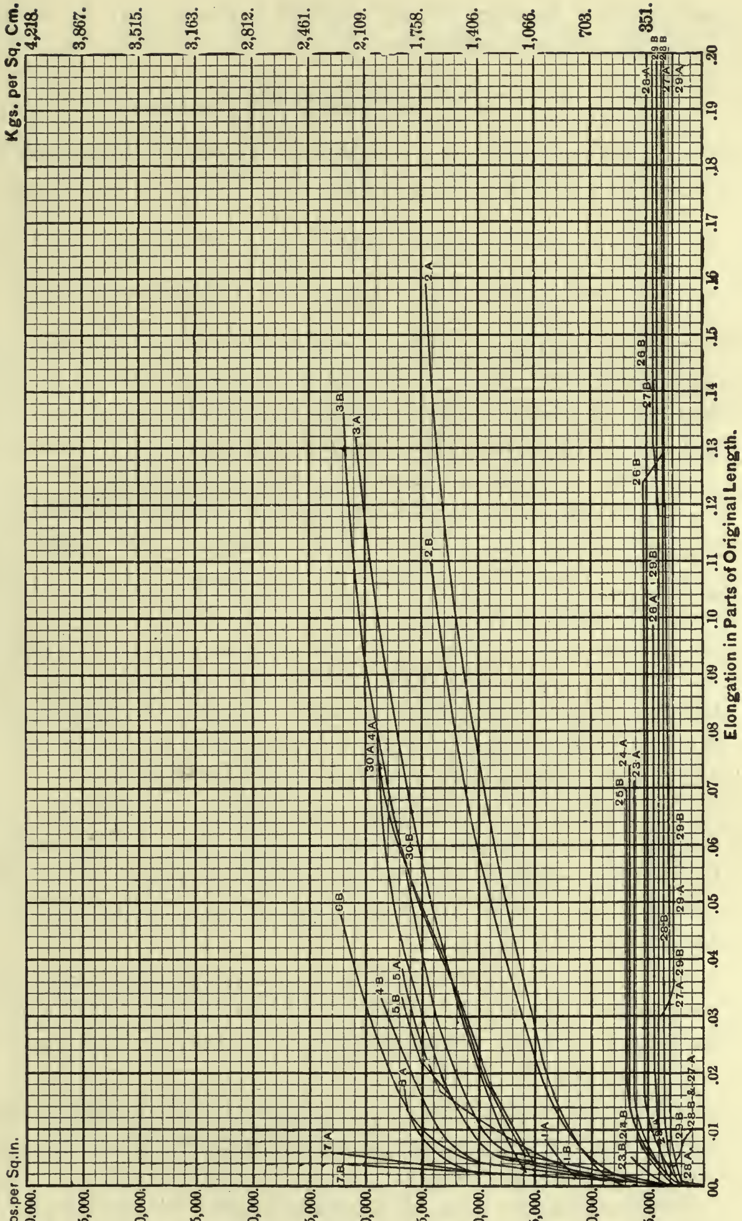
These curves may evidently be divided into three classes: viz., those which are very rigid and brittle, as 7 A, 7 B (copper, 80, bell-metal), those which are very ductile and malleable but soft and weak, as Nos. 26 to 29 (tin, 95 to 100) inclusive; and those which combine strength and ductility and possess, therefore, great resilience, as Nos. 2, 3 and 4 A (copper, 93 to 98, gun-metals). All intermediate qualities may be obtained, but these are typical and the most valuable of these compositions are evidently, for general purposes, those belonging to the last class, and of which the strain-diagrams lie between the extreme qualities, one set of which lie near the axis of abscissas, while the other set lie nearer the axis of ordinates. For some purposes, as when, for example, it is desirable to secure a high elastic limit as well as moderate toughness, alloys like ordnance bronzes, Nos. 4, 5, 6 (copper, 86 to 93), which are stiff and strong, although not very ductile, may be chosen. Cases may even arise, although certainly not often, in which the rigidity of bell-metal, No. 7 (copper, 80), may make that alloy valuable in consequence of its high elastic limit, notwithstanding its great deficiency in ductility.

207. **The Tenacities** of the valuable class of these metals range not far from 30,000 pounds per square inch (2,109 kilogs. per sq. cm.), the strength increasing somewhat with the proportion of tin up to 18 per cent. Within that range, the expression

$$T = 30{,}000 + 1{,}000\,t,$$

in which T is the tenacity and t the percentage of tin, may be taken to represent a maximum which selected materials

FIG. 9.—STRAIN-DIAGRAMS OF BRONZES IN TENSION.



and careful fluxing should enable the engineer to secure. Two-thirds these values, or

$$T = 20{,}000 + 700\,t,$$

should be expected as a minimum. In metric measures, the two values would become, nearly,

$$T = 2{,}100 + 700\,t, \text{ as a maximum ;}$$

$$T_m = 1{,}400 + 500\,t, \text{ as a minimum.}$$

The ductility should be at least 10 per cent. for the best alloy, and must be expected to be too slight to be counted upon when the proportion of tin exceeds 20 per cent. unless this percentage rises to a very high figure, as from 90 per cent. upward, when it again becomes considerable.

The modulus of ultimate resilience obtained by multiplying two-thirds the tenacity by the extension of a piece one unit in length should be, in foot-pounds, for the more valuable alloys, not less than 3,000 foot-pounds or 250 foot-pounds per cubic inch (or not far from 2.5 kilogram-metres per cubic centimetre) for good materials, and two-thirds this value for ordinary work. The elastic resilience is not to be expected to exceed 5 foot-pounds per cubic inch (or about 0.05 kilogram-metres per cubic centimetre).

The plate only exhibits one of the two sets of strain-diagrams, and a less favorable representation of the quality of these alloys than would be obtained from tests of specially prepared and carefully fluxed specimens, such as may be secured when needed.

The alloys containing from 75 down to 25 per cent. copper are stone-like, inelastic, brittle and worthless for the work of the engineer, their strain-diagrams are straight lines and do not appear in the figure.

A moderately well defined "elastic limit" is seen to exist with many of the harder of these alloys, as, *e.g.*, Nos. 3, 4, 5 and 6 (copper, 85 to 95).

208. Compression Strain-diagrams are exhibited in Figure 10 which are obtained from the same set of alloys as

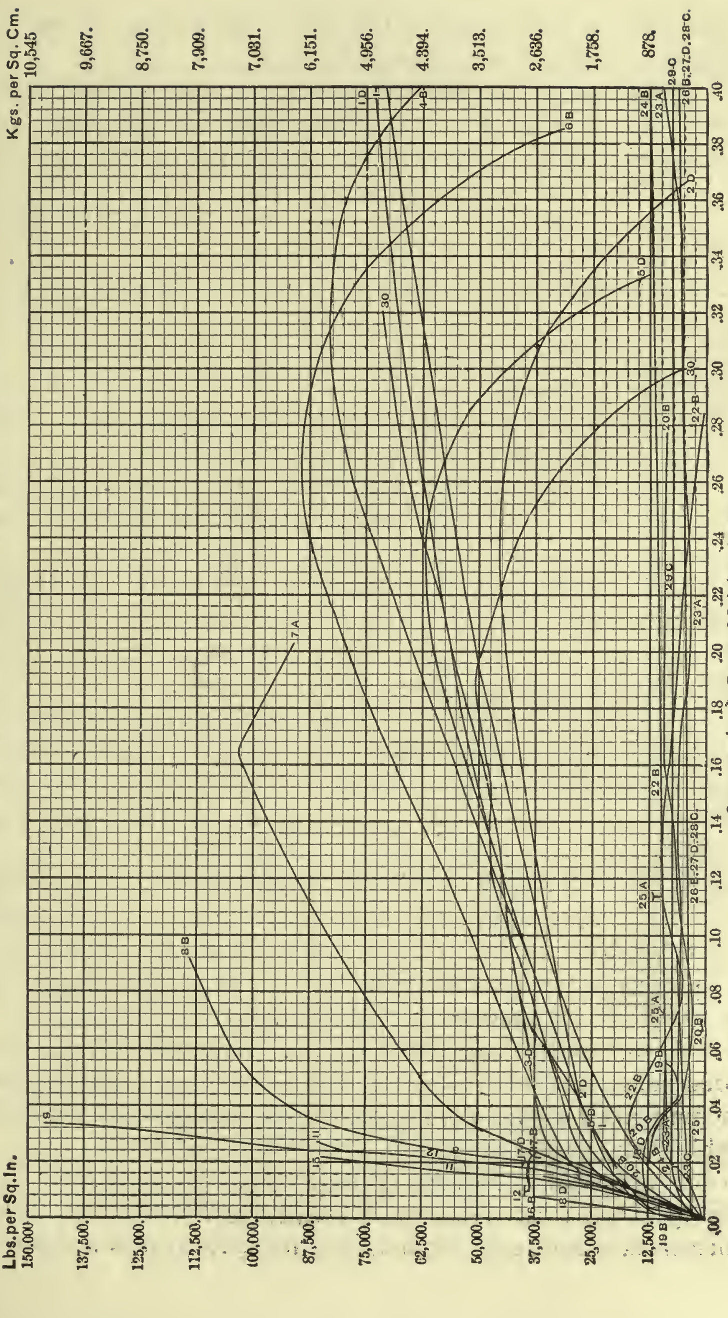


FIG. 10.—STRAIN-DIAGRAMS OF BRONZES IN COMPRESSION.

were used in the preparation of the tension diagrams shown in the preceding illustration.

The alloys do not hold precisely the same order in compression as in tension; but the same general facts are observable. The most resilient (ultimate) metals are as above, Nos. 1 to 7 and 30 (copper, 80 and upward); the most malleable are Nos. 25 to 29 (copper, 10 or less), and the most rigid are Nos. 9, 10, 11 (copper, 65 to 70).

No. 9 (copper, 70) excels enormously in strength and in elastic resilience, and in elastic resistance; No. 8 (copper, 75) is a very resilient alloy, also; Nos. 6 and 7 (copper, 80 to 86) excel in ultimate resilience, or power of resisting shocks great enough to deform the piece. Gun-bronze, No. 5 (copper, 90), is evidently one of the best of these alloys.

Some of the singular variations seen in several of the diagrams are probably due to accidental peculiarities of deformation of the test piece; possibly all may be so.

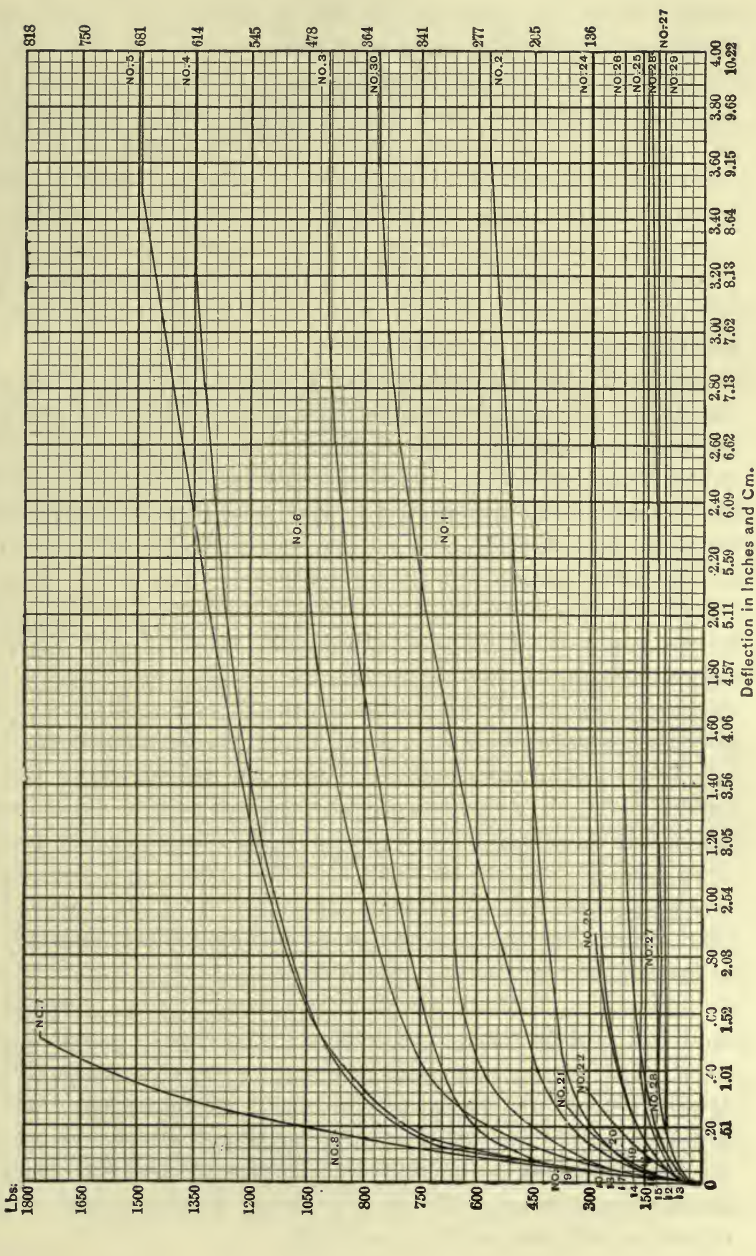
Elastic limits are not as well defined here as in the tension diagrams, and, in the hard alloys, are either obscure, as in No. 7 (copper, 80), or coincide with the point of rupture, as in Nos. 9–15 (copper, 45 to 70).

Comparing the two sets of diagrams, it is seen that, for members in tension, for bolts, sheet metal, ordnance, in fact for the majority of all common purposes, the best alloys are those lying very near the copper-end of the series and containing from 2 to 10 per cent. of that metal, and the less as the method of attack includes the action of shock to a greater extent. For compression, more tin is advisable (10 to 15 per cent.) if shock occurs, and it may be justifiable to reduce the copper to 70 per cent., even if the load is applied absolutely without jar, and maximum tenacity, simply, is sought.

209. **Transverse Tests** of the copper-tin alloys give strain-diagrams such as are seen in Figure 11. Compositions approaching copper, 80, tin, 20, exhibit the greatest strength under this form of load.

Those having less tin (6 to 10 per cent.) as Nos. 4, 5 (copper, 93; copper, 90), are evidently vastly better to resist the shock of suddenly applied loads and safer against accident;

FIG. 11.—STRAIN-DIAGRAMS. BRONZES AS BEAMS.



while those consisting principally of tin are soft and very ductile and malleable, as already seen.

210. Comparison of Resistances.—By inspection of the curves, it will be seen that the curves of tensile and torsional strength agree very closely, the torsion curve being laid down to such a scale that one foot-pound of torsional moment has the same measure as 200 pounds tenacity. The curve of transverse strength is, in form, similar to those of tension and torsion (one pound modulus of rupture corresponding to one pound tenacity), but the ordinates of the curve are usually much greater than in the two latter.

The curve of compression strength is very unlike either of the others. Laid down to the same scale as that of tenacity, the ordinates of the curve are much higher, showing that the compression resistances of the copper-tin alloys are much greater than their tenacities. The maximum compression strength is reached by one of the brittle alloys, the tenacity of which was not far from the minimum.

The tensile and compressive resistances of the alloys are in no way related to each other; the torsional strength is very nearly proportional to the tensile strength. The transverse strength may depend, in some degree, upon the compressive strength, but it is much more nearly related to the tensile strength, as is shown by the general correspondence of the curve of transverse with that of tensile resistance. The modulus of rupture, as obtained by the transverse tests, is, in general, a figure between those of tensile and compressive resistance, but there are a few cases in which it is larger than either, indicating an approach to the condition suggested in forming the equations already given.

The strength of the alloys at the copper end of the series increases rapidly with the addition of tin, up to about 4 per cent. Transverse strength continues to increase up to about 17½ per cent. of tin; while the tensile and torsional resistances also increase, but very irregularly, to the same point. As this irregularity corresponds to the irregularity of the curve of specific gravities, it is probably due to porosity, and might not be seen in sound castings.

The maximum point of the three curves is reached at about the same point, viz., at the alloy containing 82.70 copper, 17.34 tin.

From the point of maximum strength, the three curves drop rapidly to alloys containing about 27.5 per cent. of tin, and then more slowly to 37.5 per cent., at which point nearly the minimum strength is reached. The compression curve reaches its maximum between these points. The alloys of minimum strength are found from 3.75 per cent. tin to 52.5 per cent. tin. The absolute minimum is probably about 45 per cent. of tin.

From 52.5 per cent. of tin to about 77.5 per cent. tin there is a slow and irregular increase in strength to the point which has been called the second maximum.

From 77.5 per cent. tin to the end of the series, or all tin, the strengths slowly and somewhat irregularly decrease, the second minimum being reached at the end of the curve.

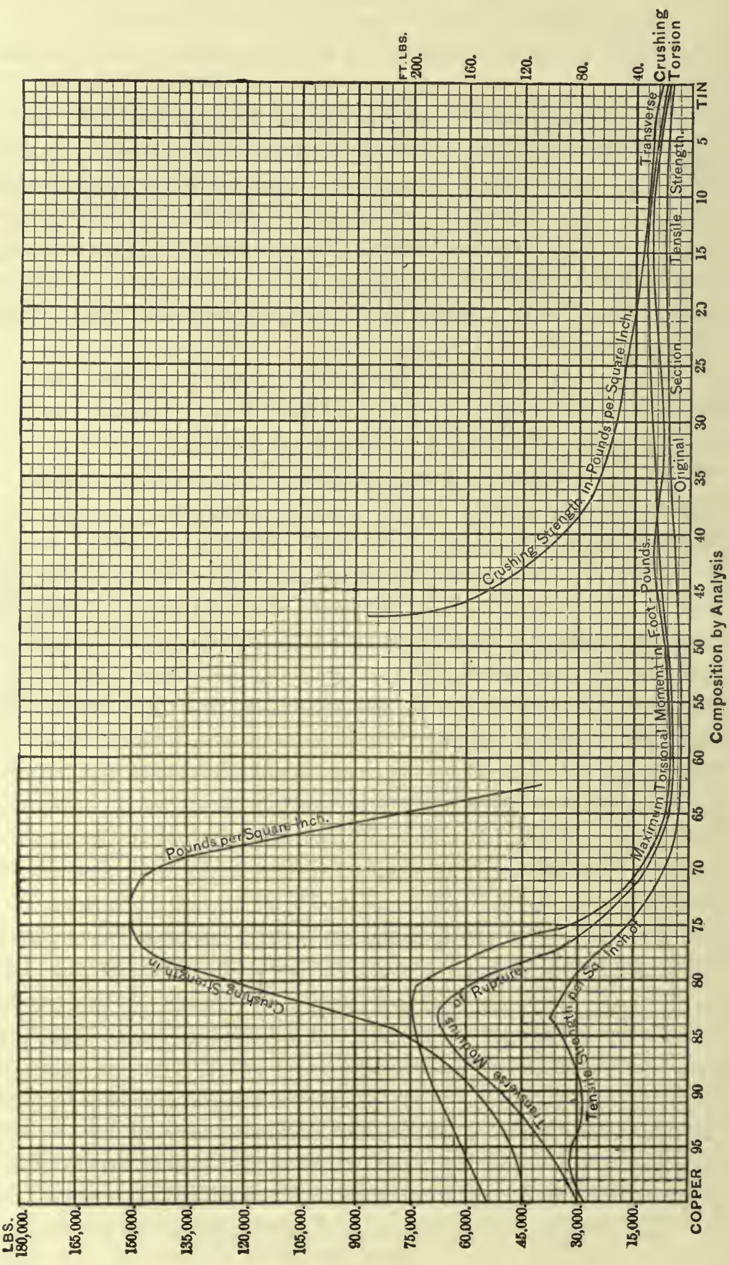
All alloys containing more than 25 per cent. tin are practically worthless for all purposes demanding strength, the average strength of these alloys being only about one-sixth of the average of those containing less than 25 per cent. of tin.

Maximum strength is associated with a peculiar color, a reddish or pinkish gray, which marks the change from the ductile to the brittle alloys, and occurs between the percentages of tin which give a silver-white alloy in which no trace of copper could be detected by the eye, and the reddish-yellow to yellowish-gray alloys like No. 6 (lower end of bar) and No. 33.

The results of these tests do not seem to corroborate the theory that peculiar properties are possessed by the alloys which are compounded of simple multiples of their atomic weights or chemical equivalents, and that these properties are lost as the compositions vary more or less from this definite constitution. It does appear that a certain percentage composition gives a maximum strength and another certain percentage a minimum, but neither of these compositions is represented by simple multiples of the atomic weights.

There appears to be a perfectly regular law of decrease

FIG. 12.—COMPARISON OF RESISTANCES.



from the maximum to minimum strength which does not have any relation to the atomic proportions.

211. **Total Resilience,** or the product of the mean resistance into the distance through which the resistance acts, is the work done in breaking a piece of metal. For tensile stress, it is equal to the mean resistance multiplied by the total elongation ; for transverse stress it is the mean resistance multiplied by the total deflection, and for torsional stress it is the mean resistance of the specimen as measured by the mean ordinate of the autographic strain diagram, expressed in foot-pounds of torsional moment, or pounds acting at the radius of one foot multiplied by the distance through which this moment is exerted as measured by the total abscissa of the diagram, and reduced to feet traversed by the resistance. Its values are given elsewhere.

The total resilience under transverse stress was calculated from the curves of deflections by transverse stress, the area of the curve being directly proportional to the resilience, the ordinates representing resistances and the abscissas deflections. The results are reduced to foot-pounds of work. In the cases of bars which bent to a deflection of more than 3½ inches (8.9 cm.) without breaking, the resilience within that limit of deflection was taken.

The torsional resilience was calculated from the area of the autographic strain-diagram and reduced to foot-pounds of work.

The resilience under tensile stress was not determined.

Referring to the plates of curves of resistances, it will be found that resilience bears a very close relation to ductility, the curves being nearly similar, except in those portions of the curves representing the alloys which bent without breaking under transverse stress, and of which the transverse resilience is taken only within a deflection of 3½ inches.

The maximum torsion resilience is given by No. 3 (96.06 copper, 3.76 tin), one of the most ductile of the strong alloys. No. 33 (88.40 copper, 11.59 tin) gave maximum transverse resilience within the deflection of 3½ inches, being the strongest alloy which reached that deflection without breaking, but its total resilience is less than those of the more ductile bars, which bent, without breaking, to deflections of more than 8 inches.

From the bar which gave maximum total resilience a rapid decrease occurs to No. 8 (76.64 copper, 23.24 tin). From No. 8 to No. 20 (35.85 copper, 73.80 tin) all bars, with one exception, show total resiliences so small, compared with the maximum, that the curve of resilience between these points approaches the bottom line of the plate so closely that it apparently coincides with it. The figures for transverse resilience agree with those of torsional resilience between these points.

From No. 20 to No. 28 (0.32 copper, 99.46 tin) there is a gradual increase of the total resiliences to the "second maximum."

The alloys which are of most value to the engineer are evidently those containing less than 20 per cent. tin, and, for the great majority of purposes, gun-bronze (copper 89.90) and the alloys containing rather less tin are likely to prove best; while those containing from 10 to 15 per cent. tin are evidently to be chosen where hardness, combined with strength, must be secured. Alloys of these metals containing from 30 to 70 per cent. of either are rigid, brittle, and valueless for the ordinary purposes of the engineer, although some of them may have use for special work.

The phenomenon of *decrease of set with time* was observed for the first time with No. 47. On relieving the bar of all pressure except that due its own weight, and except a very slight pressure (a few ounces) to insure that the pressure-block actually touched the bar and was not raised from it, the scale-beam balanced at 5 pounds, and the reading of the set was made. While reading the set the scale-beam was observed to rise, indicating *increase* of resistance to deflection, as it had similarly been observed to drop when resistance to stress took place. A number of observations of this increase of resistance to the permanent deflection were made, and also of the decrease of set, as measured by running back the pressure-screw till the scale-beam again balanced at 5 pounds, and taking additional readings. The result of these observations showed that in one observation of 39 minutes the resistance of the bar, as measured by the scale-beam, increased 18 pounds, and that in 2 hours 20 minutes the set decreased the amount of 0.0239 inch.

This fact of the decrease of set with time has since been confirmed by a large number of tests made on the same machine, and it has also been observed by other experimenters. It indicates that what has been hitherto called the "permanent set" of metals is in reality not entirely permanent, but is partially, at least, temporary, a fact already well-known.

212. Specific Gravity.—The curve of specific gravities (Fig. 13) shows considerable regularity, indicating that the densities of the alloys follow a definite law.

The alloys containing less than 25 per cent. of tin show irregular variation in specific gravity due to porosity. The figures obtained are the densities of *castings*, and not of the metals themselves, as they might be determined in fine powder, or from metal free from cavities.

The densities of the castings are, hence, much lower than that of alloys given by other authorities, and for this reason the density of No. 6 A (87.15 copper, 12.69 tin) in the shape of fine turnings gave the figure 8.943, and turnings of ingot-copper gave the figure 8.874.

The strength and density are in a certain degree dependent upon each other, and the greater the density of an alloy of any given composition the greater the strength. This has been shown in experiments on gun-metal, which uniformly exhibits an increase of strength with increase of density.

The casting of small bars, such as have been used in the experiments described, is especially unfavorable to the production of metal of great density, while in the casting of guns and other large masses the pressure of molten metal is much greater, and all conditions favor the increase of density and of strength.

It is probable that the actual specific gravities of all alloys containing less than 25 per cent. tin do not greatly vary from

8.95, and that the specific gravities of castings of these alloys will be less than 8.95 as they exhibit porosity. The specific gravity of an alloy is increased by repeated working.

In determining the specific gravities, the pieces were first washed in alcohol to free them from any dirt or grease which might be attached to them, and then thoroughly dried. Before weighing in water, the pieces were boiled for two or three hours, to remove, as far as possible, the air inclosed in the pores of the metal, and after cooling in the dish in which they were boiled, they were placed under the receiver of an air-pump, and the air was further exhausted. They were then quickly transferred to distilled water, in which they were weighed, suspended by a loop of fine platinum wire from the arm of the balance. The water in which they were weighed was kept at the same level, and the proper correction made for weight of the platinum wire.

The results given are corrected for temperature of the water, being reduced to the standard of water of maximum density (39°.4 Fahr., 4°.1 cent.).

If the formation of the gas which causes blow-holes can be prevented, or if it can be removed from the metal while the latter is still in a fluid state, it is evident that the cast metal will be entirely free from them, and a metal of great density and strength will be obtained.

No means has yet been discovered by which this desirable result may completely be accomplished, but it is not improbable that it may be done by treatment of the fluid metal, or by the use of fluxes. The subject offers a fruitful field for experiment, one which it was proposed to explore, after concluding the researches on copper-tin, copper-zinc, and triple alloys, but one which was not carried out by the U. S. Board.

The specific gravity of an alloy is increased by repeated tempering and rolling.

The specific gravity of pure copper, according to authorities quoted in "*Constants of Nature*," varies from 8.360 to 8.958, electrolytic, hammered, rolled, or pressed copper giving the highest figures and those which are probably the most nearly correct.

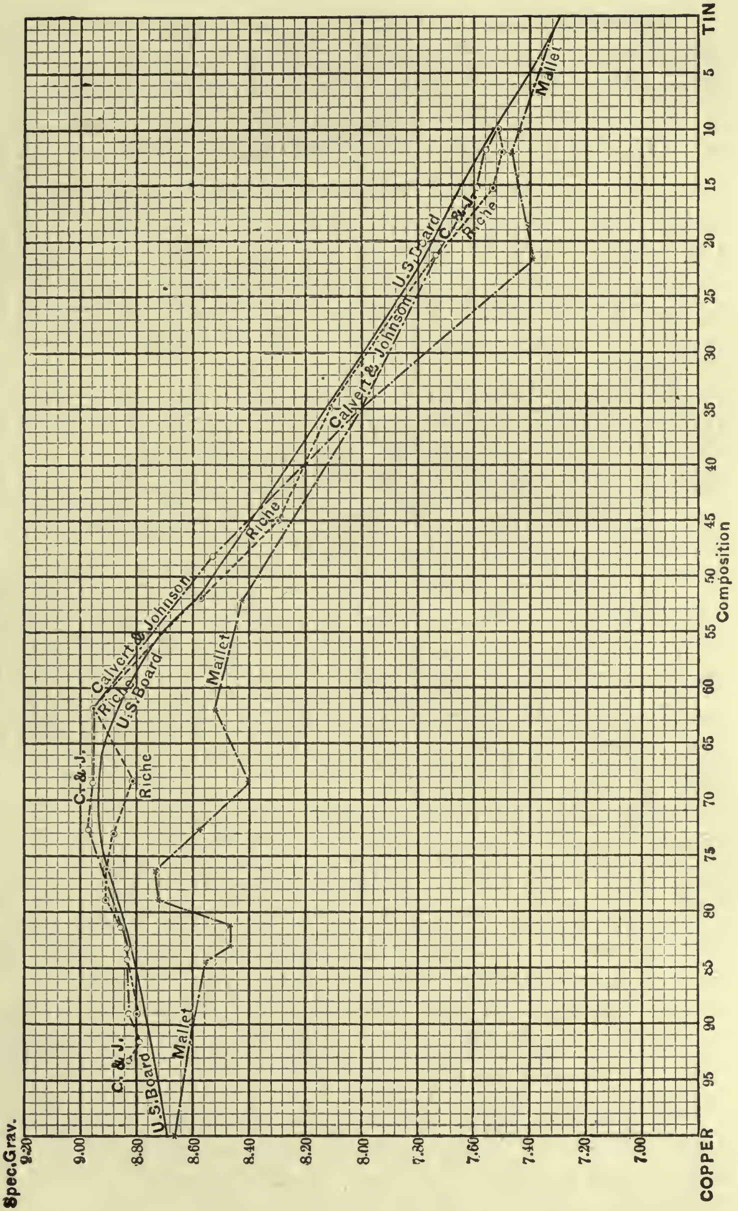


FIG. 13.—COMPARISON OF DENSITIES.

The specific gravity of all alloys containing between 25 and 38 per cent. tin, which alloys are compact and homogeneous, is greater than 8.9 (reaching 8.97 at the latter percentage).

The specific gravities given in the tables, as determined from the castings, show the cause of imperfections in strength and other qualities, and indicate that one proper method of improving strength is to increase density. They indicate that the lower the specific gravity of alloys which show a certain definite strength, the greater increase may probably be expected from any cause which brings the specific gravity up to 8.95.

Rolling, hammering, or compressing porous and ductile metals increases density. Casting under pressure has the same effect. It is probable also that temperature of pouring and rate of cooling have an influence upon density, and the use of fluxes which may remove occluded gases from the molten metals will increase it also.

The maximum density of the series is given by alloy No. 12 (62.31 copper, 37.35 tin, by analysis), the original mixture of which corresponds to the formula $SnCu_3$, and is nearly approached by alloy No. 38 (62.42 copper, 37.48 tin). The figures are 8.970 and 8.956 respectively. The former is higher than is given by any authority known to the Author for any alloy of copper and tin.

From alloy No. 12 to the end of the series, to pure tin, an almost perfectly regular decrease of specific gravity occurs, that of tin being 7.29. From the regularity of this decrease of specific gravity it would seem that these alloys are but little subject to porosity in castings. In these alloys the density has no definite relation to strength.

213. Apparent Limit of Elasticity.—The apparent limit of elasticity has been defined as the point at which distortion begins to increase in a greater ratio than the force which causes that distortion. In the curves of deflections and elongations, and in the autographic diagrams of torsional stress, it is the point at which the curve begins (usually suddenly) to change its direction and to deflect toward the horizontal.

The figure giving curves in which comparison is made of the transverse, torsional, and tensile resistance, also contains curves showing the limit of elasticity under each of the three kinds of tests. In the general summary of results (Table LXV.) the elastic limits are represented by parts of the total resistance.

It will be seen that the curves of limits of elasticity obtained from the three kinds of tests, coincide with the curves of resistance in the middle portion of the series, that containing the brittle alloys, and fall beneath them at the ends, the figures in the summary showing the elastic limit to be there 100 per cent. of the total strength, and that of the more ductile alloys to be in some cases as small as 20 per cent. of the total strength, and to increase with the decrease of ductility.

In general, the ratio obtained by tensile test is higher than that obtained by either transverse or torsional test.

In the stronger alloys, the elastic limit under tensile stress is reached at from 50 to 68 per cent. of the breaking load, and under transverse and torsional stress at 35 to 45 per cent. As the percentage of tin is increased beyond 17.5 per cent., the ratio of elastic limit to ultimate strength is increased; alloy No. 8 (76.64 copper, 23.24 tin) giving a ratio of 100 per cent.; the elastic limit was not reached till fracture took place. The same result is given by all alloys from No. 8 to No. 21 (38.37 copper, 61.32 tin). From No. 21 to pure tin, this elastic limit is reached before fracture, by both transverse and torsional tests. In both tensile tests of alloys containing between 62.5 and 82.5 per cent. of tin the elastic limit was either not reached or only just reached before fracture took place. In these alloys, the ratios of elastic limit to ultimate strength appear much higher in torsional than transverse stress. The ductile alloys, containing large percentages of tin, give ratios under torsional stress which gradually decrease as the percentage of tin increases, the decrease being nearly regular from 98.5 per cent. to 45.3 per cent., between the alloy of 27.5 copper, 72.5 tin, and pure tin. In transverse test, the ratio is much more nearly constant, varying somewhat irregularly between the same compositions from 43.8 to 27.3 per cent.

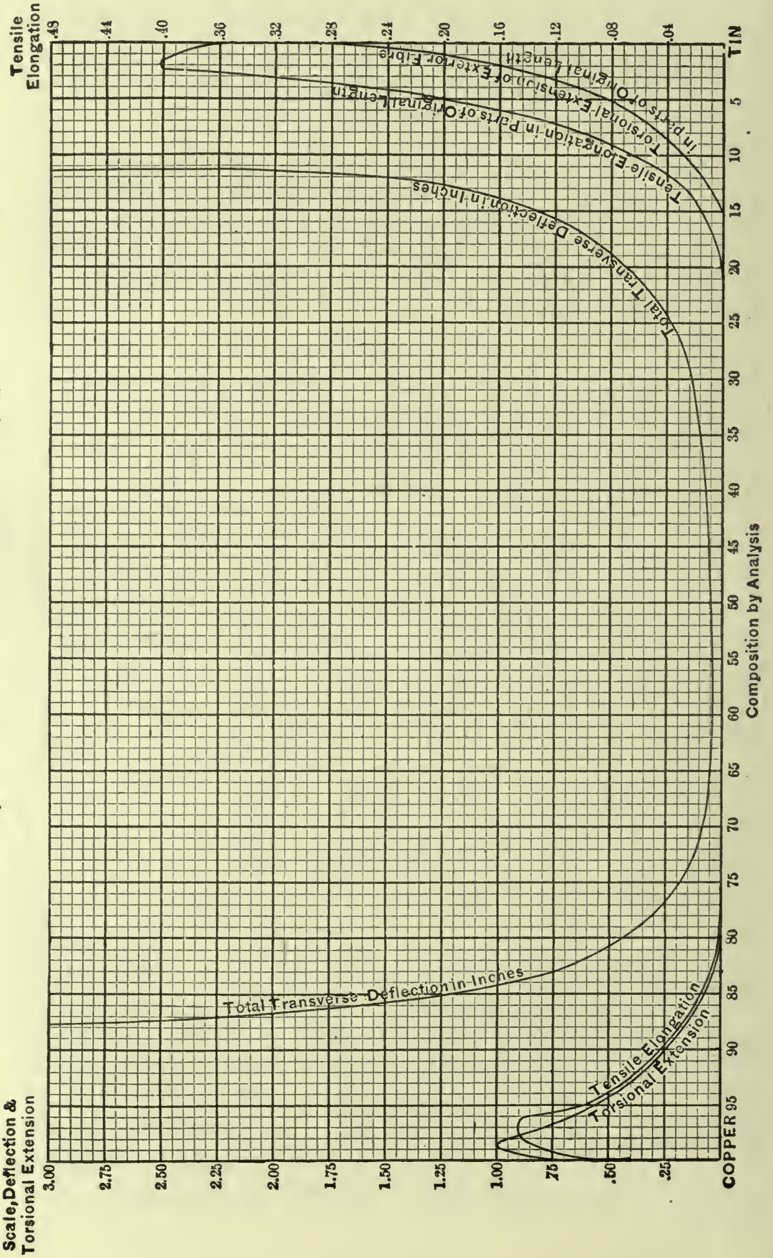


FIG. 14.—DUCTILITY OF THE COPPER-TIN ALLOYS.

214. Moduli of Elasticity.—The moduli of elasticity were calculated from deflections observed in transverse test. The figures given are considered to be the most probable moduli of each bar within the elastic limit where the deflections are proportional to the applied loads. The figures and the curve show irregularity, but not greater than should be expected from metals of different compositions.

In alloys containing less than 24 per cent. of tin (all the stronger and more valuable alloys) the modulus of elasticity by transverse stress is about 14,000,000 (984,200 kilogs. per sq. cm.).

From 25 per cent. to 35 per cent. tin, the modulus is some what greater. From 35 to 75 per cent. there is a very great irregularity, corresponding to the irregularity in strength and other properties as shown by test, and much greater than any other property.

From alloys containing 70 per cent. tin, to pure tin, the moduli become a little more regular, the tendency being to decrease as the tin increases. The modulus of these alloys averages a little more than half that of the stronger alloys containing less than 20 per cent. of tin.

215. Ductility is exhibited on the next set of curves. Figure 14. The copper-tin alloys are ductile in all directions when they contain principally tin or are nearly all copper, As the proportions alter and become more nearly equal, the ductility decreases, as the range between 25 and 75 per cent. tin is approached from either side, and within that range are very brittle. The alloys rich in copper are strong, though ductile, while those rich in tin partake of the properties of that metal. The method of variation of ductility is the same for all methods of test, but the test by transverse loading of bars gives greater opportunity for nice measurement and exhibits better the gradual introduction of this element as the lessening percentage of tin passes the figure 35 (copper, 65). Alloys containing less than 20 per cent. tin or more than 85 per cent. gain in ductility rapidly as change of composition goes on.

Ductility is thus variable, quite smoothly and regularly

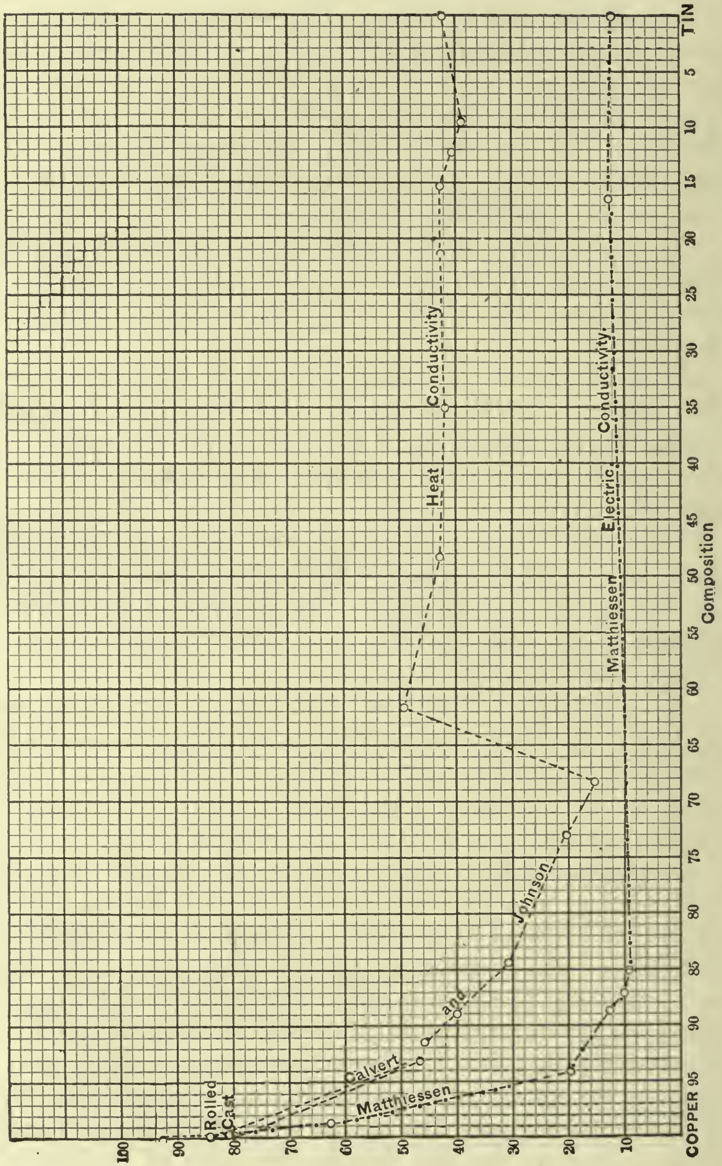


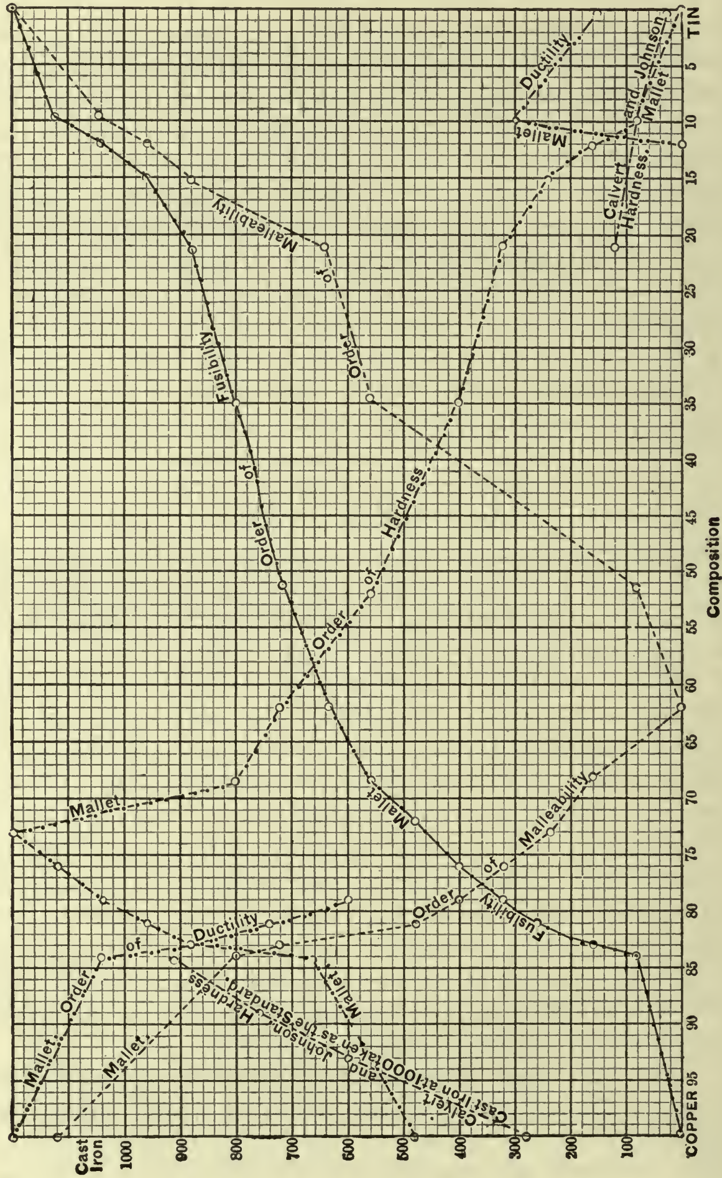
FIG. 15.—CONDUCTIVITY OF COPPER-TIN ALLOYS.

with the composition of the alloy. In tension, ductility was measured directly, except in the case of the most brittle alloys, where it was too small to be measured. In transverse tests it was easy to obtain its measure by noting the deflection, which, in some cases, was greater than can be shown on the scale; some bars, in fact, could not be broken by bending under the load. The autographic strain-diagram probably gives the best means of comparison. The maximum angle of torsion is 556.75 degrees, corresponding to an extension of the most extended fibre, originally parallel to the axis, of 2.2, nearly; the minimum, 0.4 degree, corresponds to an extension of but 0.000.006; pure tin gives a value 200,000 times greater than the most brittle alloy. Bars containing less than 12.5 per cent. tin did not break by bending to a deflection of 16 per cent. their length and 3½ times their depth. The illustrations given in the frontispiece exhibit the fracture of a number of these alloys, and present to the eye the characteristics of each, showing well the ductility or the brittleness, the toughness or the crystalline or granular surfaces revealed by breaking them.

216. **Conductivity** for heat and electricity varies in the copper-tin alloys as seen in Figure 15, which represents the data furnished by Calvert and Johnson, and by Matthiessen. There is seen to be a general correspondence, with a sudden break at the composition, copper 60 to 70, which appears in the curve for heat-conductivity, but not in that for electric conductivity. In both cases, this property remains practically constant for all alloys between copper 0 and copper 60, and rapidly improves as the alloy becomes more nearly pure copper. The standard taken for comparison is pure silver. The curves well illustrate the importance of securing purity in copper intended to be used as a conductor.

217. **The other Physical Properties** of the copper-tin alloys, as determined by various authorities, are exhibited in Figure 16. Mallet gives data relating to ductility, malleability, hardness, and fusibility, on which are based several of these curves. With this curve of hardness is compared that of Calvert and Johnson, which corresponds, roughly, with it

FIG. 16.—PROPERTIES OF COPPER-TIN ALLOYS.



so far as it goes. Hardness is here seen to increase steadily from pure copper to copper 75, at which point that of minimum ductility is reached. From this point it decreases steadily and with tolerable uniformity to the opposite end of the series.

Malleability takes an almost precisely opposite course, falling to zero at copper 60–65 and rising again to the end (pure tin).

Fusibility constantly lessens, as tin is added to copper, from end to end of the whole range.

The curve of ductility closely follows that of malleability in alloys rich in copper, but the lack of cohesion of tin causes a great falling off at the opposite end of the line.

CHAPTER X.

STRENGTH OF BRASSES AND OTHER COPPER-ZINC ALLOYS.

218. **The Brasses** include all the copper-zinc alloys containing one-half copper and upwards, and a few special alloys are also given the name, as are copper-tin-zinc alloys, of which the tin forms but a small proportion. The name bronze has been applied, occasionally, to these ternary alloys, also. The terms bronze and brass are used indifferently by the older writers, but the tendency to restrict each term to a binary alloy, or to a ternary alloy in which one constituent exists in very small proportion, is decidedly observable among later writers and they will be so used in this treatise.

In the cases of the brasses, as in that of the bronzes, no systematic investigation of the properties useful to the engineer had been made except by the U. S. Government. The U. S. Board, to which allusion has been already frequently made, authorized a determination of "the mechanical properties and of the physical and chemical relations of alloys of copper, tin, and zinc," under the arrangement of committees approved by the Board, which assigned to the Committee on Alloys the duty of "assuming charge of a series of experiments on the characteristics of alloys and an investigation of the laws of combination."

This research was conducted in the Mechanical Laboratory of the Department of Engineering of the Stevens Institute of Technology under the direction of the Author. The facts and data thus discovered and placed on record * will be summarized in this chapter after reference to earlier work on nearly related alloys.

* Report of U. S. Board, Vol. II.; Ex. Doc. 23; 46th Congress, 2nd Session. Washington: Government Printing Office, 1881.

219. Earlier Experiments.—Mallet * found the tenacity of an alloy of copper, 90.7, zinc, 9.3, to be 27,000 pounds to the square inch (1,456 kilogs. per sq. cm.), with a specific gravity of 8.6; with 3 per cent. more zinc the strength was increased to very nearly 30,000 pounds (2,109 kilogs.). Copper, 85.4, zinc, 14.6, had a tenacity of about 32,000 pounds (2,249.6 kilogs.), and with copper, 83, zinc, 17, the figure became 31,000 (2,179 kilogs.). The tenacities varied little throughout the range and down to copper, 2, zinc, 1, which is a Muntz metal. Equal parts copper and zinc exhibited a tenacity of 20,000 pounds per square inch (1,406 kilogs. per sq. cm.) in Mallet's experiments; the Author has obtained, in some cases, 40,000 (2,812 kilogs.). Alloys rapidly become weaker, passing this maximum, as the proportion of zinc is increased, as will be seen later, passing, however, a second maximum at about copper, 10, zinc, 90, which gives figures one-third as great as the first maximum.

Brass cartridge metal tested with copper and steel by Lt. Metcalfe at the Bridesburg Arsenal in samples trimmed out to a contracted section of one inch (2.54 cm.), minimum breadth, and 0.03 inch (0.076 cm.) thick gave results as follows:

TABLE LXVI.

TENACITY AND ELONGATION OF CARTRIDGE METAL.

LOAD.		PURE COPPER.	COMMERCIAL COPPER.				BRASS.		OPEN HEARTH STEEL.	
Lbs.	Kilogs.						Unannealed.	Annealed.	I.	II.
500	227	0.024	0.005	0.005	......	......	.....	.....	......	......
600	272	0.040	0.020	0.015	......	......	.....	.....	......	.....
800	363	0.078	0.063	0.040	0.033	co.27	.....	.....	......	......
1,000	454	0.155	0.156	0.087	0.050	0.057	0.013	0.050	0.0225	......
1,100	499	.....	0.266	0.130	0.075	0.085	0.025	0.075	0.030	0.005
1,200	544	.....	......	0.214	0.102	0.110	0.042	0.100	0.0425	0.0075
1,300	590	....	......	0.290	0.152	0.163	0.062	0.130	0.060	0.013
1,400	635	.....	......	... ..	0.266	0.270	0.085	0.165	0.0775	0.030
1,500	680	.....	......	......	.. ...	......	0.117	0.220	0.140	0.065
1,600	726	.....	......	......	......	.....	0.157	0.350	0.230	0.126
1,700	771	.....	......	......	......	......	0.217	.....	......	......
1,800	817	.....	......	......	......	......	0.322	.....	......	......

* *Phil. Mag.*, Vol. 21, 1842.

As the test-pieces were of the "grooved" form the elongations serve for comparison of these specimens, but have no absolute value.

220. **Sterro-Metal**, a brass which contains a little tin and iron, was tested by Baron de Rosthorn at Vienna, and gave the following results: *

TABLE LXVII.

TENACITY OF STERRO-METAL.

MATERIAL.	TENACITY.	
	Lbs. per sq. in.	Kilogs. per sq. cm.
Sterro-metal; cast	60,480	4,252
" " forged	76,160	5,354
" " cold-drawn	85,120	5,984
Gun-bronze; cast	40,320	2,834

This alloy contained copper, 55.04; zinc, 42.36; tin, 0.83; iron, 1.77.

The proportion of zinc may vary from 38 to 42 per cent. without appreciably altering the value of the alloy. The specific gravity of this metal was 8.37 to 8.40 when forged or wire drawn; it has great elasticity, stretching 0.0017 without set, and costs 30 to 40 per cent. less than gun-bronze. It has been forged into guns, cold from the casting. The strength of sterro-metal containing one per cent. and more of tin will be given in the following chapter on ternary alloys of copper, tin and zinc.

221. **The Moduli of Elasticity**, E., of various alloys have been found, as below, to the nearest round numbers:

* Holley; "Ordnance and Armor," p. 424.

TABLE LXVIII.

MODULI OF ELASTICITY OF BRASSES.

METAL.	VALUE OF E.		AUTHORITY.	REMARKS.
	Lbs. on sq. in.	Kilogs. on sq. cm.		
Brass...........	9.000,000	632,700	Tredgold.	11 tin, 89 copper, cast.
"	12,000,000	843,600	Wertheim.	Rolled.
"	13,000,000	913,900	Bauschinger.	Rolled.

As will be seen, presently, the value is very variable with ordinary cast alloys of copper and zinc, but should be tolerably uniform with rolled and drawn materials.

222. **Copper-Zinc Alloys**, including the brasses, were studied by the Author, and the investigation was, as already stated, conducted in a similar manner to that described in the discussion of the alloys of copper and tin.*

The specimens were in the form of bars, and were cast in an iron mould square in section, and similar in dimensions to that used in making bronzes. The experiments were made upon these bars as cast under ordinary conditions as before. The effects of different methods of casting, of slow and rapid cooling, of compression, either of the fluid metal or after solidification, and of rolling, tempering and annealing, were to have been made the subject of a special research.

Two series of these alloys were made and tested. The first series was composed of bars differing in composition by 5 per cent. The bars of the second series also differed in composition by 5 per cent., the first bar containing 2½ per cent. zinc, the last bar containing 97½ per cent.

The bars were first tested by transverse stress; the two pieces remaining after each transverse test were turned to size and tested by tension, and the four pieces thus formed

* This account is mainly abridged from the Report to the Committee on Alloys of the U. S. Board.

were tested by torsion. Some tests were made by compression. The turnings from the tension test-pieces were analyzed. The specific gravities were also determined.

The total weight of each casting was 4.5 kilograms (9.92 pounds).

223. Compositions Tested.—A following table (p. 371) gives the compositions of the bars according to the original mixtures, the compositions of two portions of each bar as subsequently determined by analysis, and the specific gravities.

Bar No. 16 was made by melting together the upper half of bar No. 17 (21.00 copper, 77.59 zinc) and the lower half of bar No. 15 (25.98 copper, 72.90 zinc).

The mould was heated each time before pouring into it the molten metal, the temperature given to it being higher the larger the amount of copper in the alloy. In melting the metal for bars, No. 7 to No. 21 (35 per cent. zinc to pure zinc), inclusive, except No. 16, the copper was melted first and covered with a layer of charcoal. The zinc was melted in a separate crucible, and poured into the crucible containing the molten copper, through the layer of charcoal. The mixture was thoroughly stirred with a dry stick. Some volatilization of the zinc took place, the amount being greater at some times than at others; but the causes of this variation were not determined.

Bars No. 1 to No. 6 (5 to 30 per cent. zinc) were made by first melting the copper, and then adding the zinc in the solid state. The losses of zinc vary very irregularly, and in two cases, bars Nos. 18 and 20 (85 and 95 per cent. zinc), there appeared to have been a greater loss of copper than of zinc.

The temperature of casting was then found by the formula

$$x = \frac{P'(t' - t)}{Pc} + t',$$

in which P' is the weight of the water, P the weight of metal poured, t the temperature of the water before, and t' after pouring, and c the specific heat of the alloy. The specific heat was assumed to be the mean of the specific heats of the components.

The following table gives the temperatures:

TABLE LXIX.

ALLOYS OF COPPER AND ZINC.

Estimation of Temperatures of Casting.

Number.	Composition by original mixture.		Weight grammes.		Temperatures, Fahrenheit, Degrees.			Assumed specific heat.	Temperatures of casting. Degrees.		Remarks.
	Copper.	Zinc.	Water.	Metal.	Initial.	Final.	Range.		Fahrenheit.	Centigrade.	
1..	95	5	907	131.8	54	114	60	0.09517	4454	2456.7	Second casting.
2..	90	10	907	212.3	53	118	65	0.09519	3035	1667.6	
3..	85	15	907	321.4	55	155	100	0.09521	3120	1715.5	Poured thick.
4..	80	20	907	447.3	58	172	114	0.09523	2600	1426.6	
5..	75	25	907	381.26	54	154	100	0.09525	2652	1455.5	
6..	70	30	907	257.9	52	120	68	0.09527	2631	1443.8	
7..	65	35	907	259.9	56	120	64	0.09529	2464	1351.2	
8..	60	40	907	340.5	65	152	87	0.09531	2584	1417.7	
9..	55	45	907	182.6	61	109	48	0.09535	2610	1432.1	
10..	50	50	907	199.5	54	104	50	0.09535	2492	1366.5	
11..	45	55	907	237.4	53	102	49	0.09537	2065	1129.7	
12..	40	60	907	223.3	61	112	51	0.09539	2284	1251.1	
13..	35	65	907	185.9	57	102	45	0.09541	2403	1317.3	
14..	30	70	907	203.6	60	110	50	0.09543	2444	1340.1	Second casting.
15..	25	75	907	168.0	61	98	37	0.09545	2191	1199.5	Second casting.
16..	22.5	77.5	...	.....	..	..	..	....	...	......	Not taken.
17..	20	80	907	169.3	51	.85	34	0.09547	1994	1089.6	Second casting.
18..	15	85	907	316.0	56	16	60	0.09549	....	......	
19..	10	90	907	289.5	54	106	52	0.09551	1812	988.9	Second casting.
20..	5	95	907	163.0	60	73.5	13.5	0.09553	860	460.0	
21..	0	100	4535	597.3	50	70	20	0.09555	1660	904.1	

224. **External Appearance of the Bars.**—The surfaces of bars No. 1 to No. 8 (5 to 40 per cent. zinc, original mixture) had a similar color and appearance, being generally of a dark yellow color, inclined to copper-red toward the copper end of the series, and more or less oxidized. No. 1 (5 per cent. zinc, original mixture) was variegated in color, exhibiting iridescence in places, the prevailing tints being red, yellow, brown, and green. No. 2 (10 per cent. zinc) was rough, blow-holes, ridges and depressions were found over the whole of the bar. The others, from No. 1 to No. 7 (5 to 35 per cent. zinc), were smooth. No. 8 (40 per cent. zinc) was rough, the rough-

ness being caused by slight cavities or blow-holes of irregular shape, none of which were deep. These bars were soft enough to be cut with a saw, the freshly-cut surface varying from yellowish-red at No. 1 to light yellow at No. 5 to No. 7 (25 to 35 per cent. zinc), No. 8 (40 per cent. zinc) being reddish-yellow. The hardness gradually increased with the increase of zinc.

Nos. 9, 10, and 11 (45 to 55 per cent. zinc) had surfaces similar in color to the preceding, but darker, approaching brown, and in some places covered by a light gray scale. They were harder than Nos. 1 to 8, but could be cut in the lathe with a good tool. It was noted that Nos. 5, 6, and 7 had a light yellow color, while the bars on each side, containing either less or more copper, were reddish-yellow.

Nos. 12, 13, and 14 (60 to 70 per cent. zinc) had a yellowish outside surface, a very thin skin; the metal itself when broken was nearly white.

The yellowish skin contained more copper than the rest of the casting; it sometimes was so soft that it could be cut or bent, while the inside of the bar was nearly as hard as glass; this was not determined by analysis. This soft yellow coating found on white alloys of copper and zinc was described by Mr. F. H. Storer.* The colors of the fractured surfaces of Nos. 12, 13, and 14 were nearly white. They were too hard to cut in the lathe. The ground surface of No. 12 was brownish yellow. The ground surface of No. 13 had a yellow tint, that of No. 14 was nearly silver-white.

This sudden change between No. 11 and No. 12 (from 55 to 60 per cent. of zinc) corresponds to that observed in the copper-tin alloys of 24 to 30 per cent. of tin.

Between No. 14 and No. 15 another change occurs, the yellow skin seen in No. 14 being entirely wanting in No. 15; the color of the outside surface of the latter is a dull bluish-gray. The fractured surface of No. 15 is bluish-gray, but lighter than the outside. No. 15 is much softer than No. 14, and can be cut in the lathe, although with difficulty.

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* "Memoirs of the American Academy," vol. viii., 1860, p. 54.

From No. 15 to No. 20 (75 to 95 per cent. zinc) the surfaces are much alike, bluish-gray and nearly smooth, the color becoming lighter as the proportion of zinc increases. Hardness decreases with increase of zinc. No. 21, all zinc, is softer than No. 20, and lighter in color. The fractured and freshly cut surfaces of all bars from No. 15 to No. 21 are bluish-gray. No. 20 and No. 21 only show a crystalline appearance, the others were finely granular.

We may divide the alloys of copper and zinc into three classes, each of which has a distinct color. The first class includes those containing less than 55 per cent. of zinc, and may be called the yellow class. These are also the useful metals. The second class includes those containing between 60 and 70 per cent. of zinc, which are nearly silver white and exceedingly brilliant and hard and brittle. These have a yellow skin. The third class includes all those having more than 75 per cent. of zinc, and are bluish-gray, much softer as well as stronger than the second class.

The alloys containing between 55 and 60 per cent. zinc and those containing between 70 and 75 per cent. zinc, show regular gradations between the first and second, and second and third classes, respectively, the changes from one class to the other taking place gradually, but within narrow limits.

225. **Fractures; Colors.**—The fractures of these alloys were examined by Prof. A. R. Leeds, who furnished the following description of their color and structure:

No. 0 (cast copper).—Coarsely fibrous, and radiate from centre of surface of fracture. Color, dark red from superficial oxidation. Fibres, interrupted and dotted over with minute ridges with sharp lines of separation.

No. 1 (96.07 copper, 3.79 zinc).—Surface, confusedly vesicular and projecting between the vesicular cavities upward into sharp points. Color of centre, brilliant yellow-red, changing to light red on sides of fracture. The latter portion was likewise radiate in character, approaching No. 0.

No. 2 (90.56 copper, 9.42 zinc).—Fracture, closely resembling No. 1, with vesicular surfaces inferior in size. Color, more nearly approaching yellow.

No. 3 (89.80 copper, 10.06 zinc).—Fracture, highly vesicular and extremely jagged from the great number of minute projecting points. Light yellow in centre, and feebly reddish-yellow at sides of fracture. The latter portion was likewise radiate in character.

No. 4 (81.91 copper, 17.99 zinc).—Surface in character resembling No. 3, but less acutely jagged. Color, brass-yellow.

No. 5 (76.65 copper, 23.08 zinc).—Surface pitted over with minute rounded depressions, and ridged up into regular elevations, with a somewhat rough feeling to the touch. Color, full yellow.

No. 6 (71.20 copper, 28.54 zinc).—Resembling No. 5, but the elevations more prominent and more acute to the sense of touch. Color, dark yellow.

No. 7 (66.27 copper, 33.50 zinc).—Centre of surface of fracture largely vesicular, the surfaces of the vesicles being likewise covered with minute rounded depressions. Color, gold-yellow.

No. 8 (60.90 copper, 38.65 zinc).—Surface slightly rough and uneven, with a few smooth, rounded cavities. Color, somewhat orange-yellow, apparently having undergone a slight superficial oxidation.

No. 9 (55.15 copper, 44.44 zinc).—Extremely rough and uneven. Surface tarnished, of dull reddish-yellow color. One large rounded cavity coated with smooth surface of gold-yellow color.

No. 10 (49.66 copper, 50.14 zinc).—Confusedly vesicular, with regular surface of demarkation between the depressions. Not homogeneous. Surface at centre, deep yellow, surrounded by the larger portion of a whitish-yellow alternating with reddish-yellow, and bounded at sides by a radiated border of a similar color. Splendent.

No. 11 (47.56 copper, 52.28 zinc).—In character somewhat approaching No. 10, but the lines of demarkation between depressions less evident, and the projecting ridges less prominent. Color, reddish-white. Brilliant.

No. 12 (41.30 copper, 58.12 zinc).—Largely conchoidal surface of fracture, with few surfaces and those smooth.

Dull orange-yellow color. Splendent. (The color of this fracture was nearly silver-white when freshly broken, but changed to yellow by oxidation.)

No. 13 (36.62 copper, 62.78 zinc).—Character of surface same as No. 12. Color more silvery. Splendent.

No. 14 (32.94 copper, 66.23 zinc).—Conchoidal fracture, with surface covered with rounded depressions too minute to be separately visible to the naked eye. Color, bluish-white. Splendent.

No. 15 (25.77 copper, 73.45 zinc).—Minutely vesicular fracture, giving a slightly rough surface. Color, dull bluish-white.

No. 17 (20.81 copper, 77.63 zinc).—Similar in color and surface to No. 15, but radiate fibrous in structure.

No. 18 (14.19 copper, 85.10 zinc).—Closely resembling No. 17. Color, dull bluish-white.

No. 19 (10.30 copper, 88.88 zinc).—Surface in small, uneven ridges, dotted over with rounded depressions of brilliant silvery surface. General color of mass, dull bluish-white.

No. 20 (4.35 copper, 94.59 zinc).—Extremely jagged surface. Large vesicular depressions, with splendent silvery surface. Color of mass, bright bluish-white. Sides of fracture, crystalline radiate.

No. 21 (cast zinc).—Large lamellar crystalline plates, with rough surfaces of fracture between the laminæ. Structure of crystals also radiating from centre. Splendent. Bluish-white.

The second series comprises twenty bars. They were tested, mixed, and cast in the same manner as those of the first series. The table (p. 378) gives the composition mixture of each bar, the composition by analysis, and specific gravity.

226. Temperatures of Casting. — The following table contains the temperatures of casting:

TABLE LXX.

ALLOYS OF COPPER AND ZINC.

Temperatures of Casting.

Number.	Composition by Original Mixture.		Weights, Grams.		Temperatures, Fahrenheit. (Degrees.)			Assumed Specific Heat.	Temperatures of Casting. (Degrees.)		Remarks.
	Copper.	Zinc.	Water.	Metal.	Initial.	Final.	Range.		Fahrenheit.	Centigrade.	
22	97.5	2.5	....	......	..	....	....	....	......	......	Temperature not taken.
23	92.5	7.5	907	167.26	64	112	48	0.09518	2847.2	1564.	
24	87.5	12.5	907	......	..	....	....	....	......	......	Temperature not taken.
25	82.5	17.5	907	277.17	64	140	76	0.09522	2752.3	1511.3	
26	77.5	22.5	907	482.59	68	188	120	0.09524	2558.7	1403.7	
27	72.5	27.5	907	426.95	60	158	98	0.09526	2343.9	1284.4	
28	67.5	32.5	907	577.70	64	180	116	0.09528	2091.8	1144.3	
29	62.5	37.5	907	439.55	63	168	105	0.09530	2441.9	1338.8	
30	57.5	42.5	907	397.42	58	158	100	0.09532	2552.7	1400.4	
31	52.5	47.5	907	339.05	60	142	82	0.09534	2444.3	1339.5	
32	47.5	52.5	907	296.53	54	130	76	0.09536	2568.2	1409.	
33	42.5	57.5	907	388.15	68	158	90	0.09538	2363.3	1295.1	
34	37.5	62.5	907	327.33	64	142	78	0.09540	2407.9	1319.9	Mixed well; poured hot.
35	37.5	67.5	907	224.45	88	138	50	0.09542	2255.8	1235.4	Considerable zinc volatilized; poured thick.
36	27.5	72.5	907	221.19	66	112	46	0.09544	2088.7	1142.6	
37	22.5	77.5	907	322.52	62	125	63	0.09546	1981.3	1082.9	
38	17.5	82.5	907	278.40	59	104	45	0.09548	1639.7	893.1	
39	12.5	87.5	907	165.18	68	95	27	0.09550	1647.7	897.6	
40	7.5	92.5	907	197.87	55	92	37	0.09552	1867.9	1019.9	
41	2.5	97.5	907	180.36	67	93	26	0.09554	1461.8	794.3	

The cast-iron mould was heated before pouring bars Nos. 31 to 41 inclusive, but was cold for bars Nos. 21 to 30 inclusive; when the molten metal had a high enough temperature given it, no difficulty was experienced by chilling.

As will be seen later, the zinc used in the second series, although sold as of good commercial purity, contained one per cent. lead.

227. **Analyses.**—The following table gives, at one view, all the quantities thus far referred to:

TABLE LXXI.

ALLOYS OF COPPER AND ZINC.

Analyses and Specific Gravities.

First Series.

Number.	Original Mixture.		Analyses.		Variation of Composition.		Mean Analyses.		Specific Gravity.	Mean Specific Gravity.
	Copper.	Zinc.	Copper.	Zinc.	Copper.	Zinc.	Copper.	Zinc.		
1 A....	95	5	95.98	3.90	+0.98	−1.10	96.07	3.79	8.795	8.825
1 B....	95	5	96.16	3.68	+1.16	−1.32			8.854	
2 A....	90	10	90.49	9.48	+0.49	−0.52	90.56	9.42	8.758	8.773
2 B....	90	10	90.62	9.35	+0.62	−0.65			8.788	
3 A....	85	15	89.31	10.54	+4.31	−4.69	89.80	10.06	8.643	8.656
3 B....	85	15	90.29	7.57	+5.29	−5.43			8.669	
4 A....	80	20	81.97	17.95	+1.97	−2.05	81.91	17.99	8.603	8.598
4 B....	80	20	81.85	18.03	+1.85	−1.97			8.593	
5 A....	75	25	77.84	21.78	+2.84	−3.22	76.65	23.08	8.539	8.528
5 B....	75	25	75.45	24.37	+0 45	−0.63			8.517	
6 A....	70	30	71.34	28.55	+1.34	−1.45	71.20	28.54	8.458	8.444
6 B....	70	30	71.06	28.52	+1.06	−1.48			8.429	
7 A ...	65	35	67.24	32.49	+2.24	−2.51	66.27	33.50	8.392	8.371
7 B....	65	35	65.29	34.51	+0.29	−0.49			8.350	
8 A....	60	40	62.68	36.91	+2.68	−3.09	60.94	38.65	8.443	8.405
8 B....	60	40	59.19	40.39	−0.81	+0.39			8.367	
9 A....	55	45	59.13	40 36	+4.13	−4.64	55.15	44.44	8.369	8.283
9 B....	55	45	51.16	48.52	−3.84	+3.52			8.196	
10 A....	50	50	52.21	47.48	+2.21	−2.52	49.66	50.14	8.301	8.291
10 B....	50	50	47.11	52.79	−2.89	+2.79			8.281	
11 A....	45	55	47.45	52.35	+2.45	−2.65	47.56	52.28	.....	.....
11 B....	45	55	47.67	52.20	+2.67	−2.80			8.189	
12 A....	40	60	42.09	57.32	+2.09	−2.68	41.20	58.12	8.061	8.061
12 B....	40	60	40.51	58.91	+0.51	−1.09			8.061	
13 A....	35	65	36.52	63.20	+1.52	−1.80	36.62	62.78	7.988	7.974
13 B....	35	65	36.72	62.36	+1.72	−2.64			7.959	
14 A....	30	70	31.17	67.84	+1.17	−2.16	32.94	66.23	7.847	7.811
14 B....	30	70	34.71	64.62	+4.71	−5.38			7.775	
15 A....	25	75	25.56	74.00	+0.56	−1.00	25.77	73.45	7.627	7.675
15 B....	25	75	25.98	72.90	+0.98	−2.10			7.722	
16 A....	22.5	77.5	26.44	72.73	+3.94	−4.77	25.92	73.06	7.694	7.687
16 B....	22.5	77.5	25.40	73.38	+2.90	−4.12			7.684	
17 A....	20	80	21.00	77.59	+1.00	−2.41	20.81	77.63	7.500	7.418
17 B ..	20	80	20.61	77.67	+0.61	−2.33			7.336	
18 A....	15	85	13.86	86.03	−1.14	+1.03	14.19	85.10	7.166	7.163
18 B....	15	85	14.51	84.16	−0.49	−0.84			7.159	
19 A....	10	90	10.41	89.02	+0.41	−0.98	10.30	88.88	7.181	7.253
19 B....	10	90	10.19	88.74	+0.19	−1.26			7.325	
20 A....	5	95	4.33	94.69	−0.67	−0.31	4.35	94.59	7.177	7.108
20 B....	5	95	4.36	94.48	−0.64	−0.52			7.038	
21 A....	0	100	.....	.....	......	......	.....	.....	7.140	7.143
21 B....	0	100	.....	.....	......	......	.....	.....	7.146	

TABLE LXXI.—*Continued.*

Second Series.

Number.	Original Mixture. Copper.	Original Mixture. Zinc.	Analyses. Copper.	Analyses. Zinc.	Analyses. Lead.	Variation of Composition. Copper.	Variation of Composition. Zinc.	Mean Analyses. Copper.	Mean Analyses. Zinc.	Mean Analyses. Lead.	Specific Gravity.	Mean Specific Gravity.
22 A....	97.5	2.5	97.98	1.60	None.*	+0.48	−0.90	97.83	1.88	0	8.786	8.791
22 B....	97.5	2.5	97.68	2.16	None.*	+0.18	−0.34				8.796	
23 A....	92.5	7.5	92.65	7.42	Trace.	+0.15	−0.08	92.32	7.68	Trace	8.724	8.746
23 B....	92.5	7.5	91.99	7.94	Trace.	−0.50	+0.44				8.767	
24 A....	87.5	12.5	88.86	11.06	0.12	+1.36	−1.44	88.94	10.97	0.14	8.764	8.747
24 B ...	87.5	12.5	89.01	10.88	0.16	+1.51	−1.62				8.729	
25 A....	82.5	17.5	82.85	17.06	0.17	+0.35	−0.44	82.93	16.98	0.17	8.662	8.633
25 B....	82.5	17.5	83.00	16.90	0.16	+0.50	−0.60				8.603	
26 A....	77.5	22.5	79.13	20.77	0.06	+1.63	−1.73	77.39	22.45	0.10	8.607	8.574
26 B....	77.5	22.5	75.65	24.12	0.14	−1.85	+1.62				8.542	
27 A....	72.5	27.5	75.13	24.51	0.16	+2.63	−2.99	73.20	26.47	0.19	8.511	8.464
27 B....	72.5	27.5	71.27	28.42	0.21	−1.23	+0.92				8.418	
28 A....	67.5	32.5	70.65	29.16	0.19	+3.15	−3.34	69.74	30.06	0.21	8.401	8.384
28 B....	67.5	32.5	68.82	30.95	0.23	+1.32	−1.55				8.366	
29 A....	62.5	37.5	63.36	36.46	0.10	+0.86	−1.04	63.44	36.36	0.11	8.417	8.411
29 B....	62.5	37.5	63.52	36.26	0.12	+1.02	−1.24				8.405	
30 A....	57.5	42.5	58.22	41.25	0.47	+0.72	−1.25	58.49	41.10	0.42	8.367	8.363
30 B ...	57.5	42.5	58.75	40.94	0.37	+1.25	−1.56				8.358	
31 A....	52.5	47.5	55.02	44.57	0.40	+2.52	−2.93	54.86	44.78	0.37	8.322	8.301
31 B....	52.5	47.5	54.69	44.99	0.34	+2.19	−2.51				8.280	
32 A....	47.5	52.5	49.05	50.71	0.32	+1.55	−1.79	48.95	50.82	0.29	8.228	8.216
32 B....	47.5	52.5	48.85	50.93	0.26	+1.35	−1.57				8.203	
33 A....	42.5	57.5	43.68	55.89	0.41	+1.18	−1.61	43.36	56.22	0.38	8.068	8.034
33 B....	42.5	57.5	43.04	56.55	0.34	+0.54	−0.95				8.999	
34 A....	37.5	62.5	38.25	61.18	0.62	+0.75	−1.32	38.36	61.05	0.60	7.987	7.982
34 B....	37.5	62.5	38.46	60.92	0.58	+0.96	−1.58				7.976	
35 A....	32.5	67.5	35.83	63.55	0.66	+3.33	−3.95	35.68	63.71	0.66	7.973	7.966
35 B....	32.5	67.5	35.52	63.87	0.66	+3.02	−3.63				7.959	
36 A....	27.5	72.5	28.78	70.59	0.55	+1.28	−1.91	29.20	70.17	0.55	7.785	7.766
36 B....	27.5	72.5	29.62	69.75	0.55	+2.12	−2.75				7.746	
37 A....	22.5	77.5	21.77	77.40	0.70	−0.73	−0.10	21.82	77.43	0.67	7.452	7.416
37 B....	22.5	77.5	21.86	77.46	0.63	−0.64	−0.04				7.379	
38 A....	17.5	82.5	17.16	81.87	0.99	−0.34	−0.63	17.49	81.62	0.93	7.231	7.225
38 B....	17.5	82.5	17.81	81.36	0.86	+0.31	−1.14				7.218	
39 A....	12.5	87.5	11.75	87.19	0.99	−0.75	−0.31	12.12	86.67	1.11	7.258	7.238
39 B....	12.5	87.5	12.48	86.14	1.22	−0.02	−1.36				7.217	
40 A....	7.5	92.5	7.19	92.34	0.54	−0.31	−0.16	7.20	92.07	0.78	7.293	7.131
40 B....	7.5	92.5	7.21	91.79	1.02	−0.29	−0.71				6.968	
41 A....	2.5	97.5	2.63	96.20	1.08	+0.15	−1.30	2.45	96.43	1.05	7.177	7.080
41 B....	2.5	97.5	2.26	96.65	1.02	−0.24	−0.85				6.982	

228. Results of Tests.—The next table contains the data obtained by test, arranged in order of composition, beginning with copper and ending with zinc, and carefully classified. The figures are, in each case, averages derived from two or more tests each.

* No. 22 A had 0.37 per cent. iron and 22 B 0.24 per cent. iron. The others had no iron or only traces.

TABLE LXXII.

ALLOYS OF COPPER AND ZINC.

Summary of Average Results of Experiments.

NUMBER.	COMPOSITION BY ORIGINAL MIXTURE. Cu	COMPOSITION BY ORIGINAL MIXTURE. Zn	MEAN COMPOSITION BY ANALYSIS. Cu	MEAN COMPOSITION BY ANALYSIS. Zn	MEAN SPECIFIC GRAVITY.	TESTS BY TRANSVERSE STRESS. Modulus of rupture.	Elastic limit (per cent. of breaking load).	Total deflection before breaking (inches).	Resilience within a deflection of 3¼ inches (foot-pounds).	Modulus of elasticity.	TESTS BY TENSILE STRESS. Tensile strength per square inch of— Original section (pounds).	Fractured section (pounds).	Elastic limit (per cent. of breaking load).	Total elongation (per cent.).	Diameter of fractured section (per cent. of original section).	COMPRESSION TESTS. Crushing strength per square inch (pounds).	Amount of compression (per cent.).	TESTS BY TORSIONAL STRESS. Torsional moment. Maximum (foot-pounds).	At elastic limit (per cent. of maximum).	Ductility. Angle of torsion (degrees).	Extension of exterior fibre.	Resilience (foot-pounds).	Modulus of elasticity.
0*	Cast copper		.....	.....	8.791	29,848	14.0	Bent.	191.25	....	27,800	32,496	51.8	6.47	92	42,000	10+	143.24	35.3	153.0	0.3084	320.35	..
22†	97.5	2.50	97.83	1.88	8.791	......	.....	......	.....	....	27,240	39,570	.....	.....	83	....	.....	130.01	30.2	357.0	1.1889	643.21	..
1†	95.0	5.0	96.07	3.79	8.825	......	34.1	......	.....	....	......	......	.....	.....	..	29,000	10+	97.25	24.8	174.0	0.3786	211.79	..
23†	92.5	7.5	92.32	7.68	8.746	21,784	30.0	Bent.	144.49	13,842,723	......	......	.....	.....	..	....	.....	87.17	39.3	137.0	0.2483	143.25	..
2†	90.0	10.0	90.56	9.42	8.773	......	57.9	......	.....	....	......	......	.....	.....	..	30,000	10+	140.09	17.2	458.0	1.6907	896.69	..
24†	87.5	12.5	88.94	10.97	8.747	......	.....	......	.....	....	......	......	.....	.....	..	....	.....	114.89	16.6	230.0	0.6043	333.91	..
3†	85.0	15.0	89.80	10.06	8.656	......	53.3	......	.....	....	......	......	.....	.....	..	29,500	10+	104.81	27.9	607.0	2.5011	881.59	..
25	82.5	17.5	82.93	16.98	8.633	23,197	41.2	Bent.	164.32	14,425,146	32,600	57,086	26.1	26.7	76	....	.....	155.37	28.7	328.8	1.0532	691.06	..
4	80.0	20.0	81.91	17.99	8.598	21,193	45.2	Bent.	140.93	12,469,814	32,670	57,749	30.6	31.4	75	....	.....	165.93	27.5	344.8	1.1318	776.79	..
26	77.5	22.5	77.39	22.45	8.574	25,374	44.4	Bent.	152.99	14,734,473	35,630	68,353	20.0	35.5	72	....	.....	169.37	30.9	311.5	0.9748	703.62	..
5	75.0	25.0	76.65	23.08	8.528	22,325	50.0	Bent.	152.11	13,407,355	30,520	50,921	24.6	35.8	79	42,000	10+	165.55	26.0	266.5	0.7669	563.19	..
27	72.5	27.5	73.20	26.47	8.465	25,894	43.2	Bent.	189.64	14,509,957	31,580	58,641	23.7	38.5	74	....	.....	168.66	28.3	292.7	0.8866	629.51	..
6	70.0	30.0	71.20	28.54	8.444	24,468	51.4	Bent.	161.42	14,035,326	30,510	48,956	29.5	29.2	79	....	.....	163.62	24.0	268.7	0.7780	563.39	..
28	67.5	32.5	69.74	30.06	8.384	26,930	46.1	Bent.	196.87	12,565,749	28,120	38,773	28.7	20.7	85	....	.....	143.45	23.9	202.3	0.4912	357.71	..
7	65.0	35.0	66.27	33.50	8.371	28,459	53.7	Bent.	226.98	13,831,256	37,800	65,744	25.1	37.7	75	....	.....	176.64	29.4	256.8	0.7279	605.65	..
29	62.5	37.5	63.44	36.36	8.411	43,216	53.3	Bent.	271.28	14,101,299	48,300	69,876	32.8	31.7	83	....	.....	202.17	27.0	229.8	0.6061	632.54	..
8	60.0	40.0	60.94	38.65	8.405	38,968	56.1	Bent.	211.79	12,231,927	41,065	57,365	40.1	20.67	84	75,700	10+	193.65	29.4	201.8	0.4897	527.28	..

* Bar No. 30, Report of Alloys of Copper and Tin. † Defective bar.

TABLE LXXII.—*Continued.*

NUMBER.	Composition by original mixture. Cu	Composition by original mixture. Zn	Mean composition by analysis. Cu	Mean composition by analysis. Zn	MEAN SPECIFIC GRAVITY.	Transverse: Modulus of rupture.	Transverse: Elastic limit (per cent. of breaking load).	Transverse: Total deflection before breaking (inches).	Transverse: Resilience within a deflection of 3¼ inches (foot-pounds).	Transverse: Modulus of elasticity.	Tensile strength per square inch of— Original section (pounds).	Tensile strength per square inch of— Fractured section (pounds).	Tensile: Elastic limit (per cent. of breaking load).	Tensile: Total elongation (per cent.).	Tensile: Diameter of fractured section (per cent. of original section).	Compression: Crushing strength per square inch (pounds).	Compression: Amount of compression (per cent.).	Torsional moment. Maximum (foot-pounds).	Torsional moment. At elastic limit (per cent. of maximum).	Ductility. Angle of torsion (degrees).	Ductility. Extension of exterior fibre.	Torsional: Resilience (foot-pounds).	Torsional: Modulus of elasticity.
30	57.5	42.5	58.49	41.10	8.363	63,304	47.5	Bent.	384.43	11,850,008	50,450	60,785	54.4	10.09	90	....	.....	227.04	30.6	92.5	0.1210	274.40	..
9	55.0	45.0	55.15	44.44	8.283	42,463	37.5	Bent.	198.78	9,538,189	44,280	57,774	44.0	15.31	89	78,000	10+	208.77	32.7	109.0	0.1948	308.18	..
31	52.5	47.5	54.86	44.78	8.301	47,955	38.8	Bent.	283.45	10,816,045	46,400	53,756	53.9	7.97	92	....	.....	223.26	24.4	71.5	0.0735	197.86	..
10	50.0	50.0	49.66	50.14	8.291	33,467	34.0	1.257	68.83	11,574,491	30,990	34,636	54.5	4.97	96	117,400	10+	172.23	36.0	37.8	0.0310	98.15	..
32	47.5	52.5	48.99	50.82	8.216	40,189	43.6	0.6140	29.69	12,700,126	26,050	37,259	100.0	0.84	98	....	.....	176.64	36.5	15.5	0.0036	30.99	..
11	45.0	55.0	47.56	52.28	.....	48,471	33.1	1.1693	91.63	14,027,268	24,150	24,540	100.0	0.79	99	121,000	10+	154.59	38.5	13.1	0.0026	23.56	..
33	42.5	57.5	43.36	56.22	8.084	17,691	100.0	0.0982	2.29	12,918,211	9,170	9,170	100.0	.....	..	....	.....	88.23	100.0	2.3	0.00017	5.75	..
12	40.0	60.0	41.30	58.12	8.061	7,761	100.0	0.0357	0.32	16,367,068	3,727	3,727	100.0	.....	..	....	.....	18.31	100.0	1.8	0.0001	0.86	..
34	37.5	62.5	38.36	61.05	7.982	6,727	100.0	0.0430	0.36	10,219,336	3,087	3,087	100.0	.....	..	....	.....	10.34	100.0	0.75	0.00002	0.39	..
13	3.5	65.0	36.62	62.78	7.974	4,893	100.0	0.0245	0.15	14,121,779	2,656	2,656	100.0	.....	..	....	.....	9.67	100.0	1.4	0.00006	0.48	..
35	32.5	67.5	35.68	63.71	7.966	8,895	100.0	0.0404	0.87	....	2,397	2,397	100.0	.....	..	....	.....	16.46	100.0	0.75	0.00011	0.68	..
14	30.0	70.0	32.94	66.23	7.811	8,296	100.0	0.0355	0.37	17,615,045	1,774	1,774	100.0	.....	..	....	.....	28.86	100.0	1.2	0.00005	0.70	..
36	27.5	72.5	29.20	70.17	7.766	16,579	100.0	0.0449	1.32	14,748,167	6,414	6,414	100.0	.....	..	....	.....	39.80	100.0	1.5	0.00009	0.93	..
15	25.0	77.0	25.77	73.45	7.675	22,893	100.0	0.1136	3.75	16,182,090	9,680	9,680	100.0	0.35	100.0	110,822	5.85	65.98	100.0	1.0	0.00002	0.59	..
16	22.5	77.5	25.92	73.06	7.687	23,850	100.0	0.1331	4.53	14,384,245	7,931	7,931	100.0	.....	.....	....	.....	74.64	100.0	1.5	0.00005	1.56	..
37	22.5	77.5	21.82	77.43	7.416	9,527	100.0	0.0545	0.70	12,932,440	7,000	7,000	100.0	0.12	100.0	....	.....	51.05	100.0	1.5	0.00004	0.68	..
17	20.0	80.0	20.81	77.63	7.418	22,972	100.0	0.1254	3.67	14,469,651	9,000	9,000	100.0	0.16	100.0	52,152	2.75	65.35	100.0	0.8	0.00002	0.18	..
38	17.5	82.5	17.49	81.62	7.225	14,000	100.0	0.0922	1.68	11,659,140	5,350	5,350	100.0	0.14	100.0	....	.....	25.97	100.0	1.0	0.00003	0.24	..
18	15.0	85.0	14.19	85.10	7.163	26,744	100.0	0.1840	6.52	14,180,866	8,500	8,500	100.0	0.31	100.0	48,892	10.8	49.46	100.0	1.4	0.00004	0.42	..
39	12.5	87.5	12.12	86.67	7.238	35,026	64.0	0.3124	12.49	11,359,423	12,413	12,413	100.0	0.36	100.0	....	.....	82.16	100.0	2.5	0.00009	2.30	..
19	10.0	90.0	10.30	88.88	7.253	41,347	73.0	0.5456	44.66	12,809,469	14,450	14,450	100.0	0.39	100.0	49,000	10+	89.81	85.6	7.1	0.00100	9.36	..
40	7.5	92.5	7.20	92.07	7.131	37,547	37.7	0.7910	49.37	11,757,262	10,650	10,650	100.0	0.38	100.0	....	.....	137.01	62.3	75.0	0.08040	154.97	..
20	5.0	95.0	4.35	94.59	7.108	26,162	50.7	0.4612	21.73	9,508,876	18,065	18,065	100.0	0.49	100.0	4,800	10+	81.11	67.5	21.9	0.00840	28.0	..
41	2.5	97.5	2.45	96.43	7.080	23,137	31.8	0.4097	17.15	10,054,796	11,400	11,425	87.8	0.88	99.9	....	.....	68.98	48.8	41.5	0.02670	35.66	..
21	Cast zinc.		.....	.....	7.143	7,539	57.1	0 1244	1.49	6,984,644	5,400	5,431	75.0	0.69	99.7	22,000	10+	36.66	38.1	141.5	0.26510	57.79	..

229. Conclusions from Tests.—In the preceding table, the "breaking load" by transverse stress is that which either causes a deflection of 3½ inches (9 cm.), or breaks the bar within that limit. The limit of elasticity is not a definitely marked point in any cases in which brasses or bronzes are under test, and the quantity here given as a limit is to be taken as approximate only, and not as representing a fixed natural quantity. The moduli of elasticity were calculated from a series of deflections and loads, and the highest of the series of values so obtained is usually recorded as probably most correct, errors of observation and accidental errors usually operating to depress the value.

Alloys containing less than 10 per cent. zinc were usually somewhat defective and spongy. Fluxing may be expected to give sound casting only when special care is taken, as copper has a great affinity for oxygen and absorbs air freely when the metal is fluid.

Alloys containing less than 55 per cent. zinc are yellow, and have been classed as "useful alloys." Those containing less than 40 per cent. are noticeably weaker than those containing from 40 to 55. The former are ductile and have either a fibrous or an earthy fracture; the latter are, in some cases, of nearly or quite double their strength, with less ductility, and the fractures are granular and lustrous. The maximum strength is found not far from the composition, copper, 60; zinc, 40. The white alloys (zinc, 40 to 50; copper, 60 to 50) are weak, brittle, vitreous, and useless for ordinary purposes of construction. The blue-gray alloys (zinc, 70 to 100) are granular or crystalline, stronger than the white, but weaker than the yellow alloys, and have considerable ductility. The range of valuable composition, which, in the copper-tin alloys or bronzes, extends over a variation of but 25 per cent., covers a range of 50 per cent. in the list of brasses. In both classes, a sudden and great variation of properties is observed at a certain point, and the maximum and minimum are not far apart in either the brasses or the bronzes.

Alloy No. 4 (copper, 82; zinc, 18), a good casting, was so ductile that it could not be broken by bending, but was sawn apart after test. Some interesting experiments, exhibiting the effect of prolonged stress on the brasses, were made, which will be described fully later. Maximum tenacity was exhibited by alloys containing about 40 per cent. zinc (copper, 50), and attained nearly 55,000 pounds per square inch (nearly 3,867 kilogs. per sq. cm.). The highest resistance to transverse stress was exhibited by the alloy copper, 47.7, zinc, 52.3. The softer alloys tested by tension usually stretch not only from end to end of the reduced part of the test-piece, but also in the heads by which they were held in the testing machine. In the case of an alloy containing 39 per cent. zinc; 61 copper, a peculiar irregularity of elongation during test was observed, and a similar phenomenon was noted in the deflection of the same alloy under transverse loads. Between 40 and 50 per cent. zinc, liquation was often observed to occur to a serious extent.

Tests conducted with the autographic recording machine were concordant with those made by tension, and the quality of the metal was exhibited fully by the strain-diagrams so obtained. An alloy containing 89.8 per cent. copper exhibited great strength combined with a ductility about equal to that of pure tin. An exterior fibre, originally parallel to the axis, was extended to 3½ times its original length. Alloys approximating 90 per cent. copper had very great total resilience. Alloys containing copper, 40, zinc, 60, were extremely rigid, extending, in some cases, less than 0.01 of one per cent., and even as little as 0.00006 of their original length. Alloys containing copper, 15, zinc, 85, were subject to serious loss of strength in consequence of the existence of minute pores in large numbers, which, while invisible oftentimes, may injure the casting more seriously than large blow-holes usually weaken alloys liable to them.

When testing by compression, a reduction of 10 per cent. in the length of the ductile alloys was made the limit, but the loads causing a compression of 5 and of 20 per cent. and upward, were also reported, as below. One of the silver-white alloys was found to be the strongest, carrying a load exceeding 120,000 pounds per square inch (over 8,436 kilogs. on the sq. cm.).

230. Notes taken during Tests are given at some length in the report on this investigation. A few of the compositions exhibit properties, as thus recorded, which may be given place here. In *tension tests*, in the first series, maximum average strength is given by bar No. 9 (55.15 copper, 44.44 zinc), 44,280 pounds per square inch (3,113 kilogs. per sq. cm.). An inspection of the table shows that this average result is reduced by liquation in bars No. 8 and No. 9, as No. 8 B (59.19 copper, 40.39 zinc) and No. 9 A (59.13 copper, 40.36 zinc) have nearly the same composition by analysis; and the strength of these pieces is much higher than the average of the two pieces of either No. 8 or No. 9, being 51,380 and 53,660 pounds per square inch (3,612 and 3,772 kilogs. per sq. cm.), respectively. This indicates that maximum strength is possessed by an alloy containing less than 44 per cent. zinc. Transverse tests showed the maximum transverse resistance to be exhibited by bar No. 11 (47.56 copper, 52.28 zinc), but this is not confirmed by tests made subsequently by either tensile, transverse, or torsional stress.

Bar No. 12 (41.30 copper, 58.12 zinc) confirmed the results obtained by the transverse test, showing an entirely different metal from the preceding. It was weak and brittle. The metal was so hard that the pieces could not be turned in the lathe, and were therefore tested in their original square sections. No. 12 A broke at 4,324 and No. 12 B at 3,130 pounds per square inch (3,040 and 2,200 kilogs. per sq. cm.). No attempt was made to measure the elongations; they were extremely small. The fractures were precisely like that obtained by transverse stress.

The minimum tenacity, 1,774 pounds per square inch (1,247 kilogs. per sq. cm.), was exhibited by bar No. 14 A (31.17 copper, 67.84 zinc), one piece only being tested. The average tensile strength of No. 13 (36.62 copper, 62.78 zinc), which showed the lowest transverse strength, was but little higher, being 2,656 pounds (1,867 kilogs. per sq. cm.)

The curves of strength of the first and second series show a generally close agreement, except in the highest part of two curves, which are not found to indicate the same composition of the bar of maximum strength. The curve of the second series probably is most nearly the true one.

In the series of No. 29 (63.44 copper, 36.36 zinc), No. 29 A broke at 48,760, and No. 29 B at 46,840 pounds per square inch (3,437 and 3,293 kilogs. per sq. cm.), after elongations of 31 and 32.4 per cent., respectively. The fractures were of a light brownish-yellow color, and very compact and homogeneous. The plane of fracture was inclined to the axis, as with most of the pieces, and the surfaces were slightly polished. The pieces were uniformly ductile throughout their whole lengths, as was shown by the uniform decrease of diameter as the pieces elongated. In testing No. 29 A, a sudden dull sound was several times emitted from the piece, and at the same instant the resistance decreased, in one case, 1,300 pounds (600 kilogs., nearly). This may be due to interior molecular action, of the same nature as that which produced the crackling sound noted in some transverse tests, or the irregularity in the increase of deflections noted in others.

No. 30 (58.49 copper, 41.10 zinc).—The average strength of the two pieces of this bar was higher than that of the preceding, and the highest of this series. No. 30 A broke at 52,260 and No. 30 B at 48,640 pounds per square inch (3,674 and 3,419 kilogs. per sq. cm.), after elongations of 10.18 and 10 per cent., respectively, showing much less ductility than the preceding bars, with greater strength. There was observable irregularity in the increase of elongations under increase of load, which corresponds with the irregularity of deflection observed in the transverse test of the same bar.

Heat was generated, in some cases of test by tension, sufficient to make it uncomfortable to hold the broken end of the test-piece in the hand. This was observed to be most noticeable in alloys containing rather less than 75 per cent. copper. While testing an alloy containing 63 per cent. copper, sudden depressions of resistance were occasionally observed accompanied by dull sounds probably due to internal molecular disruption.

231. The Tenacity of Brass may be roughly reckoned, when the proportion of copper exceeds one-half, as will be seen on comparing the data obtained from good specimens of brass, as

$$T = 30{,}000 + 500\,z.$$

232. In Compression Tests, it proved that No. 5 (76.65 copper, 23.08 zinc) was much stronger than either of those richer in copper, requiring 42,000 pounds per square inch (2,953 kilogs. per sq. cm.) to cause a compression of 10 per cent. The elastic limit was apparently passed at about 26,000 pounds per square inch (1,448 kilogs. per sq. cm.). From this point the curve, after turning toward the horizontal, proceeds in a nearly straight line, but slightly *convex to the axis of abscissas* till a compression of 35 per cent. is reached, showing an increase of the ratio of load to compression, and indicating that the increase of diameter which is given by the compression merely tends to increase the strength of the piece opposing a greater sectional area to the stress. The piece, after 35 per cent. compression, was bent in the form of a double curve. On continuing the compression, the bending of the piece caused it to offer a slightly diminished resistance, a diagonal crack appearing on one side, and the curve again shows a curvature concave to the axis of abscissas.

On continuing the compression, after 140,000 pounds per square inch (9,842 kilogs. per sq. cm.) of original section had been applied, the compression amounting to 52.9 per cent., the resistance decreased to 110,000 pounds (7,733 kilogs.), probably in consequence of the weakening produced by the presence of the crack. The piece was then removed, the total compression being 57.5 per cent. The piece after removal measured only 0.87 inch in length, and two diameters at the middle of the specimen measured 1.03 inches and 0.91 inch, the section being approximately elliptical.

The turned surface was slightly roughened by the compression.

No. 8 (60.94 copper, 38.65 zinc) proved to be much stronger than No. 5, the load required to produce a compression of 10 per cent. being 75,000 pounds per square inch (4,956 kilogs.

per sq. cm.). The elastic limit was apparently reached at 30,000 pounds per square inch (2,109 kilogs. per sq. cm.), after a compression of 1.25 per cent. After passing the elastic limit, the resistance again became nearly proportional to the load, the ratio being much less than before. The piece became slightly bent and the surface somewhat roughened by the strain. After a compression of 24.8 per cent., the maximum resistance to this compression being 99,000 pounds per square inch (7,000 kilogs. per sq. cm.), the resistance decreased in consequence of the bending of the specimen. When the piece was removed after a compression of 26.95 per cent. its diameter was found to have increased to about 0.73 inch.

No. 9 (55.15 copper, 44.44 zinc) was somewhat stronger than No. 8, a compression of 10 per cent. being caused by 78,000 pounds per square inch, and breaking at 136,000 (5,883 and 9,561 kilogs. per sq. cm.), after a compression of 22.6 per cent. The elastic limit apparently was reached at about 30,000 pounds per square inch (2,109 kilogs. per sq. cm.). At 136,898 pounds (9,625 kilogs.), after a compression of about 23 per cent., the piece suddenly gave way, a small piece shearing diagonally from the upper end. The piece had become slightly bent under the stress before rupture occurred, and this bending may partly account for the breaking, as, in consequence of the bending, the stress was brought upon one side of the upper surface and was not distributed evenly over the whole surface. The diameter of the piece was increased to about 0.71 inch.

No. 10 (49.66 copper, 50.14 zinc) had a much greater resistance to a given deflection than No. 9, a compression of 10 per cent. being caused by 117,400 pounds per square inch (8,253 kilogs. per sq. cm.), and fracture occurring in precisely the same manner as that of No. 9 at 123,860 pounds (8,707 kilogs. per sq. cm.), after a compression of 11.25 per cent. The elastic limit appears to have been reached at about 40,000 pounds (2,812 kilogs.), but the point is not clearly defined. The diameter was increased to about 0.71 inch before breaking, being nearly uniform throughout the length. The surface was very slightly *wrinkled* by the compression.

No. 11 (47.56 copper, 52.28 zinc) was much stronger than any other of the series tested, breaking at 138,528 pounds per square inch after a compression of 13.6 per cent., a compression of 10 per cent. being produced by 121,000 pounds (9,740 and 8,506 kilogs. per sq. cm.). The elastic limit was reached at about 35,000 pounds (2,460 kilogs.). The behavior of this piece before fracture was almost exactly like that of No. 10, as is shown by the close agreement of their curves. The fracture took place by shearing diagonally across the specimen just above the middle. The diameter was increased by the compression to about 0.67 inch.

No. 15 (25.56 copper, 74.00 zinc) exhibited a behavior under compression very different from that of the piece previously tested. It broke at 110,822 pounds per square inch (7,791 kilogs. per sq. cm.), after a compression of 5.85 per cent. An elastic limit was apparently reached at about 80,000 pounds per square inch (5,624 kilogs. per sq. cm.), the ratio of compression to load after this point being very much greater than it was before this load was reached, as is plainly shown by the curve. After 110,822 pounds (7,791 kilogs.) had been reached, the compression being 4.8 per cent., the resistance decreased to 107,562 pounds (7,563 kilogs. per. sq. cm.), as the compression increased to 5.85 per cent., and the piece then suddenly broke, the upper half flying into several fragments, a wedge-shaped piece being apparently formed at the top which seemed to split open the lower portion. The diameter was increased to 0.635 inch by the compression, as measured after breaking, on the lower part of the specimen.

233. **In Transverse Tests,** which were the first in order, an examination of the cast bars of the first series showed bars Nos. 1, 2, and 3 (3.79 to 10.09 zinc) to be defective, and the results are not considered conclusive as to the properties of the metal. These bars were soft and spongy, and, in places, showed signs of oxidation. It appears probable that the defective structure of these bars is due to the method of casting, which was not suitable for these compositions, and is probably not necessarily an inherent defect of metals of these compositions properly cast. In the second series the same

peculiarity was observed in the transverse tests of alloys containing small proportions of zinc (less than 12.5 per cent.) with one exception, a bar containing 7.5 per cent. This indicates that it may be quite possible to secure good castings of alloys containing small percentages of zinc, provided the proper conditions are discovered and observed.

The causes of the formation of blow-holes and of oxidation have not been determined. It would seem that the strength of sound castings of these metals should approach that of those having higher percentages of zinc. The curve is, therefore, continued in a straight line from pure copper to No. 4 (81.99 copper, 17.99 zinc).

All alloys of copper and zinc containing less than 55 per cent. of zinc, may be considered as included in the first class, or useful alloys, which are all distinguished by a yellow color.

The forms of the curves of strength indicate that the first class of alloys might be divided into two divisions, one showing considerably greater strength than the other. The first division includes those from No. 4 to No. 7 (17.99 to 33.50 zinc) inclusive, with also, probably, Nos. 1, 2, and 3, or all the alloys from pure copper to those containing 33.50 zinc. These show a modulus of rupture from 21,000 to 28,000 (1,476 to 1,968 kilogs. per sq. cm.), increasing slightly with the percentage of zinc. They are also characterized by great ductility and fibrous or earthy fracture. The second division includes bars No. 8 to No. 11, inclusive (38.65 to 52.28 zinc), which show much greater strength than the preceding, the modulus of rupture of No. 8 being 38,968, and that of No. 11 48,471 (2,740 and 3,407 kilogs. per sq. cm.), and less ductility. The fractured surfaces of No. 8 and No. 9 (60.94 copper, 38.65 zinc, and 55.15 copper, 44.44 zinc) resemble in appearance those of No. 7 (66.27 copper, 33.50 zinc), being earthy or fibrous, but having a darker color. The fractures of No. 10 and No. 11 (49.66 copper, 50.14 zinc, and 47.56 copper, 52.28 zinc) are very different from those of bars containing less zinc, having a granular structure and lustrous surface of fracture. The modulus of rupture of No. 10 is much less than that of the other three bars of this portion of the series, Nos. 8, 9, and 11, but this is probably exceptional, as the fracture indicates defective structure.

No 11 (47.56 copper, 52.28 zinc) gave the highest modulus of rupture of the series, 48,471 pounds (3,407 kilogs.), and this would indicate the maximum strength of the series; but this result is not confirmed by other tests of the same bar, nor by any of the tests of the second series. These all indicate that the point of maximum strength lies between No. 8 and No. 9 (38.65 and 44.44 zinc). The moduli of rupture of Nos. 8, 9 and 10, although much higher than those of the bars containing less zinc, are lower than those of nearly similar composition in the second series, but the reason of this is not apparent.

Between bar No. 11 (47.56 copper, 52.28 zinc) and bar No. 12 (41.30 copper, 58.12 zinc) there is a sudden change of properties. Nos. 12, 13, and 14 (58.12 to 66.23 zinc) represent the second class of the copper-zinc alloys, which, as noted in describing the external appearance of the bars, is distinguished by a nearly white color, vitreous fracture, and very brilliant lustre, and also by great weakness and lack of ductility. They correspond closely in all their properties to the silver-white alloys of copper and tin. The minimum strength is given by bar No. 13 (36.62 copper, 62.78 zinc), its modulus of rupture being only about one-tenth of that of the maximum, bar No. 11 (47.56 copper, 52.28 zinc), which differs from it in composition only about 20 per cent.

Bar No. 15 (25.77 copper, 73.45 zinc) shows a very much greater strength than No. 14, and marks the boundary of the third class, which includes all the bars containing more than 73.43 per cent. of zinc. This class is distinguished by a bluish-gray color, and finely granular structure, which becomes crystalline as the composition approaches pure zinc, and a much greater strength than the second class, although not so great as the first class, the yellow and useful metals.

There is a somewhat irregular increase of strength from No. 15 to No. 19 (73.45 to 88.88 zinc). The latter represents the point of "second maximum" strength in the series, which corresponds to the second maximum of the copper-tin alloys. From bar No. 19 there is a regular and rapid decrease of strength to pure zinc, which represents the "second minimum."

It will be noted that the curve of transverse strength of the copper-zinc alloys is not nearly as regular as that of the alloys of copper and tin; but in many respects the two curves show a marked resemblance. The most striking contrast between the two curves is the much greater range of composition of the useful metals among the copper-zinc alloys, the curve of copper-tin alloys showing that the useful metals are all comprised within the limits of less than 25 per cent. of tin, while in the copper-zinc alloys the useful metals may contain as much as 52 per cent. of zinc. A sudden decrease of strength takes place at a definite point in both sets of alloys, and the curves are in this respect similar. The bars of minimum strength of both are also similar in their properties. The point of minimum strength is very near the point of maximum strength in both curves. That part of the curve which represents the third class of alloys of copper and zinc, corresponds with the curve of those copper-tin alloys which contain more than 50 per cent. of tin, and, like it, shows a second maximum; but it shows that the alloys containing a large amount of zinc have much greater strength than alloys containing a large amount of tin. The former are also much harder than the latter.

The transverse tests of the second series indicate the same relations between strength, ductility, and composition that were noted in tests of the first series.

From bars No. 22 to No. 28 (1.88 to 30.06 zinc), inclusive (excepting bars No. 22 and No. 24 as defective), there is a very gradual increase in the modulus of rupture. Bars No. 29 and No. 30 (36.36 and 41.10 zinc) show a rapid increase in strength over the preceding; the corresponding moduli of rupture are respectively 43,216 and 63,304 pounds (1,296 and 4,450 kilogs. per sq. cm.), the latter being the maximum modulus of rupture of the series. This maximum does not correspond with that of transverse tests of the first series, but is confirmed by all the other tests.

234. **Tests by Torsion** confirm the results obtained and deductions made from the other experiments:

From No. 4 to No. 11 (17.99 to 52.28 per cent. zinc) the average strength of all the pieces is quite high, the curve confirming the curve of tensile results almost exactly, and indicating the character of the first class, or useful alloys.

Between No. 11 and No. 12 (52.28 and 58.12 zinc) a very sudden decrease of strength takes place, and Nos. 12, 13, and 14 (58.12 to 66.23 zinc) show very low torsional strength, these metals being in the second class, or silver-white and brittle alloys.

From No. 15 (25.77 copper, 73.45 zinc) to the end of the series (pure zinc) the torsional tests indicate the characteristics of the third class, showing greater strength and ductility than the second class, the latter quality increasing toward pure zinc, and the strength reaching a maximum at No. 19 (10.30 copper, 85.10 zinc).

No. 11 (47.56 copper, 52.28 zinc) gave a strain-diagram similar in form to that of soft cast iron or hard bronze, and very different from those obtained from alloys richer in copper. Of No. 12 (41.30 copper, 58.12 zinc) two pieces only were tested. The results correspond with those of tensile and transverse tests, showing that the metal is extremely weak and brittle. The fractures were silver-white, vitreous, and conchoidal. The pieces were too hard and brittle to be turned in the lathe, and were shaped by grinding with an emery wheel. The ductility is extremely slight, the extension of a line of particles, one inch long in the surface parallel to the axis, being only 0.00006 inch.

No. 13 C (36.52 copper, 63.20 zinc) was, if possible, even weaker and more brittle than No. 12. Only one piece was tested and this was not brought to a cylindrical form, but was tested in its original square section. The strength was much less than that of any other piece of the series, showing the composition containing 63.20 zinc to be about that of minimum strength. The strain-diagram was a straight and nearly vertical line. Of No. 33 (43.36 copper, 56.22 zinc) two pieces only were tested. They were too hard to be turned in the lathe, and also were shaped by an emery wheel. The torsional moments, after being reduced to the equivalents of those of pieces of standard diameters, were much less than those of the preceding bars. The appearance of the fractures also showed as great a difference in the structure of the metal as was indicated by the difference in strength. Both fractures were diagonal, but No. 33 A was of a pinkish gray color and finely granular structure, and No. 33 B was of a brilliant silver-white color, smooth and vitreous. The analyses of the turnings of the tension pieces show that the difference was due to liquation; No. 33 A containing 55.89 per cent. zinc, and No. 33 B 56.55 per cent. zinc. The fact that so small a difference in the percentage of zinc should make such a great difference in properties is evidence of the very rapid though continuous change which takes place on the boundary line between the first and second classes of the copper-zinc alloys, and which is plainly shown by the rapid fall of that portion of the curve corresponding to alloys of about this composition.

235. **Brass Shafts** and spindles subjected to torsion may be calculated by the formula

$$d = \sqrt[3]{\frac{5.1\,M}{s_1}},$$

given in Chapter VIII., Art. 166, in which s varies from 5,000 to 60,000, according to composition and soundness of the alloy. If Δz is taken to measure the difference between the percentage of zinc present and that of maximum resistance, 45 per cent., a rough estimate may be taken, as

$$s_1 = 50{,}000 - 333\Delta z$$

when the alloy contains less zinc, and

$$s'_1 = 50{,}000 - 3{,}000\Delta z$$

between $z = 45$ per cent. and $z = 60$ per cent.

In metric measures,

$$s_{1m} = 3{,}515 - 24\Delta z;$$

$$s'_{1m} = 3{,}515 - 211\Delta z.$$

236. The Records of Tests of a selected number of copper-zinc alloys are here given, and those of several others are presented later when considering the effect of prolonged stress on this class of materials. These records are extracted from the set presented to the U. S. Board and printed in the report of that body. Each record is accompanied by memoranda relating to the conditions of test and details of the experiment which render further explanation unnecessary.

TABLE LXXIII.

TESTS BY TENSILE STRESS.

Alloys of Copper and Zinc.—Dimensions.—Length = 5″; diameter = 0.798″.

BAR NO. 25 B.

COMPOSITION.—Original mixture: Cu, 82.5; Zn, 17.5. Analysis: Cu, 83.00; Zn, 16.90.

LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	SET.	ELONGATION IN PER CENT. OF LENGTH.	LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	SET.	ELONGATION IN PER CENT. OF LENGTH.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
1,000	0.0014	......	0.03	17,000	0.3194	......	6.39
2,000	0.0037	......	0.07	18,000	0.3600	......	7.20
4,000	0.0104	......	0.21	19,000	0.4034	......	8.07
200	......	0.0017	....	20,000	0.4460	......	8.92
6,000	0.0230	......	0.46	200	......	0.4404	....
7,000	0.0326	......	0.65	21,000	0.4892	......	9.78
8,000	0.0412	......	0.82	22,000	0.5274	......	10.55
200	......	0.0322	....	23,000	0.5586	......	11.17
9,000	0.0500	......	1.00	24,000	Measuring apparatus slipped.		
10,000	0.0616	......	1.23	32,800	Broke 2 inches from D end.		
11,000	0.0840	......	1.68	Total elongation measured after breaking,			
12,000	0.1154	......	2.31	1.17″ = 23.4 per cent.			
200	......	0.1100	....	Diameter of fractured section, 0.608″.			
13,000	0.1483	......	2.97	Tenacity per square inch original section,			
14,000	0.1880	......	3.76	32,800 pounds.			
15,000	0.2344	......	4.69	Tenacity per square inch fractured section,			
16,000	0.2747	......	5.49	56,493 pounds.			
200	......	0.2676	....				

TABLE LXXIII.—*Continued.*

BAR NO. 26 B.

COMPOSITION.—Original mixture: Cu, 72.5; Zn, 27.5. Analysis: Cu, 75.65; Zn, 24.15.

LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	SET.	ELONGATION IN PER CENT. OF LENGTH.
Pounds.	*Inch.*	*Inch.*	
2,000	0.0040	......	0.08
3,000	0.0062	......	0.12
4,000	0.0100	......	0.20
5,000	0.0144	......	0.29
6,000	0.0215	......	0.43
7,000	0.0299	......	0.60
8,000	0.0368	......	0.74
200	......	0.0221	....
9,000	0.0443	......	0.89
10,000	0.0518	......	1.04
11,000	0.0646	......	1.29
12,000	0.0698	......	1.40
200	......	0.0636	....
13,000	0.0878	......	1.76
14,000	0.1133	......	2.27
15,000	0.1513	......	3.03
16,000	0.1867	......	3.73
200	......	0.1784	....
17,000	0.2348	......	4.70
18,000	0.2813	......	5.63
19,000	0.3326	......	6.65
20,000	0.3834	......	7.67
200	......	0.3724	....
21,000	0.4334	......	8.67
22,000	0.4846	......	9.69
23,000	0.5380	......	10.76
24,000	0.5938	......	11.88
200	......	0.5788	....
25,000	0.6480	......	12.96
26,000	0.7156	......	14.31
27,000	Measuring apparatus slipped.		
36,840	Broke 2 inches from B end.		

Total elongation measured after breaking, 1.27″ = 25.4 per cent.
Diameter of fractured section, 0.587″.
Tenacity per square inch, original section, 36,840 pounds.
Tenacity per square inch, fractured section, 68,064 pounds.

BAR NO. 29 B.

COMPOSITION.—Original mixture: Cu, 62.5; Zn, 37.5. Analysis: Cu, 63.52; Zn, 36.26.

LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	SET.	ELONGATION IN PER CENT. OF LENGTH.
1,000	0.0011	......	0.02
2,000	0.0034	......	0.07
3,000	0.0055	......	0.11
4,000	0.0078	......	0.16
5,000	0.0100	......	0.20
6,000	0.0121	......	0.24
7,000	0.0142	......	0.28
8,000	0.0166	......	0.33
9,000	0.0191	......	0.38
10,000	0.0218	......	0.44
11,000	0.0257	......	0.51
12,000	0.0293	......	0.59
200	......	0.0075	....
13,000	0.0336	......	0.67
14,000	0.0392	......	0.78
15,000	0.0452	......	0.90
16,000	0.0520	......	1.04
200	......	0.0322	....
17,000	0.0643	......	1.29
18,000	0.0678	......	1.35
19,000	0.0812	......	1.62
20,000	0.1061	......	2.12
200	......	0.0814	....
21,000	0.1142	......	2.28
22,000	0.1350	......	2.70
23,000	0.1571	......	3.14
24,000	0.1836	......	3.67
200	......	0.1683	....
25,000	0.2097	......	4.19
26,000	0.2371	......	4.74
27,000	0.2668	......	5.34
28,000	0.2961	......	5.92
200	......	0.2784	....
29,000	0.3287	......	6.57
30,000	0.3665	......	7.33
31,000	0.3988	......	7.98
32,000	0.4260	......	8.52
200	......	0.4252	....
33,000	0.4790	......	9.58
34,000	0.5173	......	10.35
35,000	0.5585	......	11.17
36,000	0.6090	......	12.18
200	......	0.5886	....
37,000	0.6548	......	13.10

Measuring apparatus slipped.
47,840 | Broke 1 inch from B end.
Total elongation measured after breaking, 1.62″ = 32.4 per cent.
Diameter of fractured section, 0.656″.
The piece drew down very uniformly through the whole length to a diameter of about 0.685″.
Tenacity per square inch, original section, 47,840 pounds.
Tenacity per square inch, fractured section, 70,772 pounds.

TABLE LXXIII.—*Continued.*

BAR NO. 4 A.

Composition.—Original mixture: Cu, 80; Zn, 20. Analysis: Cu, 81.97; Zn, 17.95.

LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	SET.	ELONGATION IN PER CENT. OF LENGTH.
Pounds.	*Inch.*	*Inch.*	
1,600	0.0010	......	0.02
2,000	0.0020	......	0.04
3,000	0.0040	......	0.08
4,200	0.0065	......	0.13
5,000	0.0077	......	0.15
6,000	0.0106	......	0.21
7,000	0.0139	......	0.28
8,000	0.0175	......	0.35
120	......	0.0099	....
9,000	0.0223	......	0.45
10,000	0.0290	......	0.58
11,000	0.0424	......	0.85
12,000	0.0626	......	1.25
120	......	0.0610	....
13,000	0.0895	......	1.79
14,000	0.1337	......	2.67
16,000	0.2227	......	4.45
120	......	0.2204	....
18,000	0.3253	......	6.51
20,000	0.4459	......	8.92
Elongation increased in 2 m. to 0.4542.			
Elongation increased in 4 m. to 0.4575.			
100	......	0.4489	....
22,000	0.5809	......	11.62
24,000	0.7183	......	14.37
26,000	0.8504	......	17.01

LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	SET.	ELONGATION IN PER CENT. OF LENGTH.
Pounds.	*Inches.*	*Inch.*	
30,000	1.2525	......	25.05
30,400	1.3080	......	26.16
30,600	At this point the fastenings of the measuring instruments became loose, in consequence of the drawing down of the square head of the specimen.		

Continued the test without measuring elongations, and the piece broke near the middle at 32,200 pounds per square inch.

Total elongation as measured after breaking, 1.52″ = 30.40 per cent.

Diameter of fractured section, 0.585″.

Tenacity per square inch, original section, 32,200 pounds.

Tenacity per square inch, fractured section, 59,899 pounds.

The following measurements of diameter of different portions of the specimen were made after breaking:

	A end.	*C end.*
At fractured surface.........	0.585″	0.585″
½ inch from fracture.........	0.705	0.698
1 inch from fracture.........	0.712	0.698
2 inches from fracture......	0.710	0.708
3 inches from fracture......	0.710	0.720

BAR NO. 5 A.

Composition.—Original mixture: Cu, 75; Zn, 25. Analysis: Cu, 77.84; Zn, 21.78.

800	0.0010	......	0.02
1,200	0.0020	......	0.04
2,000	0.0043	......	0.09
3,000	0.0073	......	0.15
4,000	0.0096	......	0.19
5,000	0.0125	......	0.25
6,000	0.0155	......	0.31
7,000	0.0206	......	0.41
8,000	0.0250	......	0.50
200	......	0.0143	....
9,000	0.0319	......	0.64
10,000	0.0380	......	0.76
11,000	0.0469	......	0.94
12,000	0.0631	......	1.26
200	......	0.0600	....
13,000	0.0933	......	1.87
14,000	0.1324	......	2.65
16,000	0.2326	......	4.65
200	......	0.2293	....
18,000	0.3440	......	6.88
20,000	0.4605	......	9.21
Elongation increased in 1 m. to 0.4713″.			
Elongation increased in 2 m. to 0.4795″.			

22,000	0.5820	......	11.64
24,000	0.7053	......	14.11
25,000	0.7655	......	15.31
26,000	Measuring apparatus slipped; continued test without measuring elongations.		
34,040	Broke ¾ inch from A end.		

Total elongation, measured after breaking 1.80″ = 36 per cent.

Diameter of fractured section, 0.585″.

Tenacity per square inch, original section, 34,040 pounds.

Tenacity per square inch, fractured section, 63,322 pounds.

Diameters after breaking.

	Inch.
At fracture..............................	0.585
1 inch from fracture....................	0.672
2 inches from fracture..................	0.685
3 inches from fracture..................	0.694
4 inches from fracture..................	0.696
5 inches from fracture..................	0.705

TABLE LXXIII.—*Continued.*

BAR NO. 8 B.

COMPOSITION.—Original mixture: Cu, 60; Zn, 40. Analysis: Cu, 59.19; Zn, 40.39.

LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	SET.	ELONGATION IN PER CENT. OF LENGTH.	LOAD PER SQUARE INCH.	ELONGATION OF 5 INCHES.	SET.	ELONGATION IN PER CENT. OF LENGTH.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
2,000	0.0016	......	0.03	28,000	0.2310	......	4.62
3,000	0.0040	......	0.08	200	......	0.2190	....
4,000	0.0063	......	0.13	30,000	0.2648	......	5.30
5,200	0.0075	......	0.15	32,400	0.3235	......	6.47
6,000	0.0103	......	0.21	200	......	0.3062	....
7,000	0.0113	......	0.23	34,000	0.3850	......	7.70
8,000	0.0134	......	0.27	36,000	0.4526	......	9.05
200	......	0.0008	....	200	......	0.4373	....
9,000	0.0152	......	0.30	36,000	0.4860	......	9.72
10,000	0.0173	......	0.35	38,000	0.5700	......	11.40
11,000	0.0191	......	0.38	Measuring apparatus slipped.			
12,000	0.0220	......	0.44	50,520	(Elongat'n measured with calipers).		
200	......	0.0075	....	51,380	Broke in middle.		
13,000	0.0249	......	0.50				
14,000	0.0296	......	0.59				
16,000	0.0406	......	0.81				
200	......	0.0336	....				
18,000	0.0545	......	1.09				
20,000	0.0773	......	1.55				
200	......	0.0716	....				
22,000	0.1100	......	2.20				
24,000	0.1445	......	2.89				
200	......	0.1341	.. .				
26,000	0.1960	......	3.94				

Total elongation, measured after breaking, 1.48″ = 29.6″ per cent.
Diameters of fractured section, 0.672″ and 0.678″ (elliptical).
Diameter of piece 1 inch from fracture, 0,687″.
Tenacity per square inch original section, 51,380 pounds.
Tenacity per square inch fractured section, 71,762 pounds.

BAR NO. 9 A.

COMPOSITION.—Original mixture: Cu, 55; Zn, 45. Analysis: Cu, 59.13; Zn, 40.36.

2,000	0.0024	......	0.05	200	......	0.1091	....
3,000	0.0038	......	0.08	28,000	0.1139	......	2.28
4,000	0.0056	......	0.11	30,000	0.1489	......	2.98
200	......	0.0016	....	32,000	0.1791	......	3.58
5,000	0.0072	......	0.14	200	......	0.1712	....
6,000	0.0086	......	0.17	36,000	0.3017	......	6.03
7,000	0.0102	......	0.20	40,000	0.4236	......	8.47
8,000	0.0115	......	0.23	200	......	0.4077	....
200	......	0.0027	....	44,000	0.6201	......	12.40
9,000	0.0131	.....	0.26	48,000	Measuring apparatus slipped.		
10,000	0.0137	......	0.27	53,660	Broke at shoulder, B end.		
11,000	0.0152	......	0.30				
12,000	0.0167	......	0.33				
200	......	0.0082	....				
13,000	0.0182	......	0.36				
14,000	0.0200	......	0.40				
15,000	0.0217	......	0.43				
16,000	0.0240	......	0.48				
200	......	0.0201	....				
17,000	0.0259	......	0.52				
18,000	0.0289	......	0.58				
19,000	0.0323	......	0.65				
20,000	0.0364	......	0.73				
22,000	0.0460	......	0.92				
24,000	0.0614	......	1.23				
26,000	0.0832	......	1.66				
28,000	0.1136	......	1.27				

Total elongation, measured after breaking. 1.27 = 25.40 per cent.
Diameter of fractured section, 0.675″.
Diameter of piece 1 inch from fracture, 0.680″.
Diameter of piece 3 inches from fracture, 0.680″.
Diameter of piece 4 inches from fracture, 0.687″.
Diameter of piece 5 inches from fracture, 0.704″.
Diameter of piece 6 inches from fracture, 0.710″.
Tenacity per square inch, original section, 53,660 pounds.
Tenacity per square inch, fractured section, 74,975 pounds.

TABLE LXXIV.

RECORD OF TESTS BY COMPRESSIVE STRESS.

Alloys of Copper and Zinc. Dimensions: Length = 2″ (5.08 **cm.**); diameter = 0.625″ (15 cm.).

BAR NO. 2.

COMPOSITION.—Original mixture: Cu, 90; Zn, 10. Analysis: Cu. 9.56; Zn, 90.42.

LOAD.	COMPRESSION.	LOAD PER SQUARE INCH.	COMPRESSION IN PER CENT. OF LENGTH.	LOAD.	COMPRESSION.	LOAD PER SQUARE INCH.	COMPRESSION IN PER CENT. OF LENGTH.
Pounds.	*Inch.*	*Pounds.*		*Pounds.*	*Inch.*	*Pounds.*	
500	0.002	1,630	0.10	12,000	0.294	39,114	14.70
1,000	0.004	3,250	0.20	13,000	0.334	42,373	16.70
2,000	0.009	6,519	0.45	14,000	0.372	45,633	18.60
3,000	0.012	9,778	0.60	15,000	0.408	48,892	20.40
4,000	0.022	13,038	1.10	16,000	0.442	52,152	22.10
5,000	0.046	16,297	2.30	17,000	0.482	55,411	24.10
6,000	0.083	19,557	4.15	18,000	0.530	58,671	26.50
7,000	0.119	22,816	5.95	19,000	0.563	61,930	28.15
8,000	0.152	26,076	7.60	20,000	0.599	65,190	29.95
9,000	0.187	29,335	9.35	Removed piece slightly bent, surface very rough.			
10,000	0.225	32,595	11.25				
11,000	0.262	35,855	13.10				

BAR NO. 5.

COMPOSITION.—Original mixture: Cu, 75; Zn, 25. Analysis: Cu, 76.65; Zn, 23.08.

2,000	0.0085	6,519	0.43	22,000	0.476	71,709	23.80
3,000	0.013	9,778	0.65	23,000	0.502	74,968	25.10
4,000	0.016	13,038	0.80	24,000	0.528	78,228	26.40
5,000	0.019	16,297	0.95	26,000	0.562	84,747	28.10
6,000	0.022	19,557	1.10	28,000	0.613	91,266	30.65
8,000	0.032	26,076	1.60	30,000	0.652	97,785	32.60
9,000	0.042	29,335	2.10	32,000	0.691	104,303	34.45
10,000	0.065	32,595	3.25	34,000	0.734	110,822	36.70
11,000	0.109	35,855	5.45	36,000	0.773	117,341	38.65
12,000	0.154	39,114	7.70	38,000	0.828	123,860	41.40
13,000	0.203	42,373	10.15	39,000	0.876	127,119	43.80
14,000	0.243	45,633	12.15	40,000	0.916	130,379	45.80
15,000	0.273	48,892	13.65	41,000	0.966	133,638	48.30
16,000	0.309	52,152	15.45	42,000	1.011	136,898	50.55
17,000	0.339	55,411	16.95	43,000	1.058	140,157	52.90
18,000	0.366	58,671	18.30	Resistance decreased to—			
19,000	0.399	61,930	19.95	34,000	1.150	110,822	57.50
20,000	0.424	65,190	21.20	Removed piece squeezed out of shape with a diagonal crack on one side.			
21,000	0.451	68,449	22.55				

TABLE LXXIV.—*Continued.*

BAR NO. 9.

Composition.—Original mixture: Cu, 55; Zn, 45. Analysis: Cu, 55.15; Zn, 44.44.

LOAD.	COMPRESSION.	LOAD PER SQUARE INCH.	COMPRESSION IN PER CENT. OF LENGTH.	LOAD.	COMPRESSION.	LOAD PER SQUARE INCH.	COMPRESSION IN PER CENT. OF LENGTH.
Pounds.	*Inch.*	*Pounds.*		*Pounds.*	*Inch.*	*Pounds.*	
1,000	0.005	3,259	0.25	20,000	0.150	65,190	7.50
2,000	0.008	6,519	0.40	22,000	0.173	71,709	8.65
3,000	0.010	9,778	0.50	24,000	0.202	78,228	10.10
4,000	0.012	13,038	0.60	26,000	0.227	84,747	11.35
5,000	0.014	16,297	0.70	28,000	0.253	91,266	12.65
6,000	0.016	19,557	0.80	30,000	0.280	97,785	14.00
7,000	0.019	22,816	0.95	32,000	0.299	104,303	14.95
8,000	0.023	26,076	1.15	34,000	0.335	110,822	16.75
9,000	0.026	29,335	1.30	36,000	0.362	117,341	18.10
10,000	0.032	32,595	1.60	38,000	0.388	123,860	19.40
11,000	0.040	35,855	2.00	39,000	0.405	127,119	20.25
12,000	0.050	39,114	2.50	40,000	0.415	130,379	20.75
13,000	0.061	42,373	3.05	41,000	0.436	133,638	21.80
14,000	0.075	45,633	3.75	41,500	0.452	135,268	22.60
15,000	0.087	48,892	4.35	42,000	.....	136,898	.....
16,000	0.100	52,152	5.00	Broke suddenly, a small piece breaking off			
17,000	0.113	55,411	5.65	from upper corner.			
18,000	0.125	58,671	6.25	Bent slightly.			
19,000	0.138	61,930	6.90				

BAR NO. 11.

Composition.—Original mixture: Cu, 45; Zn, 55. Analysis: Cu, 47.56; Zn, 52.28.

1,000	0.002	3,259	0.10	26,000	0.102	84,747	5.10
2,000	0.007	6,519	0.35	28,000	0.115	91,266	5.75
3,000	0.010	9,778	0.50	30,000	0.130	97,785	6.50
4,000	0.011	13,038	0.55	32,000	0.147	104,393	7.35
5,000	0.013	16,297	0.65	34,000	0.164	110,822	8.20
6,000	0.014	19,557	0.70	36,000	0.188	117,341	9.40
7,000	0.016	22,816	0.80	37,000	0.198	120,600	9.90
8,000	0.018	26,076	0.90	38,000	0.210	123,860	10.50
9,000	0.019	29,335	0.95	39,000	0.221	127,119	11.05
10,000	0.021	32,595	1.05	40,000	0.239	130,379	11.95
12,000	0.028	39,114	1.40	41.000	0.253	133,638	12.65
14,000	0.037	45,633	1.85	41,500	0.267	135,268	13.35
16,000	0.046	52,152	2.30	42,000	0.272	136,898	13.60
18,000	0.056	58,671	2.80	42,500	.....	138,528	Broke
20,000	0.066	65,190	3.30	just as beam rose,			
22,000	0.078	71,709	3.90	Fracture diagonally across the middle of the			
24,000	0.090	78,228	4.50	specimen.			

TABLE LXXV.

RECORD OF TESTS BY TRANSVERSE STRESS.

Alloys of copper and zinc. Dimensions: Length, $l = 22''$; **breadth,** $b = 1''$ (2.54 cm.); depth, $d = 1''$ (2.54 cm.).

BAR NO. 4.

COMPOSITION.—Original mixture: Cu, 80; Zn, 20. Analysis: Cu, 81.91; Zn, 17.99.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.	LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inches.*	*Inches.*	
10	0.0042	......	....	420	0.4414	....	....
20	0.0080	......	....	440	0.5885	....	....
40	0.0124	......	9,030,560	460	0.7520	....	....
80	0.0206	......	10,708,667	480	0.9590	....	....
120	0.0296	......	11,349,217	500	1.1763	....	1,189,949
160	0.0363	......	12,339,278	520	1.3463	....	....
200	0.0449	......	12,469,814	540	1.6163	....	....
3	......	0.0056	....	560	1.86	....	....
240	0.0544	......	12,350,618	580	2.22	....	....
280	0.0692	Beam sinks slowly.	11,327,350	600	2.62	....	641,107
320	0.0980	......	9,141,138	620	3.27	....	....
360	0.1695	......	6,074,807	Bent down without breaking. Bar removed.			
400	0.3288	......	3,405,686	Breaking load, $P = 620$ pounds.			
3	......	0.2445	....	Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 21,193$.			
400	0.3352	......	....				

BAR NO. 5.

COMPOSITION.—Original mixture: Cu, 75; Zn, 25. Analysis; Cu, 76.65; Zn, 23.28.

10	0.0024	......	....	440	0.4110	....	....
20	0.0066	......	....	460	0.5396	....	....
40	0.0111	......	10,347,419	480	0.6989	....	....
80	0.0204	......	11,260,425	500	0.9489	....	1,513,020
120	0.0288	......	11,964,201	520	1.10	....	....
160	0.0354	......	12,978,117	540	1.32	....	....
200	0.0439	......	13,081,592	560	1.62	....	....
3	......	0.0059	... .	580	1.94	....	....
240	0.0514	......	13,407,355	600	2.28	....	755,634
280	0.0620	......	12,967,651	620	2.64	....	....
320	0.0772	Beam sinks slowly.	11,902,213	640	3.39	....	....
				10	......	3.19	....
360	0.1094	......	9,448,876	Bent without breaking. Removed bar.			
400	0.2010	......	5,714,246	Breaking load, $P = 640$ pounds.			
3	......	0.136	....	Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 22,325$.			
400	0.2129	......	....				

TABLE LXXV.—*Continued.*

BAR NO. 6.

COMPOSITION.—Original mixture: Cu, 70; Zn, 30. Analysis: Cu, 71.20; Zn, 28.54.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.	LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inches.*	*Inches.*	
10	.00067	......	....	520	0.6832	......	....
20	0.0114	......	....	540	0.8532	......	....
40	0.0172	......	6,691,260	560	1.1092	......	....
80	0.0256	......	8,991,379	580	1.2972	......	....
120	0.0334	......	10,337,393	10	......	1.1467	....
160	0.0406	......	11,338,883	580	1.3462	......	....
200	0.0501	......	11,485,995	600	1.55	......	1,113,771
3	......	0.0052	....	620	1.80	......	....
240	0.0582	......	11,864,913	640	2.15	......	....
280	0.0680	......	11,847,464	660	2.45	......	....
320	0.0794	......	11,595,933	680	2.80	......	....
360	0.0957	Beam sinks	10,823,479	700	3.30	......	610,324
400	0.1268	......	9,076,471	Bent without breaking. Removed bar.			
3	......	0.0408	....	Breaking load, $P = 700$ pounds.			
440	0.2147	......	....				
480	0.4258	......	....	Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 24,468$.			
500	0.5396	......	2,660,088				

BAR NO. 7.

COMPOSITION.—Original mixture: Cu, 65; Zn, 35. Analysis: Cu, 66.27; Zn, 33.50.

10	0.0028	......	....	3	......	0.5538	....
20	0.0058	......	....	620	0.6734	......	....
40	0.0124	......	9,168,783	640	0.8436	......	....
80	0.0233	......	9,759,049	660	1.0268	......	....
120	0.0317	......	10,759,827	680	1.2058	......	....
160	0.0384	......	11,843,014	700	1.41	......	1,411,082
200	0.0466	......	12,198,812	720	1.59	......	....
3	......	0.0033	....	740	1.79	......	....
240	0.0546	......	12,493,727	760	2.04	......	....
280	0.0642	......	12,396,423	780	2.34	......	....
320	0.0728	......	12,493,727	Repeated.			
360	0.0836	......	12,239,668	780	2.84	......	....
400	0.0948	......	11,992,925	800	3.34	......	680,796
3	......	0.0112	....	820	3.84	......	....
440	0.1110	Beam sinks slowly.	11,226,865	10	......	3.54	....
480	0.1454	......	....	Bent without breaking.			
520	0.2128	......	6,914,525	Bar removed.			
560	0.4680	......	....	Breaking load, $P = 820$ pounds.			
600	0.5958	......	2,862,360	Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 28,459$.			

TABLE LXXV.—*Continued.*

BAR NO. 8.

COMPOSITION.—Original mixture: Cu, 60; Zn, 40. Analysis: Cu, 60.94; Zn, 38.65.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*	
40	0.0203	......	5,488,205
80	0.0291	......	7,835,438
120	0.0380	......	8,795,568
160	0.0447	......	9,969,625
200	0.0534	......	10,431,698
10	......	0.0105	......
240	0.0626	......	10,678,327
280	0.0721	......	10,816,556
320	0.0820	......	10,869,170
360	0.0906	......	11,067,272
400	0.1000	......	11,141,054
10	......	0.0135	....
400	0.1020	......	....

Left under strain 18 hours; deflection and resistance to deflection unchanged.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
10	......	0.0146	....
440	0.1101	......	11,130,936
480	0.1193	......	11,206,425
520	0.1290	......	11,227,419
560	0.1425	......	10,945,596
600	0.1585	......	10,543,585
10	......	0.0283	....
640	0.1747	......	10,203,600
720	0.2555	......	7,848,884
800	0.5021	......	4,437,784
10	......	0.3060	....

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inches.*	*Inches.*	
800	0.5090	......	....

Resistance decreased in 1 hour to 782 pounds.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
10	......	0.3224	....
840	0.5275	......	....
880	0.9685	......	....
900	0.9885	......	2,535,900
920	1.04	......	....
940	1.26	......	....
960	1.33	......	....
980	1.53	......	....
1,000	1.[illegible]2	......	1,719,298
1,100	2.67	......	....

Resistance decreased in 30 sec. to 1,026 pounds.
Resistance decreased in 1 m. to 1,020 pounds.
Resistance decreased in 17 hr. 30 m. to 990 pounds.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
1,130	2.72	......	....
1,140	2.75	......	....

Ran down pressure screw about 1 inch further; maximum resistance to rapid motion 1,160 pounds.
Bent without breaking.
Breaking load, $P = 1,140$ pounds.

Modulus of rupture, $R = \frac{3Pl}{2bd^2} = 38,968$.

BAR NO. 9.

COMPOSITION.—Original mixture: Cu, 55; Zn, 45. Analysis: Cu, 55.15; Zn, 44.44.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
20	0.0080	......	....
40	0.0148	......	7,888,340
80	0.0285	......	8,194,687
120	0.0398	......	8,800,055
160	0.0505	......	9,247,321
200	0.0612	......	9,538,189
10	......	0.0080	......
240	0.0800	......	8,756,005
280	0.0900	......	9,080,354
320	0.1004	......	9,302,585
360	0.1110	......	9,466,607
400	0.1317	......	8,864,649
10	......	0.0213	....
440	0.1496	......	8,584,370
480	0.1790	......	7,826,643
520	0.247	......	7,069,010
560	0.2645	......	....
600	0.3306	......	5,297,071
10	......	0.1663	....
640	0.3951	......	....
680	0.5060	......	....
700	0.5315	......	4,839,294
720	0.5833	.....	....
800	0.8367	......	2,790,663
10	......	0.6250	....
800	0.8581	......	....

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
860	1.0364	......	....
880	1.1250	......	....
900	1.1953	......	2,197,622
920	1.2722	......	....
940	1.3423	......	....
960	1.4647	......	....

Resistance decreased in 5 min. to 950 pounds.
Resistance decreased in 20 min. to 942 pounds.
Resistance decreased in 16 hr. to 916 pounds.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
10	......	1.2233	....
920	1.4785	......	....
940	1.5175	......	....
960	1.5900	......	....
980	1.6815	......	....
1,000	1.7675	......	1,653,646
1,020	1.86	......	....
1,100	2.24	......	1,433,283
1,160	2.65	......	....

Crackling sound heard from bar.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
1,180	2.79	......	....
1,200	Bar bent and supports slid out from under it.		

Breaking load, $P = 1,200$ pounds.

Modulus of rupture, $R = \frac{3Pl}{2bd^2} = 42,463$.

TABLE LXXV.—*Continued.*

BAR NO. 10.

COMPOSITION.—Original mixture: Cu, 50; Zn, 50. Analysis: Cu, 49.66; Zn, 50.14.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*	
20	0.0065	......	....
40	0.0110	......	10,711,665
80	0.0219	......	10,760,578
120	0.0330	......	10,711,665
160	0.0429	......	10,986,324
200	0.0509	......	11,574,491
A slight crackling sound was heard while the strain remained on the bar, the deflection being held constant.			
10	0.0025	......	....
200	0.0509	Beam sinks slowly.	....
240	0.0623	......	11,347,832
280	0.0773	......	10,670,093
320	0.1009	......	9,342,185
360	0.1337	......	7,931,600
400	0.1736	......	6,787,347
10	.. ..	0.0816	....
440	0.2220	......	5,838,341
480	0.2752	......	....
520	0.3291	......	4,654,415
560	0.3909	......	....
600	0.4568	......	3,869,144
10	......	0.3165	....
640	0.5182	......	....

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inches.*	*Inches.*	
680	0.5990	... ..	....
720	0.6700	......	3,165,537
760	0.7647	......	....
800	0.6813	......	2,704,656
10	......	0.6699	....
800	0.8713	......	....
840	0.9493	......	....
880	1.0613	......	....
920	1.1690	......	2,318,265
940	On applying the stress several slight cracks were heard, but there was no visible appearance of breaking. The resistance suddenly decreased, and on balancing the scale beam was found to be 580 pounds.		
580	1.2570	......	....
10	... ..	1.1195	....

Applied stress again, and the resistance reached 500 pounds when the bar broke.
The crackling sound noticed first at 200 pounds continued throughout the test while the bar was strained, even when the deflection was held constant for several minutes.
Breaking load, $P = 940$ pounds.

Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 33,467$.

ALLOYS OF COPPER AND ZINC.

BAR NO. 32.

Resistance decreased in 22 hrs. to 751 pounds.			
3	......	0.1638	....
751	0.3364	......	....
800	0.3490	......	....
820	0.3583	......	....
840	0.3790	......	....
860	0.3948	......	....
880	0.4145	......	....
900	0.4343	......	6,283,536
920	0.4518	......	....
940	0.4669	......	....
960	0.4905	......	....

980	0.5122	......	....
1,000	0.5302	......	5,718,889
1,020	0.5444	......	....
1,040	0.5718	......	....
1,080	0.6140	......	5,333,432
1,100	Broke in middle just as beam rose.		

Breaking load, $P = 1,100$ pounds.

Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 40,189$.

The crackling sound noted at 520 pounds continued till the end of the test, even when the deflection was held constant for several minutes.

TABLE LXXV.—*Continued.*

BAR NO. 33.

COMPOSITION.—Original mixture: Cu, 42.5; Zn, 57.5. Analysis: Cu, 43.36; Zn, 56.22; Pb, 0.38.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*	
10	0.0030	......	....
20	0.0072	......	....
40	0.0164	......	5,950,134
60	0.0279	......	5,246,355
120	0.0354	......	8,246,381
160	0.0421	......	9,271,468
200	0.0497	......	9,817,123
3	......	0.0063	....
240	0.0556	......	10,530,451
280	0.0614	......	11,125,005
320	0.0672	......	11,616,928
360	0.0724	......	12,130,383
400	0.0789	......	12,367,832
3	......	0.0115	....
440	0.0850	......	12,628,285
480	0.0909	......	12,882,137
520	0.0982	......	12,918,211
540	Broke just as beam rose.		

Breaking load, $P = 540$ pounds.

Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 17,691$.

BAR NO. 39.

COMPOSITION.—Original mixture: Cu, 12.5; Zn, 87.5. Analysis: Cu, 12.12; Zn, 86.67; Pb, 1.22.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
10	0.0022	......	....
20	0.0056	......	....
40	0.0128	......	8,982,413
80	0.0234	......	9,826,913
120	0.0329	......	10,484,031
160	0.0430	......	10,695,338
200	0.0526	......	10,929,173
3	......	0.0011	....
240	0.0641	......	10,762,079
280	0.0729	......	11,040,112
320	0.0818	......	11,244,489
360	0.0921	Beam sinks slowly.	11,235,332
400	0.1016	......	11,316,427
3	......	0.0064	....
440	0.1115	......	11,342,857
480	0.1216	......	11,346,204
520	0.1316	......	11,359,423
560	0.1421	......	11,327,574
600	0.1528	......	11,286,725
3	......	0.0148	....
Resistance increased in 10 minutes to 10 pounds.			
3	......	0.0114	....
640	0.1663	......	11,061,926
680	0.1796	......	10,882,925
720	0.2006	......	....
760	0.2116	......	10,323,831
800	0.2261	......	....
3	......	0.0378	....
840	0.2450	......	9,854,991
880	0.2624	......	....
920	0.2856	......	....
960	0.3124	......	8,832,898
1,000	Broke just as beam rose.		

Breaking load, $P = 1,000$ pounds.

Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 35,026$

BAR NO. 41.

COMPOSITION.—Original mixture: Cu, 2.5; Zn, 97.5. Analysis: Cu, 2.45; Zn, 96.43; Pb, 1.05.

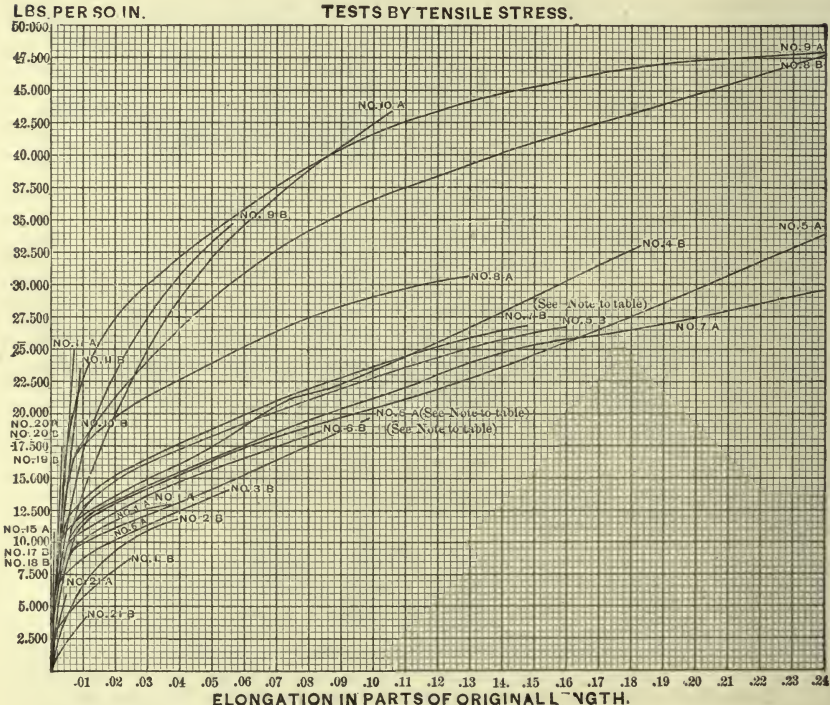
LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
20	0.0067	......	....
40	0.0154	......	8,117,624
80	0.0255	......	9,581,630
120	0.0362	......	10,124,235
160	0.0486	......	10,054,796
200	0.0618	......	9,883,964
3	......	0.0051	....
240	0.0764	......	....
280	0.0932	Beam sinks slowly.	9,175,542
320	0.1124	......	8,695,074
360	0.1352	......	8,132,338
400	0.1601	......	7,630,593
3	......	0.0498	....
440	0.1895	......	....
480	0.2225	......	6,588,717
520	0.2596	......	....
560	0.3137	......	5,452,091
600	0.3950	......	4,639,208
3	......	0.0270	....
600	0.4097	......	....
630	Crack appeared in bottom of bar; resistance decreased rapidly, and bar broke.		

Breaking load, $P = 630$ pounds.

Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 23,137$.

237. The Method of Variation of Resistance with distortion is illustrated by strain-diagrams, several of which, as obtained by tests in tension, are given in Figure 17. These strain-diagrams are produced, in this case, by plotting the record of test, making the ordinates of the curve proportional to the load and the abscissas variable with the extension. In

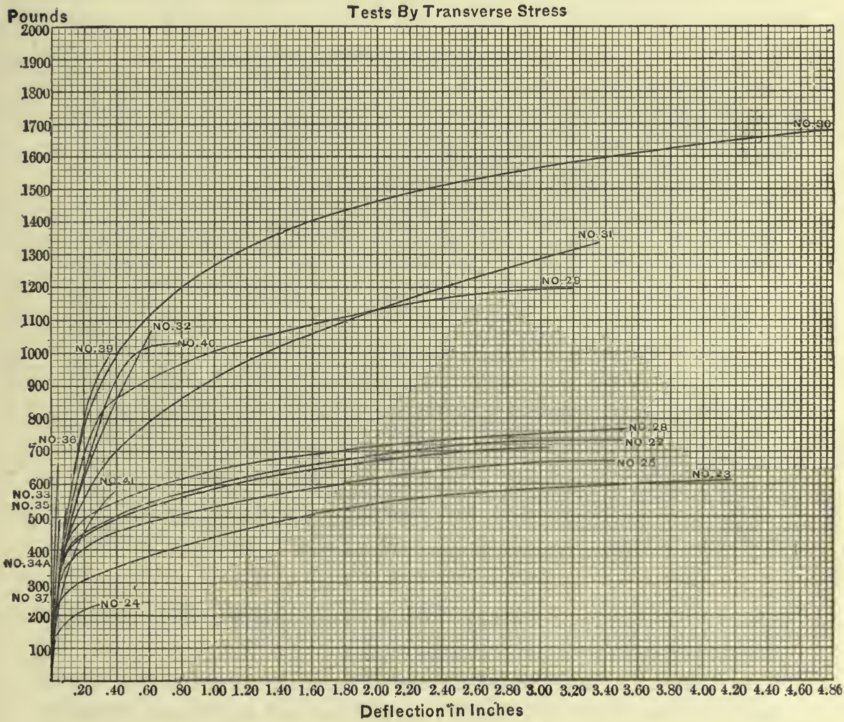
FIG. 17.—STRAIN-DIAGRAMS OF BRASSES.



preparing the test-pieces, the yellow alloys, Nos. 1 to 10, containing less than 0.55 zinc, were easily turned in the lathe. The white alloys, Nos. 12 to 15, 0.60 to 0.70 zinc, could not be turned as they were too brittle to be worked; these were tested in the bar, unturned. The blue-gray alloys, Nos. 16 to 21, containing over 75 per cent. zinc, were more easily cut than the first class and were tested in standard form and size.

Studying these diagrams, it is seen that, in some cases, there appears the semblance of an elastic limit at not far from one-half the maximum resistance. This is most easily seen in the diagrams of Nos. 4 to 8. The tenacity varies enormously, as, for example, between Nos. 8 or 9 and 21.

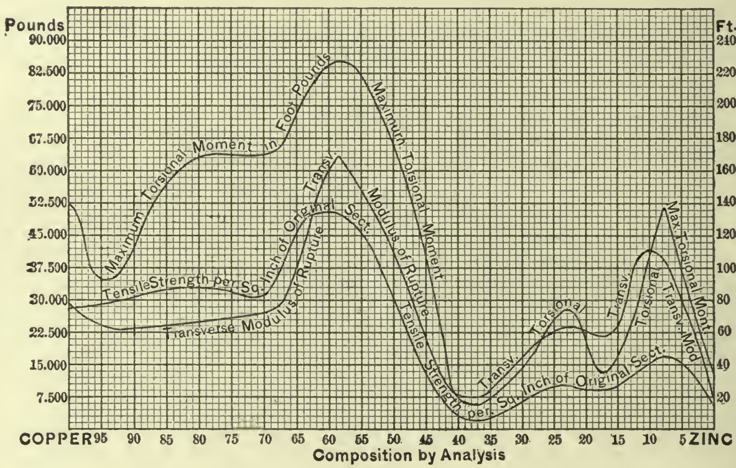
FIG. 18.—STRAIN-DIAGRAMS OF BRASSES.



The ductility is correspondingly variable, as illustrated by the same cases. The elastic resilience is evidently greatest with brittle alloys, as Nos. 11 A, 11 B; but the total resilience, as measured by the area covered by the curves, is seen to be enormously greater in the strong and ductile alloys, of which Nos. 8 and 9 (Muntz metal) containing 40 and 45 per cent. zinc are examples. Nos. 8, 9 and 10, which contain from 40 to 50 per cent. zinc, are obviously by far the best compositions for general use, and the next best class contains less zinc, as Nos. 4 to 7 (zinc, 20 to 35).

238. Strain-Diagrams obtained by Transverse Stress, Figure 18, are illustrative of the same facts as were exhibited by tests in tension. These are another set of bars similarly graded from copper, 100, to zinc, 100. Here again a Muntz metal, No. 30 (zinc, 40), is by far the best. Nos. 29 to 32, form a valuable group (zinc, 37.5 to 50), and the lower num-

FIG. 19.—COMPARISON OF RESISTANCES.



bers, containing less zinc, stand next in order. The smoothness of these curves is remarkable.

No definite elastic limits are found here, although some alloys, as Nos. 22–28, present indications of one nearly as well defined as is sometimes the case with the best iron.

239. Comparisons of Resistances, as determined by the several methods of test, are made by plotting the curves of resistance side by side, as in Figure 19. No direct relation is known to exist among these variations of load and of distortion, but a close correspondence of general form is seen in the diagrams.

The curves are so irregular that it is evident that further investigation will be needed to ascertain their exact form, as determined by composition and unaltered by physical and accidental conditions. The positions of the maximum and the minimum are very nearly the same, as indicated by all forms of test, and may be taken, for practical purposes, as at zinc, 35 to 40, and at zinc, 60 to 65, respectively. All methods of test concur in showing that the valuable alloys for the ordinary work of the engineer lie on the copper side of the maximum, where alloys are found which are tough as well as strong. Those lying on the zinc side of the minimum, and near the composition, copper, 15 to 20, zinc, 85 to 80, may prove valuable as bearing metals and for castings or worked parts not required to be of great strength ; their malleability constitutes their prominent good quality.

The curves of resistances to various kinds of stress show that they have a close relation depending upon the composition, in a portion of the series, but exhibiting a very different law in other portions.

The alloys between 17.5 and 32.5 per cent. zinc by original mixture, or between 16.98 and 30.06 per cent. zinc by analysis, show a remarkable similarity in all properties. They have all nearly the same strength, and nearly the same ductility, the latter decreasing slightly as the percentage of zinc increases. They are similar in color and appearance, so that one could scarcely be distinguished from the other. Their moduli of elasticity are nearly the same. The moduli of rupture by transverse stress in this group varied from 21,193 to 26,930 pounds per square inch (1,490 to 1,893 kilogs. per sq. cm.), these moduli being calculated from the loads which caused deflections of 3½ inches (9 cm.), as all of the bars bent without breaking. The mean tensile strength of the two pieces from each bar varied from 28,120 to 35,630 pounds per square inch (1,977 to 2,505 kilogs. per sq. cm.), the lowest figure being exceptional, and the piece possibly slightly defective, as the next higher figure was 30,510 pounds (2,144 kilogs. per sq. in.).

All bars which contained less than 15 per cent. zinc by mixture, or less than 11.06 per cent. zinc by analysis, were defective, and their resistances were accordingly lower than would be observed with sound castings. A few pieces of this group gave higher results than the average, and these may be taken as probably nearly the results which would be given if the bars had been sound throughout.

Between the compositions containing 32.5 and 37.5 per cent. zinc by mixture, or 30.06 and 36.36 per cent. zinc by analysis, occurs a rapid increase of strength. The latter alloy (63.44 copper, 36.36 zinc), had a modulus of rupture of 43,216 pounds (3,038 kilogs. on the sq. cm.), and a mean tenacity of 48,300 pounds per square inch (3,395 kilogs. per sq. cm.).

Between the compositions containing 37.5 and 55 per cent. zinc by mixture, or 36.36 and 52.28 per cent. zinc by analysis, is another group of alloys, which contains that of maximum strength by transverse, tensile, and torsional tests, but not by compressive test, and higher than that of the first group. The moduli of rupture vary from 33,467 to 63,304 pounds (2,353 to 4,450 kilogs. per sq. cm.), the mean tenacity from two-thirds to four-fifths as much. The figures decrease as the proportion of zinc increases beyond that which is contained in the alloy of maximum strength (58.49 copper, 41.10 zinc). The curves of test indicate that this composition is nearly that of maximum strength, and probably within 2 per cent. of the actual maximum. The alloy of maximum strength contains about 41 per cent. of zinc. The compressive strength of this group bears no relation to tensile, transverse, or torsional strength, as it increases regularly with the increase of zinc; and the maximum compressive strength of all alloys of copper and zinc is probably reached at an alloy containing more than 55 per cent of zinc. The ductility of this group has no relation to strength, and always decreases as the proportion of zinc increases.

The alloys containing less than 55 per cent. of zinc by mixture (52.28 zinc by analysis), are the yellow metals or useful alloys.

Between the compositions containing 55 and 60 per cent. zinc by mixture (or 52.28 and 58.12 zinc by analysis) there is a rapid decrease of strength as well as a rapid decrease of ductility.

Between the compositions containing 60 and 70 per cent. zinc by mixture (or 58.12 and 66.23 per cent. by analysis) there is some uniformity of strength, these being the second class, silver-white, brittle alloys. The moduli of rupture of this group, and the tenacity are low.

Between the compositions containing 70 per cent. zinc by mixture and pure zinc, comprising the bluish-gray alloys, the curves of resistances gradually fall.

240. **Resilience.**—The resilience of pieces containing less than 15 per cent. of zinc are uncertain in consequence of their being defective. Two torsion pieces within this limit give the maximum resiliences of 896.69 and 881.59 foot-pounds, these pieces being also the most ductile under torsional test. From the latter of these figures there is a rapid and comparatively regular decrease of total resilience by torsion to alloy 38.46 copper, 61.05 zinc, only about $\frac{1}{23,000}$th of the maximum. The resiliences by transverse test, on the contrary, increase from the defective bars to the bar of maximum strength, 58.49 copper, 41.10 zinc, with considerable regularity, as the strength increases, and then as the bars become of such low ductility as to break, the resilience decreases, and the curve takes nearly the same form as the curve of torsional resilience to the end of the series.

From alloy 41.30 copper, 58.12 zinc, to 14.19 copper, 85.10 zinc, the resiliences are small, corresponding with the combination of low strength and low ductility. At alloy 7.20 copper, 92.07 zinc, there is a second maximum of resilience, the very large increase of strength of the alloy over those of minimum strength contributing to give this alloy more resilience than cast zinc, although the latter has much the greater ductility.

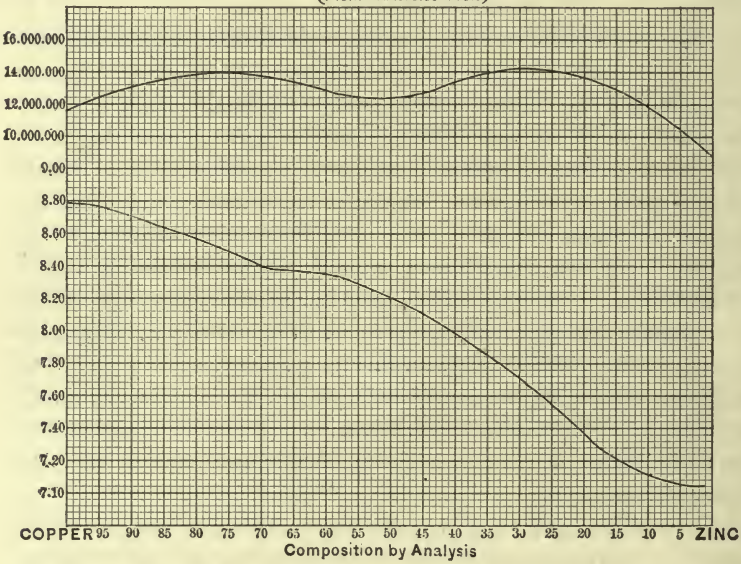
241. **Limit of Elasticity.**—In the table of results of tests, figures are given representing the transverse load at the apparent elastic limit and corresponding modulus $\left(R = \frac{3}{2}\frac{Pl}{bd^2}\right)$.

The relation between the elastic limit and ultimate strength appears to vary considerably. The percentage ratios by transverse tests appear to be greater than those by the other methods of test.

In the more ductile alloys, containing less than 50 per cent. of zinc, the elastic limit is generally from 20 to 50 per cent. of the ultimate strength ; as the percentage of zinc increases beyond 50 per cent., and the alloys become more brittle,

FIG. 20.—MODULI OF ELASTICITY AND SPECIFIC GRAVITY.

(From Transverse Tests)



the elastic limit is not clearly defined, but appears to approach more nearly to the ultimate strength in tensile than in other tests.

In brittle alloys, containing from 56.22 to 85.10 per cent. zinc, the elastic limit is not reached until fracture takes place.

From 85.10 per cent. to pure zinc, the ratio decreases by transverse tests, while in tensile tests the ratio apparently remains at 100 per cent. till 96.43 per cent. zinc is reached. In torsion tests the elastic limit begins to be less than the ultimate strength after 86.67 per cent. zinc, the ratio decreasing as the percentage of zinc increases.

242. The Moduli of Elasticity of the copper-zinc alloys are variable according to a law which is probably nearly represented by the upper curve in Figure 20. The modulus for copper is low, and the figure gradually rises as zinc is added, until passing zinc 25, it falls again, passing a minimum at about zinc 50, and a second maximum not far from zinc 75, and falls off rapidly to a minimum at pure zinc. Further investigation is needed to determine to what extent these fluctuations are due to chemical and what to physical causes. The Author is inclined to believe that sound castings containing large amounts of copper would give higher figures.

The moduli of elasticity given in the above table were selected from the records of test by transverse stress.

The average figure for the alloys is nearly 13,000,000 (913,900 kilogs. per sq. cm.). The variation of the figures of bars of different composition does not have any relation to density, strength, or other mechanical property, but follows a law of its own.

There appears to be an increase of the modulus with increase of percentage of zinc up to the alloy containing 16.98 per cent. of zinc. It then appears to be nearly uniform from 16.98 to 36.36 zinc. From 36.36 zinc to 44.44 zinc there is a regular and rapid decrease, and from 44.44 zinc to 52.28 zinc there is a regular and rapid increase. This break, almost a cusp in what might otherwise be a regular curve, is indicated by all observations between the limits of 36.36 and 52.28 zinc.

The increase in the modulus continues from the alloy containing 52.28 per cent. zinc to that containing 66.23 per cent. zinc. The latter alloy gives the maximum modulus of the series. From this point there is a rapid decrease to pure zinc, which gives the minimum modulus.

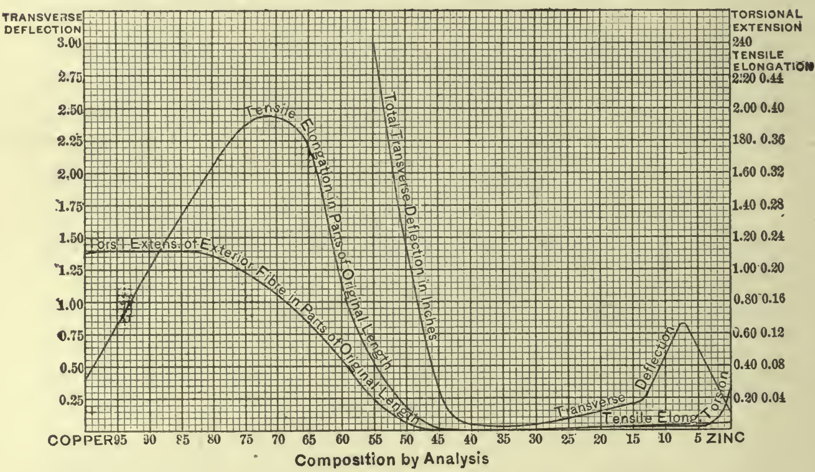
The bars which make this break include the strongest bars of the series, and those which exhibited the phenomena of irregularity in increase of deflection under transverse stress and of emitting the crackling sound (cry of tin) when held at a constant deflection. They also include metals of a wide range of ductility and hardness, and of a structure varying from fibrous to coarsely granular.

243. The Curve of Specific Gravities is presented on the lower part of the same figure, under that of the moduli of elasticity. This curve is not as smooth as that given for the bronzes, and it may ultimately be found necessary to revise it to some extent. The general method of variation is very similar to that given for copper-tin alloys. Its equation may be taken as approximately,

$$D = 7 + 0.019\, C,$$

in which D is the specific gravity and C the percentage of copper. It is not, however, a straight line, but has probably

FIG. 21.—COMPARATIVE DUCTILITY.



the same smooth and moderate curvature observed in that given for the bronzes. A smooth curve osculating that here given on the upper side of the latter, is perhaps the true curve. It would terminate at very nearly or quite S. G. = 9 on the copper side, and at S. G. = 7.15 at the zinc end.

244. Comparisons of Ductility of the copper-zinc alloys are graphically exhibited in the above figure, as determined by the several methods of test. It is seen that it varies in the opposite direction to the change of strength with variation of composition and to be different in its distribution from that observed in the copper-tin alloys. All bars containing between 16.98 and 38.65 per cent. zinc have a high degree of ductility, the mean extension of the two pieces of each bar varying from 20.67 to 38.5 per cent. With the increase of zinc beyond 38.65 per cent. the ductility decreases till 52.28 per cent. zinc is reached, the mean extension of the alloy of this composition being only 0.79 per cent., or but little more than one-fiftieth of the maximum. From 52.28 to 70.17 per cent. zinc, the elongations could not be determined, most of the pieces being tested in their original rectangular sections. Their extensions were, without doubt, much less than 0.79 per cent., as the test-pieces appeared nearly as brittle as glass. From 77.43 to 96.43 per cent. zinc the elongations very slowly increase, that of the former composition being only 0.12 per cent., and that of the latter 0.88 per cent.

The form of the curve and one test showing an exceptionally high ductility of 607 degrees angle of torsion, or an extension of 2.5011 (No. 3, 89.80 copper, 10.06 zinc), indicate that the maximum ductility of the alloys of copper and zinc is found among alloys containing small quantities of zinc. From 16.98 to 61.05 zinc there is a very regular decrease of ductility, the latter having an extension of 0.00002, or only about $\frac{1}{125,000}$th of the maximum. From 61.05 to 88.88 zinc there is a uniform want of ductility, the figures of extension varying from 0.00002 to 0.00011. From 88.88 zinc to pure zinc, the ductility increases.

245. **A Summary** of many of the results of the tests which have been described will be found included in the table already given at the end of Chapter V., in which the brasses are described.

When brasses are desired to work freely, as with automatic machinery, one or two per cent. of lead should be added; giving freedom of working and ease in cutting such as cannot be attained otherwise. Such compositions are called "leaded brass."

Bismuth in brasses causes hot- and cold-shortness, firecracks, and general deterioration.

CHAPTER XI.

STRENGTH OF KALCHOIDS AND OTHER COPPER-TIN-ZINC ALLOYS.

246. **The Kalchoids.**—The bronzes and brasses were not distinguished by early Greek and Latin writers, who applied the same names to both (Greek, *Kalchos;* Latin, *Aes.*). It has also been common to add to the copper-tin, or bronze, alloys small proportions of zinc, and lately, to the copper-zinc alloys, or brasses, small quantities of tin, thus forming an intermediate collection of indefinite number and proportions, to which may be here applied the indefinite terms of the ancients, and which may be called the kalchoids, or kalchoid alloys. These and solders and other copper-tin-zinc alloys naturally fall into one group.

The effect of substituting a small quantity of zinc for tin in making the bronzes is not perceivable except as making them a little less subject to "cold shuts," or blow-holes and similar defects, making them a little softer and a trifle weaker and giving them slightly better working qualities when turned in the lathe or otherwise shaped with cutting tools. The effect of substituting a small proportion of tin for zinc in the brasses, however, is very marked, causing increased hardness, strength, rigidity and elasticity, and, if the proportions of copper and zinc are about equal, making the alloy too hard and brittle to work.

In general, the effects of the two metals, zinc and tin, upon copper are similar, but that of adding tin is much more observable than that of introducing zinc. It was found in collating the results of investigations made by the Author for the U. S. Board and in other researches, that the effect of one part tin is nearly equivalent to two parts of zinc.

These facts are well illustrated in the account of that work to be presented in the present chapter. They are well shown also, in experiments on "sterro-metal."

247. **Sterro-metal,** tested at Woolwich, exhibited a tenacity somewhat variable with composition, but always considerable, as seen below.* Its stiffness and resistance to abrasion were also found to be very great. The tenacity may be taken at an average of 60,000 pounds per square inch (4,218 kilogs. per sq. cm.), its elastic limit at one-half that amount, and its elongation at 0.07. The test pieces used were three diameters long.

TABLE LXXVI.

TENACITY OF STERRO-METAL.

Breaking weight, lbs. per square inch.	Kilogs. per square cm.	Ultimate elongation at breaking point in inches.	Treatment.	Mixture.
60,020	4,213	.1	as received.	Austrian.
46,060	3,386	.05	cast in sand.	Copper, 60 ; zinc, 39 ; iron, 3 ; tin, 1.5.
43,120	3,032	.015		Copper, 60 ; zinc, 44 ; iron, 4 ; tin, 2.
54,220	3,819	.016	cast in iron.	
52,080	3,662	.02	cast in iron and annealed.	
62,720	4,410	.045	forged red hot.	
70,806	4,978	....	cast in iron and forged red hot.	....
72,845	5,121	....		....
76,160	5,355	....	....	Copper, 60 ; zinc, 37 ; iron, 2 ; tin, 1.
84,920	5,985	....	....	Copper, 60 ; zinc, 35 ; iron, 3 ; tin, 2.
60,480	4,252	....	after simple fusion.	Copper, 55.04 ; spelter, 42.36 ; iron, 1.77 ; tin .83.
76,160	5,355	....	forged red hot.	
84,920	5,985	....	drawn cold.	
62,720	4,410	....	after simple fusion.	Copper, 57.63; spelter, 40.22 ; iron, 1.86 ; tin, 0.15.
73,680	5,040	....	forged red hot.	
82,880	5,827	....	drawn cold and reduced from 100 to 77 transverse sectional area.	

* "Strength of Materials ;" Anderson, Lond., 1872.

This greater tenacity, as compared with brass and Muntz metal, is probably partly due to the presence of iron, but largely also to the one or two per cent. tin. As will be seen later, the Author has obtained higher figures by the use of tin alone.

248. **The Copper-Tin Zinc Alloys** were made the subject of a special and systematic investigation, at the request of the Committee on Alloys of the U. S. Board of 1875, with a view to the determination, not simply of the strength and other properties of specific combinations, but to ascertain the law governing the variation of such useful qualities with variation of composition, in such manner that, by the study of a limited number of these alloys, the properties of all possible combinations of the three metals might be fully determined. Before entering upon this investigation it, therefore, became necessary to devise a plan and to invent a method of research, which should enable the Author so to choose the set of alloys to be studied as to make their number a minimum, while so fixing their proportions as to distribute them with a satisfactory degree of uniformity over the whole field to be explored, thus making the research complete and productive of a maximum result at minimum cost of time, labor, and money.

249. **The Plan of Investigation,** if it could be made thus effective, should evidently lead not only to the determination of the strength and elasticity, ductility and resilience, and other important properties of all possible alloys of copper with zinc, copper with tin, and tin with zinc, and of all copper-tin-zinc alloys, but should also reveal the composition of the alloy of maximum strength or other quality, or combination of qualities, that could possibly be formed and that man can make, using these elements. Such a plan was devised by the Author. Its principle is as follows: *

In any equilateral triangle, *B*, *C*, *D*, Fig. 22, let fall perpendiculars from the vertices to the opposite sides, as for

* On a New Method of Planning Researches, etc., by R. H. Thurston. Proc. Assoc. for Advancement of Science, vol. xxvi. Trans. Am. Soc. C. E., 1881. Also, for later work, by A. Wright, Proc. Roy. Soc., 1891–4.

example, $\overline{CE}$. From any point within the triangle, A, let fall perpendiculars $\overline{AG}$, $\overline{AH}$, $\overline{AF}$, and draw $\overline{AB}$, $\overline{AC}$, $\overline{AD}$ to the vertices, thus obtaining three triangles, $\overline{ABD}$, $\overline{ABC}$, $\overline{ACD}$; their sum is equal to the area of the whole figure $\overline{BCD}$.

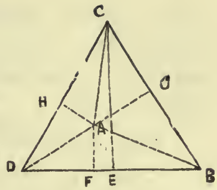


FIG. 22.

Now we have, since the triangle is equilateral, and

$$\frac{\overline{CE} \times \overline{BD}}{2} = \frac{\overline{AF} \times \overline{BD}}{2} + \frac{\overline{AG} \times \overline{BC}}{2} + \frac{\overline{AH} \times \overline{CD}}{2},$$

$$\overline{CE} \times \overline{BD} = (\overline{AF} + \overline{AG} + \overline{AH}) \times BD;$$

and

$$\overline{CE} = \overline{AF} + \overline{AG} + \overline{AH};$$

which follows wherever the point A may be situated; it is true for every point in the whole area $\overline{BCD}$. Assuming the vertical $\overline{CE}$ to be divided into 100 parts; then $\overline{AF} + \overline{AH} + \overline{AG} = 100$ and $\frac{\overline{AF}}{100}$, $\frac{\overline{AH}}{100}$, $\frac{\overline{AG}}{100}$, measures the relation of each of the altitudes of the small triangles to that of the large one.

But we may now conceive the large triangle to represent a triple alloy of which the areas of the small triangles shall each measure the proportion in which one of the constituents enters the compound, and

$$BCD = 100 \text{ per cent.} = (\overline{AF} + \overline{AG} + \overline{AH})\, BD, \text{ or}$$

$CE = 100$ per cent. $= \overline{AF} + \overline{AG} + \overline{AH}$ per cent. and the altitude of each small triangle measures the percentage of some one of the three elements which enter that alloy which is identified by the point. Thus every possible alloy is represented by some one point in the triangle $\overline{BCD}$, and every point represents and identifies a single alloy, and only that. The vertices *B*, *C*, *D*, in the case to be here considered, represent respectively, copper = 100, tin = 100, zinc = 100.*

250. Alloys Chosen for Test.—Thus, having determined a method of studying all possible combinations, the Author next prepared to examine this field of work in the most efficient and complete manner possible, with a view to determining, by the study of a limited number of all possible copper-tin-zinc alloys, the properties of all the numberless, the infinite, combinations that might be made, and with the hope of detecting some law of variation of their valuable qualities with variation of composition, and thus ascertaining which were the most valuable for practical purposes.

With this object in view, the triangle laid down to represent this research, was laid off in concentric triangles, Fig. 23, varying in altitude by an equal amount—10 per cent.—on which were laid out the following series of alloys:

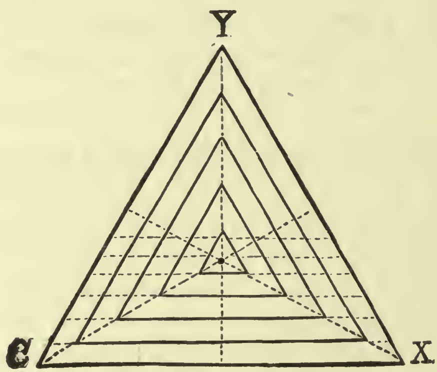


FIG. 23.

* The same general principle may be employed, as stated in the discussion before the Am. Assoc. for Advancement of Science (Nashville meeting, 1877), where four variables are studied. It has been so employed by Professor Howe (Trans. A. I. M. E., Feb. 1898, vol. xxviii, pp. 346, 894: "Use of Tri-axial Diagram and Triangular Pyramid"). Professor J. Willard Gibbs proposed the use of the principle in still another field in 1876 (Trans. Conn. Acad., 1876, p. 108). It is in constant use in the laboratories of Cornell University.

TABLE LXXVII.

SCHEDULE OF COPPER-TIN-ZINC ALLOYS TESTED.

COPPER.	ZINC.	TIN.	COPPER.	ZINC.	TIN.
10	10	80	30	40	30
10	20	70	30	50	20
10	30	60	30	60	10
10	40	50	40	10	50
10	50	40	40	20	40
10	60	30	40	30	30
10	70	20	40	40	20
10	80	10	40	50	10
20	10	70	50	10	40
20	20	60	50	20	30
20	30	50	50	30	20
20	40	40	50	40	10
20	50	30	60	10	30
20	60	20	60	20	20
20	70	10	60	30	10
30	10	60	70	10	20
30	20	50	70	20	10
30	30	40	80	10	10

These alloys were first tested in the Autographic Recording Machine, and their strain-diagrams carefully studied. It was found that only a few were of value, and that the alloys represented by that part of the field lying on the tin-zinc side of a line running from copper = 70, tin = 30, zinc = 0, to the point copper = 40, zinc = 60, tin = 0, were too soft or too brittle and weak to be useful. The research was now restricted to the examination of alloys lying nearer the point copper = 100, *i.e.*, the upper vertex of the triangle as seen in the figure, and all such alloys were tested by tension, compression, and torsion, and by transverse stress.

251. **Details of the Work.**—In the study of these copper-tin-zinc alloys, the same general method of experiment was adopted as in the investigations of the brasses and the bronzes already described.*

To ascertain what results would be obtained by casting together brass and bronze of known properties, the first series

* The observer entrusted with this work, under the direction of the Author, was Mr. M. I. Coster, M. E.

of ternary alloys was prepared in proportions based upon results obtained in the earlier researches relating to copper-tin and copper-zinc alloys as the strongest, the weakest, the most and the least resilient alloys respectively; and by various combinations of these, twelve alloys were obtained.

This constitutes the first series. No. 5 (Cu 88.135, Sn 1.865, Zn 10) was made up of the most resilient bronze and brass; its resilience was less than that of either of its components. No. 6 (Cu 45, Sn 23.75, Zn 31.25), composed of the least resilient bronze and brass, was less resilient than the brass, but more so than the bronze. No. 7 (Cu 66.885, Sn 1.865, Zn 31.2), formed of the most resilient bronze and the least resilient brass, was much less resilient than the bronze, but considerably more so than the brass. No. 8 (Cu 66.25, Sn 23.75, Zn 10) was made of the least resilient bronze and the most resilient brass. It was less resilient than either the bronze or the brass. The greatest resistance to torsion of all the bars of the series was exhibited by No. 7, and the mean of its torsional moments exceeded that of all the others. It was of a more homogeneous structure, and may be considered the best alloy of the series. No. 5 was the most ductile and the most resilient. No. 12 (Tobin's alloy, Cu 58.22, Sn 2.30, Zn 39.48) was shown by all the tests to be the strongest alloy. It exceeded good wrought iron in strength, and was sufficiently resilient to resist shocks. Its modulus of elasticity, as calculated from the transverse test, is 11,500,000 (metric, 808,450). From the results obtained, it is evident that it does not necessarily follow that two alloys which are separately good and strong, or poor and weak, will, when cast together, give an alloy which is similarly strong or weak.

A second series was next tested, to afford a general survey of the field containing what were known to be good alloys and to locate approximately the position of the best compositions.

In this set, 36 alloys were made by all possible combinations obtainable by a difference of 10 per cent. in the three metals. As a rule, the bars of this series were not as strong as those of the first series; this may have been due to the fact that the other bars were cast under greater pressure. It was noted that if the amount of tin does not exceed 40 per cent., the alloys are strengthened by an increase of copper up to 20 per cent. If further addition of copper is made the alloys become brittle, and when the copper amounts to 50 per cent., compositions are obtained which are practically worthless. If more copper is added the alloys increase in strength until a maximum is attained for the greatest percentage of copper in their series, *i. e.*, 80 per cent. When the amount of tin exceeds 40 per cent. the alloy becomes weaker as the percentage of copper is increased. Up to 20 per cent. of copper, an increase of tin causes a decrease of strength and an increased ductility. Between 20 per cent. and 40 per cent. of copper, the alloys become stronger for an increase of tin up to 20 per cent. They then become weaker as the tin is further increased. When the amount of copper exceeds 40 per cent. an increase of tin again appears to weaken the alloy; this is only true when the least quantity of tin amounts to 10 per cent., as in this series. The results of tests of this series show that more than five-sixths of the alloys in the field here explored are comparatively worthless.

A third series of 24 alloys was next made for the purpose of locating the best alloys still more precisely, and to determine the properties of those lying within the now greatly restricted field of investigation, which had now been contracted to a small fraction of the total area.

A line was drawn from 45 per cent. copper on the zinc side of the triangle to 72.5 per cent. of copper on the tin side. These points represent the percentages at which the marked change of color and of strength in the brass and bronze alloys takes place. The alloys of this series were all located in that portion of the field containing all the more useful compositions and were made to vary in composition by 5 per cent. The castings of this and succeeding series had smoother surfaces than those preceding. Some volatilization of zinc took place during the pouring of the molten metal in the first three numbers of the series. A great difference was noted in the results obtained from the upper and lower ends of the bars; the upper end giving the best figures. The difference between the strain-diagrams of these two portions of the bar was such that the former in one case had an ordinate of 0.92 inch at the elastic limit and a maximum ordinate of 1.76 inches, while the other end had for its ordinate at the elastic limit 1.38 inches and for a maximum ordinate 1.56 inches. The general laws exhibited by the curves representing the properties of alloys of copper, tin, and zinc, were approximately determined from the tests of this series. For a certain amount of copper (when this exceeds 50 per cent.) an addition of tin increases the brittleness, while zinc increases the ductility of the alloy. If the amount of copper is increased it is necessary also to increase the tin in a certain ratio in order to obtain an alloy of about the same percentage of ductility. It was shown by the tests of this series that if the composition has 80 per cent. of copper, 10 per cent. of tin will make it quite ductile, while 15 per cent. of tin will render it rather brittle. Hence the amount of tin necessary to make a strong alloy, when there is 80 per cent. of copper, lies somewhere between 10 per cent. and 15 per cent., and an alloy composed of Cu 80, Sn 12.5, Zn 7.5 was taken as very nearly representing the best proportions.

Next, a fourth series was made. This series consisted of but five alloys, which were chosen without regard to regularity, but to determine doubtful points previous to the preparation of the final series. No. 1 (Cu 55, Sn 0.5, Zn 44.5) contained but 0.5 per cent. of tin, and is the only instance in the entire investigation where so small an amount of any of the metals was introduced in an alloy. This was done in order to ascertain the effect of so small a percentage when added to an alloy of known properties. This alloy was brass (Muntz metal, nearly), and 0.5 per cent. of tin was substituted for zinc, thus leaving but 44.5 per cent. of zinc. The smallest quantity of zinc in any bar of the series was 2.5 per cent. in No. 5 (Cu 82.5, Sn 15, Zn 2.5). The difference in ductility between the two ends of the bars was more marked in No. 2

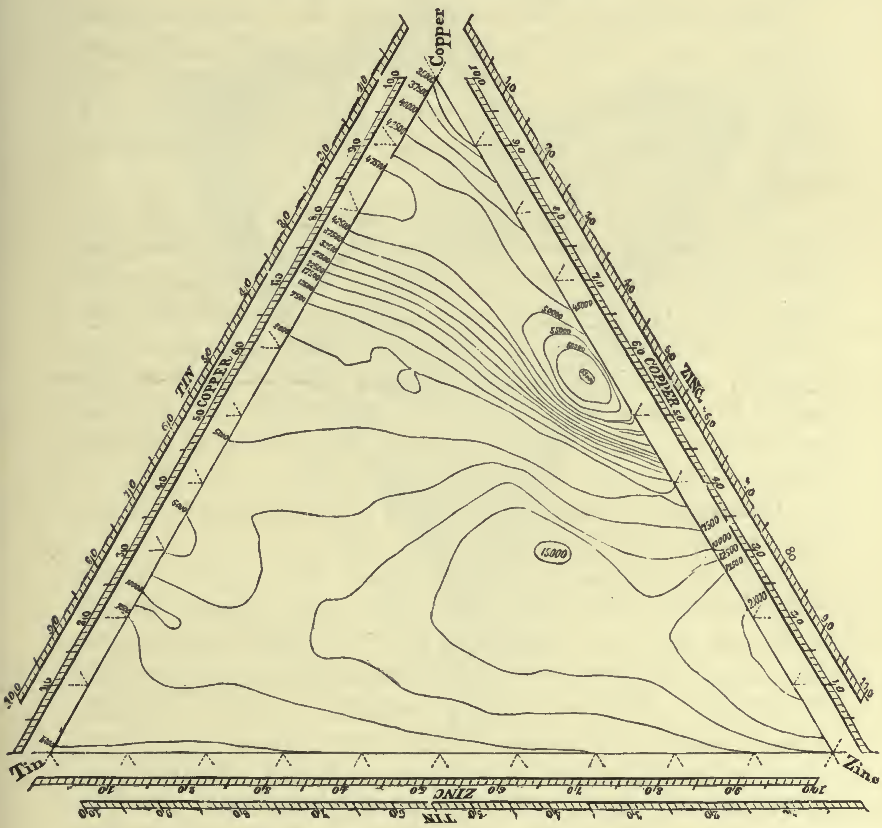
(Cu 67.5, Sn 5, Zn 27.5) than in any other alloys thus far tested. The upper end, No. 2 A, was turned in the autographic machine through an angle of 70.8°, while the lower end, B, broke after it was turned through 7.5°, the latter being only about 10 per cent. of the former. This difference was exhibited, in a more or less marked degree, by all the bars of this series.

Comparing the data thus obtained by test of the several sets of alloys made as above, it became evident that all the most useful alloys are located between the line drawn from 88 per cent. of copper on the bronze side of the triangle to 65 per cent. of copper on the brass side, and from 83 per cent. of copper on the bronze side to 55 per cent. on the brass side. Twelve alloys in this part of the field were next made, varying by 2.5 per cent., omitting those which had already been tested and a few not absolutely necessary to the determination of the law of variation of strength. The results obtained fully confirmed previous conclusions. It was found that, in nearly all cases, the upper portion of the bar was considerably more ductile than the lower and also generally stronger. All the alloys of this series were strong; the strongest, No. 1 (Cu 60, Sn 2.5, Zn 37.5), had a mean maximum torsional moment of 216 foot-pounds (tenacity about 40,000 lbs. or 2,892 kilogs.), and the weakest, No. 7 (Cu 72.5, Sn 10, Zn 17.5), 122 foot-pounds (tenacity about 24,000 lbs., or 1,672 kilogs.). All the alloys located between the lines forming the boundaries of the set of compositions in this series are useful and strong. Commencing with the strong brasses on one side of the triangle, greater strength is obtained when any appreciable amount of tin is added; as the quantity of tin is increased, the alloys continue to be superior in strength to either the brasses or the bronzes; but their strength gradually decreases with the diminution of the amount of zinc, if the alloy contains more than 60 per cent. of copper, until we obtain strong bronzes on the other side of the field. An addition of tin for the same amount of copper, if this addition does not exceed 30 per cent., increases the ductility of the alloy. In alloys containing 40 per cent. of copper a substitution of a moderate quantity of tin for zinc does not seem to affect the ductility. If the alloys contain more than 40 per cent. of copper, an increase of tin causes a decrease of ductility. The most ductile alloy was No. 8 B, 2d series (Cu 10, Sn 80, Zn 10), which had an angle of torsion in the autographic machine of 418.4° ; no other alloy tested contained such a large quantity of tin. From the percentage of extensions of the alloys having a torsional moment of more than 150 foot-pounds, and strength of more than 30,000 pounds per square inch (2,109 kilogs. per sq. cm.), four curves of maximum strength with a percentage of extension have been constructed (Fig. 27). The lowest curve thus plotted has an extension of 0.03 per cent. and connects the points representing the strong brittle alloys. It starts at 43 per cent. of copper on the brass side and cuts the bronze side of the triangle at 77 per cent. of copper. The other curves have an extension of 3, 7.3, and 17 per cent. respectively. They all appear to converge to a point on the right of the brass side and agree nearly with arcs of circles of about 7 inches radius on the scale of the figure. By means of these curves of extension, alloys of different degrees of ductility can be selected. The effect of tin upon alloys of copper and zinc within limits may be compared to that of carbon on wrought-iron. Commencing with brass of about 55 per cent. of copper, which is of itself ductile and strong, we obtain by the addition of a small percentage of tin an alloy of much greater strength, having a higher modulus of elasticity, but not quite as ductile. By further addition of tin, up to about 2.5 per cent., the alloy becomes gradually less ductile, but it increases in strength. But if more tin is added, we obtain compositions which become more brittle as the tin is increased, and at the same time decrease in strength. A slight modification of proportions often causes very great changes in the properties of the alloys, as in No. 1, 4th series, where 0.5 per cent. of tin, added to ordinary brass produced an alloy stronger than wrought iron.

The facts thus brought out are best exhibited by the profile map and the model which are to be presently described.

252. The Method of Exhibiting and Recording Results, which, as devised by the Author for this case, was intended so to present the data secured in the manner described that it could be seen, at a glance, what law, if any, controlled the

FIG. 24.—COPPER-TIN-ZINC ALLOYS.



variation of strength, or of the quality, with change of composition, and that the investigator could readily determine where to seek the alloy possessing a maximum of any quality, desirable or otherwise, should it happen, as would in all probability be the case, that that alloy had not been included among those studied during the investigation. The plan finally adopted was novel but as thoroughly satisfactory as was that of laying out the work. It was the following:

The figures obtained by the test of alloys studied were inserted upon a triangular plan, each in its place as determined, in the manner described in Art. 249, for that composition.

When the figures thus obtained had been entered on the triangular map, lines of equal strength, of equal ductility, or of equal resistance could be drawn, as in topographical work lines of equal altitude are drawn, and the map became thus a useful representation of the valuable qualities of all possible alloys.

Figure 24 represents such a map* of all copper-tin-zinc alloys. The scale of altitudes is obtained by considering the relation of tension to torsion resistance as 25,000 pounds per square inch (1,758 kilogrammes per square centimetre) for each 100 foot-pounds (13.82 kilogrammetres) of torsional moment for the standard test-specimen, which specimen was turned to a standard gauge, and made ⅝ inch (1.84 cm.) diameter and 1 inch (2.54 cm.) long in the cylindrical part exposed to strain.

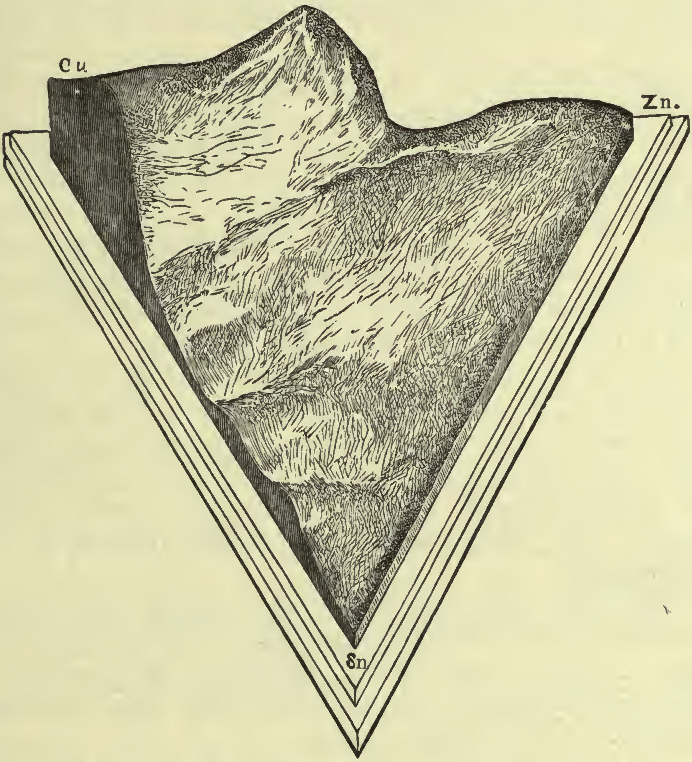
These facts were also exhibited by another method devised by the Author; thus:

Upon a triangular metal base, laid off as above, erect a light metallic staff by drilling a hole for its support at each point laid down as representative of an alloy tested; make the altitude of each of these wires proportional to the strength of that alloy. There is thus produced a forest of wires, the tops of which are at elevations above the base-plane proportional to the strengths of the alloys studied. Similar constructions may be made to represent the elasticity, the ductility, or any other property of all these alloys. Next fill in between these verticals with clay, or better, with plaster, and carefully mould it until the tops of all the wires are just visible, shining points in the now smooth surface of the model.

* Reports of U. S. Board testing Iron, Steel, etc. Washington, 1878–1881. The Strongest of the Bronzes; R. H. Thurston. Trans. Am. Soc. C. E. 1881, no. ccxlv.

The surface thus formed will have a topography characteristic of the alloys examined, and its undulations will represent the characteristic variations of quality with changing proportions of the three constituents. This was made for the Author,

FIG. 25.—MODEL OF COPPER-TIN-ZINC ALLOYS.



and was cast in an alloy of maximum tenacity, the plaster cast made as above being used as a pattern.

Figure 25 is a representation of this model made from a photograph.

253. **General Deductions.**—The remarkable variations of quality here so strikingly shown attracted attention, and a further investigation was made.

These alloys were purposely made without other precautions than those observed by every founder, and without using deoxidizing fluxes.

The data obtained were consequently quite variable, and the result of this work indicated that the same alloy, especially where the proportion of copper is great, may give very different figures accordingly as it is more or less affected by the many conditions that influence the value of all brass-foundry products.

Some variations in the model are probably due to such accidental circumstances. But, allowing for minor variations, it is evident that the alloys of maximum strength are grouped, as shown in Figures 24 and 25, about a point not far from copper = 55, zinc = 43, tin = 2. This point is encircled in the map, Figure 24, by the line marked 65,000 pounds per square inch (4,570 kilogs. per sq. cm.) tenacity, and represented on the model, Figure 25, by the peak of the mountain seen at the farthest side—the copper-zinc side.

This is the strongest of all bronzes, and an alloy of this composition, if exactly proportioned, well melted, perfectly fluxed, and so poured as to produce sound and pure metallic alloy, with such prompt cooling as shall prevent liquation, is the strongest bronze that the engineer can make of these metals. The "naval bronzes" now usually approximate this composition.

The Author finally made this alloy, and of it constructed the model represented in the last figure. It is a close-grained alloy of rich color, fine surface, and takes a good polish. It oxidizes with difficulty, and the surface then takes on a pleasant shade of statuary bronze green.

The *exact* composition of this, which the Author has called the "maximum alloy," was not considered as fully determined by this preliminary investigation. The metals used in making it were commercial copper, tin, and zinc, and the methods of mixing, melting, and casting were purposely those usual in the ordinary brass foundry, and necessarily subject to some uncertainty of result.

The precise location of this "strongest of the bronzes" was intended to be made in an independent and later research, in which chemically pure metals, more carefully handled, and especially well fluxed with phosphorus or other effective flux, should be used. This research was carried out several years later, under the eye of the Author, and an account of it is given later.

Testing the alloy above referred to, it was found to have considerable hardness and but moderate ductility, though tough and ductile enough for most purposes; it would forge if handled skilfully and carefully, and not too long or too highly heated, had immense strength, and seemed unusually well adapted for general use as a working quality of bronze. In composition it is a brass, with a small dose of tin.

The alloy made as representing the best for purposes demanding toughness, as well as strength, contains less tin than the above composition (Cu, 55; Sn, 0.5; Zn, 44.5).

It had a tenacity of 68,900 pounds per square inch (4,841 kilogs. per sq. cm.) of original section, and 92,136 pounds (6,477 kilogs.) on fractured area, and elongated 47 to 51 per cent. with a reduction to from 0.69 to 0.73 of its original diameter.

No exaltation of the normal elastic limits was observable during tests made for the purpose of measuring it if noted. This alloy was very homogeneous, two tests by tension giving exactly the same figure, 68,900. The fractured surface was in color pinkish yellow, and was dotted with minute crystals of alloy produced by cooling too slowly. The shavings produced by the turning tool were curled closely, like those of good iron, and were tough and strong.

254. **The Strain-Diagrams** from the autographic machine (No. 1,001) are shown in *fac simile* in the accompanying engraving. The tenacity, as estimated from the resistance to torsion, is nearly equal to that determined by direct experiment, and four samples tested give strain-diagrams that are all nearly precisely alike. They exhibit an ill-defined elastic limit, e, at about $\frac{2}{5}$ their ultimate resistance, and about the same as a piece of excellent gun-bronze (Cu, 90; Sn, 10 per cent.), 1,252 A, the strain-diagram of which lies beside them in dotted line. The elastic resilience, which is measured by the area of the curve up to e, is superior to that of the gun-bronze, and the elastic range is seen to be greater, on

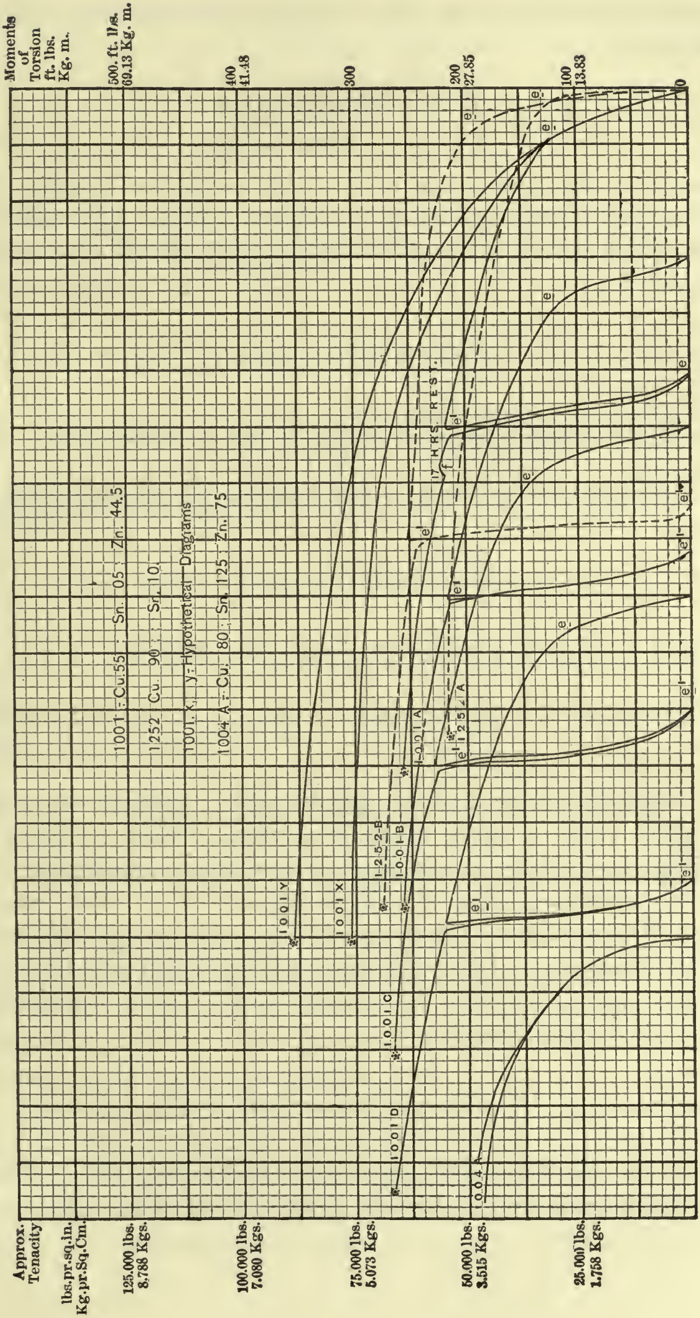
inspection of the "elasticity lines," *e' e'*. In ductility they excel 1,252 *A*, somewhat, as is seen by comparing 1,001 *A* with 1,252 *A*. Their toughness is shown by the great area and the altitude of the curve; their excellence of quality is also shown by its smoothness of outline. The homogeneousness of structure is exhibited by the similarity of the diagrams and by the smoothness of the bend at *e*, which marks the elastic limit.

At *f* is a depression of the normal line of elastic limits produced by 17 hours intermission of distortion under the load there carried. This slight depression marks this alloy as one of the "tin class."

Diagram 1,252 *B* is given by a fine gun-bronze; 1,001 *x* is an hypothetical diagram, such as would be produced were the alloy here described so carefully fluxed and cast as to exceed in strength the unfluxed alloys actually tested, 1,001 *A*, *B*, *C*, *D*, in as great a proportion as 1,252 *B* excels 1,252 *A*. The diagram 1,001 *y* would be produced were it possible to so far improve this alloy as to cause it to excel 1,252 *A* as greatly as No. 1,001 actually did excel the gun-bronze made under similar conditions in this preliminary rough work. No. 1,004 *A* is copied to exhibit the superiority of the alloy 1,001 to one but little removed from it, and which is considered by some brass founders an excellent composition.

255. **The Tenacities of the Strong Alloys** of copper, tin, and zinc, as obtained by the investigation just described, are, as has been seen, quite variable, and the result of the whole has been fully confirmatory of Major Wade's conclusion relative to useful alloys of copper with softer metals: that they are subject to great variation of quality, as ordinarily made, and that it is impossible to predict with certainty the soundness, the uniformity, and homogeneousness, or the strength of any casting in bronze or brass. A study of the figures here obtained, however, and of the map or model exhibiting them, shows that, with good castings of any of the more valuable compositions, certain methods of variation and a general law may be formulated. Thus, for true bronzes containing usual amounts of tin, the tenacity, as such castings are commonly

FIG. 26.—STRAIN-DIAGRAMS OF BRONZES.



made in the course of every-day business in the foundry, should be about—

$$T_c = 30,000 + 1,000\,t;$$

where t is the percentage of tin, and not above 15 per cent. Thus gun-bronze can be given about 30,000 + (1,000 × 10) = 40,000 pounds per square inch, if well made. In metric measures

$$T_c^1 = 2,109 + 70.3\,t,$$

giving for good gun-metal 2,109 × 703 = 2,812 kilogs. per sq. cm.

For brass (copper and zinc) the tenacity may be taken as

$$T_z = 30,000 + 500\,z,$$

where the zinc is not above 50 per cent.; and

$$T_z^1 = 2,109 + 35.15\,z.$$

Thus copper 70, zinc 30, should have a strength of 30,000 + (500 × 30) = 45,000 pounds per square inch, or 2,109 + (35.15 × 30) = 3,165 kilogrammes per square centimetre.

Referring once more to Figures 24 and 25, it is seen that a line of maximum elevation crosses the field marking the crest of the mountain in Figure 25, of which the "maximum bronze" is the peak. This line of valuable alloys may be practically covered by the formula:

$$M = z + 3\,t = \text{Constant} = 55,$$

in which z is the percentage of zinc, and t that of tin. Thus a maximum is found at about $t = 0$, $z = 55$, while the other end of the line is $z = 0$, $t = 18$.

Along this line the strength of any alloy should be at least

$$T_m = 40,000 + 500\,z.$$

$$T_m^1 = 2,812 + 35.15\,z.$$

Thus the alloy $z = 1$, $t = 18$ will also contain copper = $100 - 19 = 81$, and this alloy Cu, 81; Zn, 1; Sn, 18, should have a tenacity of at least

$$T_m = 40,000 + (500 \times 1) = 40,500 \text{ lbs. per sq. in.}$$

$$T^1_m = 2,812 + (35.15 \times 1) = 2,847 \text{ kilogs. per sq. cm.}$$

The alloy Cu, 60; Zn, 5; Sn, 16, should have at least the strength

$$T_m = 40,000 + (500 \times 5) = 42,500 \text{ lbs. per sq. in.}$$

$$T^1_m = 2,812 + (35.15 \times 5) = 2,988 \text{ kilogs. per sq. cm.}$$

while the alloy Zn, 50; Sn, 2; Cu, 48, should give, as a minimum per specification:

$$T_m = 40,000 + (500 \times 50) = 65,000 \text{ lbs. per sq. in.}$$

$$T^1_m = 2,812 + (35.15 \times 50) = 4,570 \text{ kilogs. per sq. cm.}$$

These are rough working formulas that, while often departed from in fact, and while purely empirical, may prove of some value in framing specifications. The formula for the value of T_m fails with alloys containing less than 1 *per cent. tin*, as the strength then rapidly falls to $t = 0$.

The table which follows will present, in convenient form, probably fair minimum values to be expected when good foundry work can be relied upon, and may ordinarily be used in specifications with the expectation that a good brass-founder will be able to guarantee them.

TABLE LXXVIII.

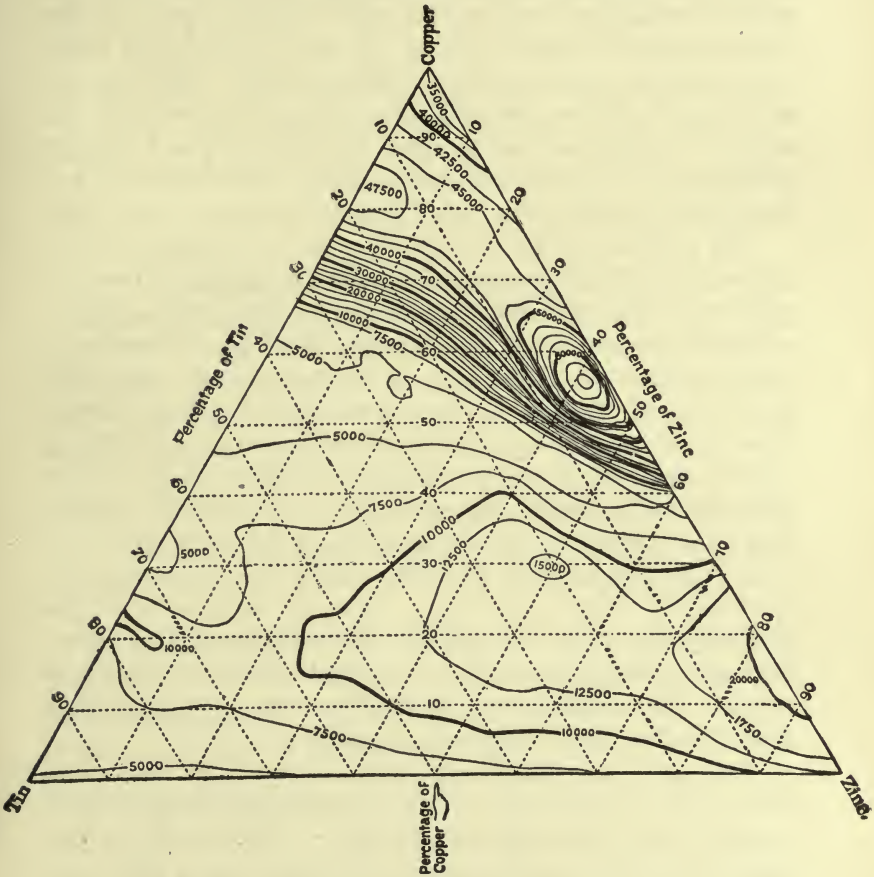
MINIMUM TENACITY OF ALLOYS.

ALLOY.			TENACITY.—Probable Minimum.	
Cu.	Zn.	Sn.	Lbs. per sq. in.	Kgs. per sq. cm.
100	0	0	30,000	2,109
95	5	0	32,500	2,285
90	10	0	35,000	2,460
85	15	0	37,500	2,636
90	0	10	40,000	2,812
95	0	5	35,000	2,460
97½	0	2½	32,500	2,285
90	5	5	37,500	2,636
85	10	5	40,000	2,812
75	20	5	45,000	3,163
68	30	2	47,000	3,304
64	35	1	48,500	3,410
60	40	0	50,000	3,515

256. **Ductility.**—The ductility of these alloys is a subject of as much interest to the engineer as their strength; and in this quality the ternary alloys are as variable as in every other. Referring again to the map, Figure 27, it is seen that a closely grouped set of slightly curved and slowly converging lines cross it from tin = 25, to zinc = 55, the mean line having an equation nearly $2.2t + z = 55$. Along this line the alloys have immense tenacity, as exhibited by the fact that some of them, if not nearly all, are too hard to be cut by steel tools, and in shaping them only grinding tools—either the emery wheel or the grindstone—could be used, and even then with most unsatisfactory results. Yet such was the brittleness of these metals that no reliable test of their strength could be obtained. The strain-diagrams obtained were straight, and nearly vertical lines, terminating suddenly, when the piece snapped, without indication of approach to an elastic limit. They were perfectly elastic up to the point of fracture, but were so destitute of resilience that no use can probably be made of them by the engineer. Their brittleness was such that they would often break in the mould by contraction in

cooling, although cast in a straight bar. In some cases they crack by the heat of the hand, and were broken at one end by the jar transmitted from a light blow struck at the other end.* The border line of this valueless territory is shown

FIG. 27.—TENACITY OF COPPER-TIN-ZINC ALLOYS.



on the map by a slightly curved dotted line to which a line having the equation $2.5t + z = 55$ is nearly tangent. The alloys lying along this line have nearly equal ductility, extending, according to measurements obtained by the autographic machine, about .03 of one per cent.

* Report to U. S. Board. Figure from the R.R. Gazette.

Above this line is another having nearly the equation $4t + z = 50$, which last line is that of equal ductility for alloys exhibiting extensions of 3 per cent. Still nearer the "pure copper corner" is a line fairly representing alloys containing about $3\frac{3}{4}t + z = 48$, and along which the extensions were 7.3 per cent., and another such line extending from standard gun-metal compositions on the one side to Muntz metal on the other—Cu 90, Sn 10, to Cu 55, Zn 45,—of which the equation is nearly $4.5t + z = 45$, represents alloys averaging an extension of 17 per cent. These lines are best seen on the sheet of extensions, Fig. 28. All alloys lying above the line taken here as a boundary line give figures for tenacity that exceed 30,000 pounds per square inch (2,109 kilogs. per sq. cm.).

The addition of tin and of zinc to cast copper thus increases tenacity at least up to a limit marked by the line $3t + z = 55$; but the influence of tin is nearly twice as great as that of zinc, and the limit of useful effect is not reached in the latter case until the amount added becomes very much greater than with the former class—the copper-tin alloys. Brasses can be obtained which are stronger than any bronzes, and the ductility of the working compositions of the former class generally greatly exceeds that of the latter. Ternary alloys may be made containing about $4t + z = 50$, which exceed in strength any of the binary alloys, and compositions approaching copper, 55; tin, 2; zinc, 43; may be made, of extraordinary value for purposes demanding great strength, combined with the peculiar advantages offered by brass or bronze. The addition of one-half per cent. tin to Muntz metal confers vastly increased strength.

The range of useful introduction of tin is thus very much more restricted than that of zinc; alloys containing 12 to 15 per cent. tin are so hard and brittle as to but rarely find application in the arts, while brass containing 40 per cent. zinc, is the toughest and most generally useful of all the copper-zinc "mixtures." The moduli of elasticity of these alloys are remarkably uniform, more than one-half of all those here described ranging closely up to fourteen millions, or one-half that of well-made steel-wire. The moduli gradually and slowly increase from the beginning of the test to the elastic limit.

The Fracture of these Alloys is always illustrative of their special characteristics. Those broken by torsion in the autographic testing machine were, if brittle, all more or less conoidal at the break; ductile alloys yield by shearing in a plane at right angles to the axis of the test piece; the former resemble cast iron and the latter have the fracture of wrought iron. Every shade of gradation in this respect is exhibited by an observable modification of the surface of fracture varying from that characteristic of extreme rigidity and brittleness, through an interesting variety of intermediate and compound forms to that seen in fracture of the most ductile metals.

257. **Possibilities of Improvement.**—The tenacities and ductilities given are within the best attainable figures where they relate to the most valuable working bronzes and brasses. These figures represent the result of ordinary founders' work; and metals rich in copper, made with no greater precaution against oxidation and liquation than is usual in brass foundries, may be vastly improved by special treatment suggested, by using pure ingot metals, fluxing carefully, as with phosphorus or manganese, casting in chills, rapid cooling, and finally rolling, or otherwise compressing, either hot or cold.

Unannealed copper wire is reported by Baudrimont* as having a tenacity of about 45,000 pounds per square inch (3,163 kilogs. per sq. cm.), and Kirkaldy reports 28.2 tons per square inch (63,168 pounds per square inch, 4,440 kilogs. per square cm.), the wires having diameters of 0.0177 and 0.064 inches (0.044 and 0.165 cm.) respectively.

A way should be found to secure equal purity, homogeneousness, and density in cast copper, and such metal should then possess tenacity and toughness equal to that of rolled metal. Gun-bronze, which ordinarily has a tenacity of about 35,000 pounds per square inch (2,460 kilogs. per sq. cm.) has been made at the Washington Navy Yard, by skil-

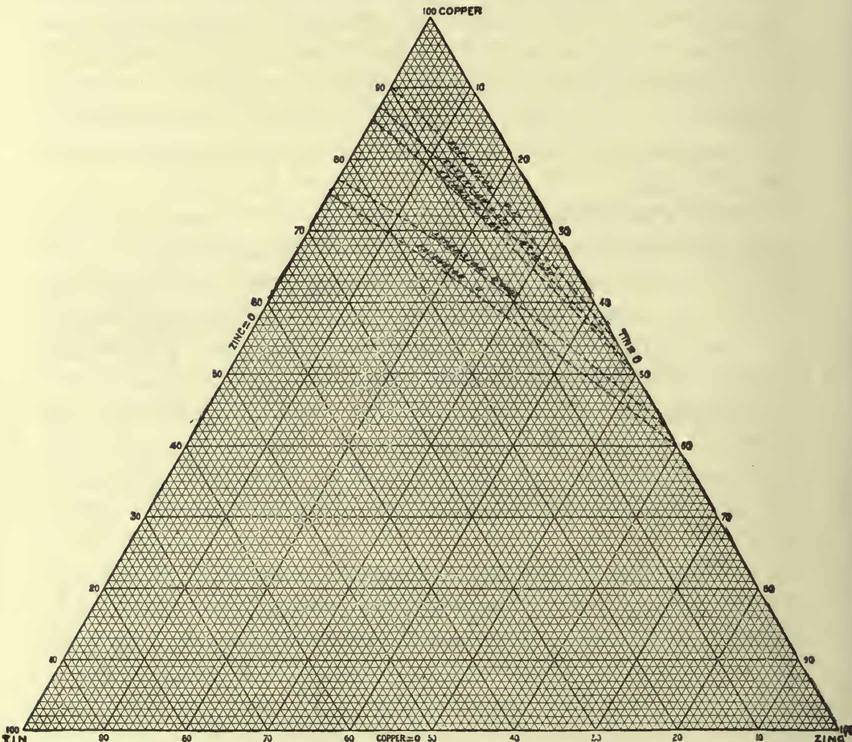
* Annales de Chimie, 1850.

ful mixture, melting and pouring, and by the Author, also, to attain a tenacity of above 60,000 pounds (4,218 kilogs.).

The effect of thorough fluxing with deoxidizing substances is so important that no founder can safely neglect it.

FIG 28.

DUCTILITY OF COPPER-TIN-ZINC ALLOYS.



Bronzes fluxed with phosphorus, arsenic, and manganese, have been given fifty per cent. higher tenacity than the ordinary unfluxed alloy, and the addition of a little iron, as in the so-called "sterro-metal" of the Baron de Rosthorn, and in Parson's "Manganese Bronze," has still further strengthened the copper-tin-zinc alloys.

Dr. Anderson made experiments at Woolwich, showing an increase of strength of sterro-metal, by forging, to the extent of 25 per cent., and by drawing cold of 40 per cent. Brass, containing copper, 62 to 70, zinc, 38 to 30, attains a strength in the wire mill of 90,000 pounds per square inch, and sometimes of 100,000 (6,327 to 7,030 kilogs. per sq. cm.), and these alloys should be made equally tenacious in the casting. The Author has no doubt that the methods indicated as those best adapted to secure dense, strong and tough metal will yet be found capable of yielding alloys of more than double the strength representative of what is now ordinary brass-founders' work. It should be possible to secure copper-tin-zinc alloys having tenacities represented by:

$$T_{mm} = 60{,}000 + 1{,}000t + 500\,z,$$
$$T^1{}_{mm} = 4{,}218 + 70.3t + 35.15z,$$

throughout that area on the map representing the most useful alloys, from copper, 100, to $4t + z = 50$.

Manufacturers of special bronzes are approaching this degree of excellence.

In the working of copper in the foundry the melter meets with difficulty from the formation of either the oxide or carbide. Could he secure immunity from combination with one or the other of these elements, he would find innumerable uses for cast copper.

The general character and the method of variation of strength and ductility of the alloys of copper, tin, and zinc are so well exhibited by the illustrations presented, that no difficulty will be met with by the engineer in the endeavor to select the alloy best adapted to any specific purpose where such an adaptation is determined by physical qualities alone. Caution must be used in selecting alloys where great strength is demanded, since a slight change of composition by the addition of tin or zinc may make a serious change in the direction of lessened ductility and toughness. The engineer will rarely use those lying on the tin and zinc side of the line of alloys having 0.07 (7 per cent.) ductility, as on Figs. 27 and 28. Extraordinary care must be taken in making the strongest alloys.

Alloys to be hammered or rolled will be found more difficult to work as the percentage of tin is increased, and the minutest addition of tin to the brasses usually rolled is found to sensibly decrease their manageability.

258. **The "Maximum Bronzes"** form a group demanding special consideration as including a collection of generally unfamiliar but exceptionally valuable alloys.

The work planned by the Author in the investigation of this part of the subject was left incomplete by the U. S. Board, but was continued, as opportunity offered, at intervals up to the year 1884.* The position and characteristics of the strongest possible alloys of the three metals constituting the "Kalchoids" having been determined with a fair degree of accuracy, as already described, the next step was to ascertain what modifications might be produced in them by careful fluxing and the use of still more carefully prepared alloys. This later study was made in the years 1882–3, in the same manner as the earlier investigations for the U. S. Government, at the suggestion and under the supervision of the Author, by Mr. W. E. H. Jobbins, whose report is here abridged.†

The area chosen as the field of this investigation was a small triangular portion surrounding the peak of the mountain, Fig. 25, marked 65,000 on Fig. 24, as this area embraces all that portion of the field in which the most valuable alloys had been proven to be located. The data obtained gave exceedingly high figures, the lowest average value of tenacity being above 50,000 pounds per square inch (3,515 kilogs. per sq. cm.). As this research extended over a very limited area, it was possible to conduct the investigation with much greater exactness than before, and thus settle the composition of the "strongest of the bronzes."

The metals varied with differences of but one per cent.; 23 combinations were chosen; 2 test-pieces were made of each

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* The U. S. Board was strangled by refusal of appropriations, leaving the work in hand unfinished. Some of the work necessary to the presentation of the reports actually made was, however, concluded by the Author, at some expense, in the Mechanical Laboratory of the Stevens Institute of Technology.

† "Investigation Locating the Strongest of the Bronzes," J. F. I., 1884.

composition, making 46 test-pieces. Usually, the data obtained from two specimens of the same composition agreed so closely that the average value was safely taken; but, when there was a marked difference, the data agreeing more closely with the results anticipated from analogy were adopted, and the other value rejected as being probably erroneous. The copper employed was from Lake Superior, the zinc from Bergen Port.

In the use of tin, phosphorus was added to give soundness in these copper-tin and copper-tin-zinc alloys, which are so liable to be made seriously defective by the absorption of oxygen and the formation of oxide. It has been found possible to produce, on a commercial scale, an alloy of phosphorus and tin, which, while containing a maximum percentage, does not lose phosphorus when remelted. The best proportions for practical purposes are said to be tin 95 per cent. and phosphorus 5 per cent.

After careful study, the following limits of the field were decided upon: Copper, maximum 60, minimum 50; Zn, 48 and 38; Sn, 5 and 0. These limits include the best alloys for purposes demanding toughness as well as strength.

The compositions are given in the following table:

TABLE LXXIX.

BEST COPPER-TIN-ZINC ALLOYS, OR KALCHOIDS.

NO.	CU.	ZN.	SN.	NO.	CU.	ZN.	SN.	NO.	CU.	ZN.	SN.
1	55	43	2	9	53	43	4	17	58	40	2
2	54	44	2	10	55	41	4	18	54	45	1
3	54	43	3	11	57	41	2	19	53	44	3
4	55	42	3	12	57	43	0	20	54	42	4
5	56	42	2	13	55	45	0	21	56	41	3
6	56	43	1	14	52	46	2	22	57	42	1
7	55	44	1	15	52	43	5	23	58	41	1
8	53	45	2	16	55	40	5				

The castings were made much as in all the earlier investigations, the same precaution being taken to prevent volatilization of zinc, and care was taken to secure rapid cooling to prevent liquation. All the compositions thus made were strong and usually tough; all could be turned and worked safely, and all were evidently of commercial value for the purposes of the engineer. All test-pieces were sound, and even microscopic examination revealed no defects in structure. The investigation was made by the use of the Author's autographic machine as permitting most rapid work and most exact determinations of quality and behavior, especially as to the latter near the elastic limit. The samples were all reduced to the standard form and size.

259. **Results of Tests.**—The formula used is $M = wh + f$; where w = moment necessary to deflect the pencil one inch; h = height of the curve above the base line at θ_r, f = friction in foot-pounds, and M is the total torsional moment.

In this case, $w = 96.93$ foot-pounds, and $f = 4.75$, h being measured on the strain-diagram of each test-piece. To obtain the required values of T the formula $T = [300 - \frac{1}{3}\theta_r]\,M$,* in which M is known, and θ_r is measured directly from the autographic record; T is the calculated tenacity. The values of M, T, θ_e and θ_r, the total moment, the approximate tenacity, and the angles of torsion at the elastic limit and at rupture, have been included in the following table:

TABLE LXXX.

STRENGTH OF BEST COPPER-TIN-ZINC ALLOYS OR KALCHOIDS.

ORIGINAL MARK.		STRESS IN TORSION. FOOT-POUNDS. M.		APPROXIMATE STRESS IN TENSION. FOOT-POUNDS. T.		ANGLES.	
		Ultimate.	Average.	Ultimate.	Average.	θ_e	θ_r
I X I	A	270.208	261.065	77,309	74,805	1.5°	43°
	B	251.922		72,301		1	40
O B	A	178.321	193.369	53,946	56,653	1.1	5.05
	B	208.400		59,810		0.7	40
Z 3	A	251.922	235.929	75,576	70,778	1	13.77
	B	219 935		65,980		1	10
J 4	A	243.392	250.851	73,017	73,965	2	19.8
	B	258.319		74,912		2	30.3

* This relation between torsional and tensional resistances was obtained by experiment on the machine used in this investigation. Trans. Am. Soc. C. E., no. clxiii., vol. vii., 1878.

TABLE LXXX.—*Continued.*

ORIGINAL MARK.		STRESS IN TORSION. FOOT-POUNDS. *M.*		APPROXIMATE STRESS IN TENSION. LBS. PER SQ. IN. *T.*		ANGLES.	
		Ultimate.	Average.	Ultimate.	Average.	θ_e	θ_r
F 5	A	268.881	266.212	75,824	75,467	4.6°	55°
	B	263.543		75,109		2	46
G 6	A	227.689	224.151	64,208	63,700	2.05	53.3
	B	220.612		63,193		2	42.1
K 7	A	286.847	268.851	80,910	75,826	2	54
	B	250.855		70,741		2	53
R 8	A	194.634	189.488	58,390	56,844	2	9.1
	B	184.331		55,299		2.69	5.72
S 9	A	222.853	226.725	66,853	68,017	1.5	5.78
	B	230.597		69,179		1.79	4.5
L 10	A	249.014	250.948	74,704	75,284	2.1	4.6
	B	252.881		75,864		2.8	8.8
Z 11	A	260.645	249.014	74,269	69,116	2.4	39.8
	B	237.382		63,964		1.9	35
D B	A	227.689	234.474	61,020	61,390	2.3	95.2
	B	241.259		61,762		1.6	131.4
M 13	A	227.689	217.996	64,208	61,058	2	52.4
	B	208.303		57,908		1.1	65
U 14	A	163.715	170.450	49,113	51,139	2.3	4.9
	B	177.185		53,155		2	7.2
V 15	A	189.886	208.788	56,965	62,636	2.6	4
	B	227.689		68,306		2	5
N 16	A	225.750	239.974	67,725	71,842	1.6	3.8
	B	253.198		75,959		1.6	6.8
A 17	A	227.689	238.771	63,200	68,344	1.4	54
	B	250.952		73,488		1.8	43.2
P 18	A	254.829	259.737	72,871	72,186	1.6	43.4
	B	260.645		71,501		1.8	54
T 19	A	231.566	214.119	69,459	64,230	2.2	8
	B	196.671		59,001		1.4	4.8
Q B O	A	229.628	244.168	68,888	73,250	1.6	6.4
	B	258.707		77,612		1.8	7.2
H B I	A	283.908	266.768	81,381	75,135	2.9	38
	B	229 628		68,888		2.4	8
E B B	A	305.233	263.508	85,770	73,378	2	56
	B	221.773		60,986		2.5	76
B 33	A	225.750	200.499	63,084	54,061	1 6	63
	B	175.247		45,038		1.2	128

The neck subjected to distortion is in all cases, one inch (2.54 cm.) long between shoulders and 5/8 inch (1.5875 cm.) in diameter.

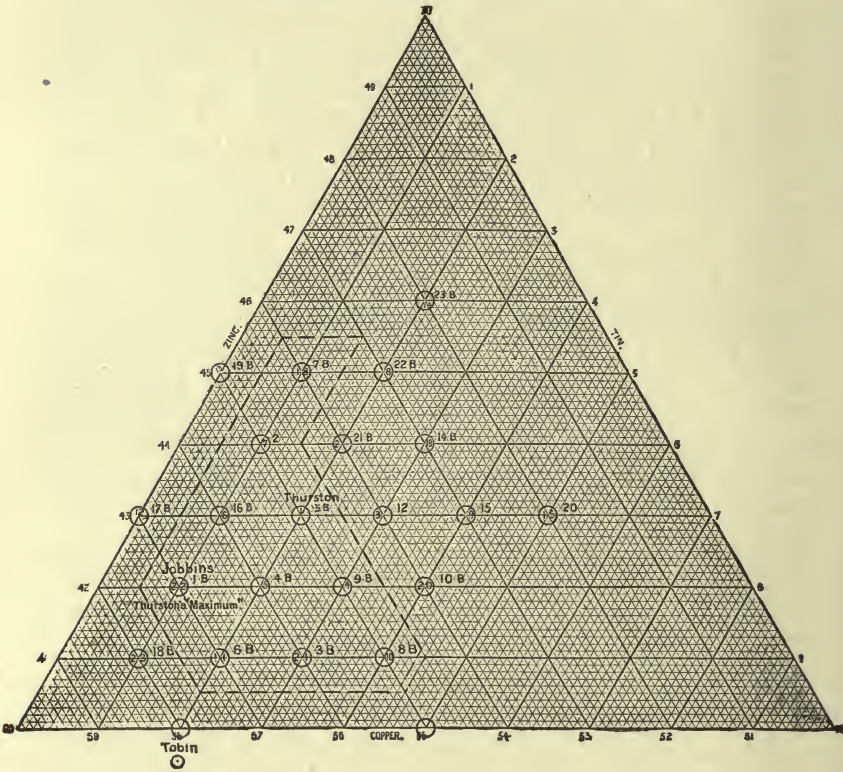
260. Discussion.—It proved, notwithstanding the precautions taken in making these alloys, to be a matter of some difficulty to decide satisfactorily the relative positions of the alloys studied. Nos. 7 and 22 were the best alloys made.

No. 7 was a fine grained alloy, with a smooth, even fracture, tough fibrous appearance, and twisted apart slowly and evenly. No. 22 was an alloy, golden in color, very close grained and with a fracture in all respects similar to No. 7, and exceedingly tough. It was found that, when the average values of M and T were used, No. 7 stood first upon the list, while, when the higher values were taken, No. 22 was first. In the case of No. 22 there was a difference in the values which indicated a change in composition either from volatilization or from some other cause. No. 22 must be considered the strongest alloy.

The third upon the list is No. 21. It exhibited considerable liquation. The metal was of a bright straw color and had a smooth, regular fracture and considerable ductility. No. 5 was fourth and No. 1 fifth. No. 5 was a very fine-grained alloy, possessing great ductility and a smooth, square fracture and very close and compact grain. Higher results can undoubtedly be obtained from an alloy of this composition; these specimens showed signs of slight liquation.

No. 1 was a tough metal, the pieces being twisted apart slowly, snapping suddenly, as in the previous case; better results should be expected from this alloy; it exhibited signs of an imperfect mixture of the metals. This was the strongest alloy reported by the Author previously. The sixth position was assigned to No. 11, which exhibited a fine regular fracture and high ductility; it twisted apart slowly and evenly. No. 18 was a good alloy, and although more crystalline than those previously mentioned, had a smooth fracture and high moduli; it was very ductile. The eighth upon the list, No. 10, was a very brittle alloy; its values for θ_r being but 4.6° and 8.8°; its color was gray, with a fracture closely resembling steel. Its tenacity was 75,000 pounds per square inch (5,272 kilogs. per sq. cm.), a higher figure than some of the preceding alloys have given; it was very hard. No. 4 stands ninth. There was considerable liquation; while it exhibited a smooth and regular fracture and broke off slowly and evenly. It was light yellow in color. Its upper end was granular and uneven in fracture; it was of a very light gray color, indicating a brittle metal, but it was quite strong and ductile. This alloy contained 1 per cent. more zinc and 1 per cent. less tin than No. 10, and, though having slightly less strength, it was far more ductile. The next best alloy, No. 20, an alloy very bright in color, almost white, and having a ragged fracture, was an exceedingly brittle alloy, its average value for θ_r being but 6.8° ; its tenacity was very good. The eleventh, No. 16, was a remarkably dense alloy, very hard, with a fracture closely resembling steel. Its strength was very great. No. 3, the twelfth on the list, was less brittle than the preceding, its average value of θ_r being 11.9°. While testing the A end a "set" took place. It broke suddenly, giving a very ragged, granular fracture; it was light in color. Thirteenth, No. 17, was a very ductile alloy, its values for θ_r averaging 48.6°. It was of a deep golden color, and had a smooth, regular fracture. Fourteenth, No. 19, was close-grained, brittle, nearly white in color, and gave a very ragged and uneven fracture; it broke suddenly. Fifteenth, No. 9, was another very brittle alloy, with a fracture closely resembling steel. Sixteenth, No. 6, was very ductile, giving a smooth, regular fracture. Its values of tenacity were good. Seventeenth, No. 12, was not a triple alloy, as it contained copper and zinc only. It was an exceedingly beautiful alloy, of a deep golden color and very closely grained. This was, by far, the most ductile alloy tested, the average of θ_r being 113.3°. Eighteenth, No. 23, was the second most ductile alloy. This alloy had a fine fracture, smooth and regular. In color, it very closely resembled green bronze. Nineteenth, No. 13, was also a binary alloy, and though resembling No. 12 in appearance its ductility was only about one-half that of No. 12. Twentieth, No. 15, was exceedingly brittle, and closely resembled steel in fracture. Twenty-first, No. 2, was surrounded by alloys which gave much better results, and therefore a weak specimen; this was not looked for in this place. It was ductile and had a good, even fracture; it resembled No. 23 in color. Twenty-second and twenty-third, Nos. 8 and 14, both contained large amounts of zinc and little copper, and consequently were both brittle and weak.

FIG. 29.—STRONGEST OF BRONZES.



261. Conclusions. The Strongest Bronzes.—The results obtained from this investigation are well exhibited in the ac-panying diagram, Fig. 29. It was concluded that the alloy numbered 22 was what the Author has called the "strongest of the bronzes," and that its composition (Cu, 57; Sn, 1; Zn, 42) should locate the peak seen in the model, Fig. 25, and on the map, Fig. 24. No. 5, however (Cu, 56; Sn, 2; Zn, 42), is likely to prove a more generally useful alloy in consequence of its greater ductility and resilience; and alloys with a little less tin may often prove even better than that. The Author has called the compositions, copper, 58 to 54; tin, ½ to 2½; zinc, 44 to 40, which may be considered as representative of a group having peculiar value to the engineer, the "*maximum bronzes.*" This cluster lies immediately around the peak seen on the model, Fig. 25, including the point of maximum altitude. The safest alloys under shock are those containing the smallest quantities of tin.

262. **The Conclusions** reached after concluding the investigations which have been described in the present chapter are confirmed by the fact that a number of single compositions have been independently discovered by other experimenters, accidentally or incidentally to special investigations, which have peculiarly high tenacity, all of which approximate more or less closely, in their proportions, to these "maximum" bronzes and *strongest* "Kalchoids."

Thus, Mr. Farquharson, president of the Naval (British) Commission, proposed, in 1874, an alloy composed of 62 parts of copper, 37 parts of zinc, and one part of tin. This is the reglementary naval alloy. When cast in bars it has shown on test a resistance of 70,000 pounds per square inch (5,000 kilogs. per sq. cm.). It rolls and works well, can be hammered into sheets, and is fusible only above red heat. It may be used as a lining for engine-pumps. It is but slightly oxidizable, and is not sensibly attacked by sea water, as shown by experiments with it extending over a period of years. A slight loss of zinc during melting must be taken into account. The British naval bronze for screw-propellers, stern bearings, bow-castings, and similar work, is composed of copper, 87.65; tin, 8.32; zinc, 4.03, and is reported to have a tenacity of 15 tons per square inch (2,362 kilogs. per sq. cm.), and to average 13½ tons (2,126 kilogs.) in good castings. Tobin's alloy, already described, is one of the "maximum" bronzes, also, containing copper, 58.22; tin, 2.30; zinc, 39.48. Sterro-metal is always a brass of nearly the same proportions of copper and zinc, *i.e.*, a Muntz metal, containing from a fraction of 1 per cent. to sometimes 2 per cent. of tin, as well as some iron.

The bronze used for journal bearings in the U. S. Navy contains copper, 88; tin, 10; zinc, 2.* The strongest U. S. copper-tin-zinc alloy is that discovered by Mr. Tobin and described by the Author in earlier articles, and, as has been stated, had a tenacity of 66,500 pounds per square inch of original section, and 71,378 per square inch of fractured area (4,575 and 5,019 kilogrammes per sq. cm.) at one end of the bar, which was, as usual, cast on end, and 2 per cent. more at the other. This, like the "maximum alloy," was capable of being forged or rolled at a low red heat or worked cold. Rolled hot, its tenacity was 79,000 pounds (5,553 kilogs. per sq. cm.), and when cold-rolled, 104,000 (7,311 kilogs.). It could be bent double either hot or cold, and was found to make excellent bolts and nuts.

These and other compositions which have been occasionally introduced as having extraordinary strength and exceptional value, all contain a small amount of tin, and invariably fall within the field mapped out as described in this chapter as that containing the kalchoids of maximum possible strength. The latter, the "maximum alloys," as the Author has called them, will probably be very generally, if not exclusively, used when alloys are required of peculiar strength.

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* This kalchoid composition has been prescribed by the U. S. Ordnance Bureau for gun-carriages and also Cu 55, Zn 44.5, Sn 0.5; the latter having a mean tenacity of 50,000 to 60,000 and a maximum of 64,000 pounds per square inch.—Reports, 1898.

CHAPTER XII.

STRENGTH OF ZINC-TIN AND OTHER ALLOYS.

263. **The Zinc-Tin Alloys** form the third bounding line of the system of copper-tin-zinc alloys which have been studied, as the copper-tin and copper-zinc compounds form the two sides first examined. Within the field represented on the map, Art. 252, page 425, and on the tin-zinc side of the depression which lies parallel with the crest of maximum strength, are also a set of ternary alloys characteristically different from those which have been the object of specia. investigation. These are the gray and the white alloys of copper, tin, and zinc, which have no use .in the work of the engineer except for bearing metals and as solders. The characteristics and uses of these alloys are so similar to those of the tin-zinc alloys that they are here classed and treated of together.

The zinc-tin alloys are usually easily made, and are sound and dense and uniform in quality and structure. They are soft, weak, smooth of texture, as a rule, and readily alloy with the surface coating of tin-plate and with zinc; they thus make good "soft solders" as well as good metals with which to line the bearings of heavy journals in heavy machinery. Common solders are elsewhere described. Among them are "yellow solder," composed of equal percentages of copper and zinc, with one part tin either added or substituted for two or three per cent. zinc; "black solder," composed of 30 copper, 45 zinc, and tin, 25; these fall among the stronger alloys outside the gray mixtures.

No tests of the tin-zinc alloys were made in the research described in the preceding chapter, but the study of the model, Fig. 25, page 427, gives the value of this set of compounds as satisfactorily as if they had all been directly investigated.

264. **The Strength of Tin-Zinc Alloys** is seen to vary very smoothly and uniformly from the pure zinc to the pure tin end of the series. It may, therefore, be assumed as substantially true that the strength of the tin-zinc alloys is the mean of that of their constituents. This is also practically true of their other physical and mechanical properties. Hence, the *tenacity* of good alloys of this class should be expected to be not far from

$$\left.\begin{aligned} T &= 4{,}500\,t + 7{,}000\,z, \\ T_m &= 316\,t + 492\,z, \end{aligned}\right\} \quad \ldots\ldots \quad (16)$$

in British and metric measures, respectively, where t and z represent the proportion of each metal in unity of weight.

The *Resistance to Compression* is, for tin-zinc alloys, fairly taken as below, for ten per cent. compression,

$$\left.\begin{aligned} C &= 6{,}000\,t + 20{,}000\,z, \\ C_m &= 422\,t + 1{,}406\,z, \end{aligned}\right\} \quad \ldots\ldots \quad (17)$$

The Modulus of Rupture may be taken for tin-zinc compositions, at

$$\left.\begin{aligned} R &= 3{,}500\,t + 7{,}500\,z, \\ R_m &= 246\,t + 527\,z, \end{aligned}\right\} \quad \ldots\ldots \quad (18)$$

and the *Modulus of Elasticity* at 7,000,000 British, 492,000 metric for all. The *Specific Gravity* is fairly reckoned at

$$S.\,G. = 7.3\,t + 7.15\,z. \quad \ldots\ldots\ldots \quad (19)$$

265. **The Gray Alloys** of copper, tin, and zinc are more uniformly modified by the addition of copper to the tin-zinc compounds than are the yellow and stronger alloys. Those containing little zinc are very irregular in strength, but, on the whole, weaker than those containing little tin, and are generally but little stronger than the latter metal. These copper-tin-zinc alloys, rich in zinc and poor in tin, are strongest where the compositions contain between copper, 15 or 20, zinc, 85 or 80, and are weakened quite uniformly by the addition of tin, and by either the increase or diminution of the

proportion of zinc, the tensile strength becoming insignificant when the proportions are such that, approximately,

$$z + 2t = 90 \text{ per cent.},$$

along which line lie the alloys of maximum hardness and brittleness.

The tenacity of this group of alloys usually ranges between 3,000 and 5,000 pounds per square inch, sometimes reaching 10,000 (211, 351, 703 kilogs. per sq. cm., respectively); the resistance to compression is not known; the modulus of rupture falls, usually, not far from 5,000 pounds per square inch, rising to above 10,000 (352 and 703 kilogs. per sq. cm.), and as often falling below the smaller figure. The modulus of elasticity is generally about 12,000,000 (844,000 metric), although with the softer alloys it falls to one-half that amount.

266. **Earlier Investigations** of these alloys have been of little value in determining their properties. An alloy of tin, 80; zinc, 20, is said, by earlier writers, to have a tenacity of 10,000 pounds per square inch (703 kilogs. per sq. cm.), or double that estimated as above. The alloy, zinc, 77; tin, 14; copper, 14; antimony, 3; lead, 1, which falls into the class here considered, very nearly, is Burton's alloy for ploughshares. Magee's, for the same purpose, is copper, 85; tin, 12; zinc, 3. Zinc, 20; tin, 20, is Brayton's alloy for eyelets. Strubing's anti-friction metal is composed of zinc, 75; tin, 18; lead, 4½; antimony, 2½. The alloy composed of equal parts tin and zinc is said by Laboulaye to be remarkably durable under wear, and to have nearly the strength of brass, a statement which is not confirmed by the investigations here described and requires confirmation. The strength of many of these alloys has never been determined.

An "anti-friction metal," of unknown composition, tested by the Author, had a tenacity of 11,100 pounds per square inch (773 kilogs. per sq. cm.), and broke without stretching.

An alloy of gold, 14; silver, 10, with a trace of copper, is often made into wire to replace brass, and is found to have about the same strength.

Various alloys examined by Muschenbroek,* who was the only physicist, or engineer, who had given much time to the study of the mechanical properties of alloys until a very recent period, were found to have tenacities as given in the following table to the nearest thousand.

TABLE LXXXI.

TENACITY AND DENSITY OF VARIOUS ALLOYS.

ALLOYS.				TENACITY.		S. G.
				Lbs. per sq. in.	Kilogs. per sq. cm.	
Gold,	66.7;	Silver,	33.3....	28,000	1,968	....
"	83.3;	Copper,	16.7....	50,000	3,515	....
Silver,	83.3;	"	16.7....	49,000	3,445	....
"	80.0;	Tin,	20.0....	41,000	2,882	....
Tin (Eng.),	90.9;	Lead,	9.1....	7,000	492	....
" "	88.9;	"	11.1....	8,000	562	....
" "	85.7;	"	14.3....	8,000	562	....
" "	80.0;	"	20.0....	11,000	773	....
" "	66.7;	"	33.3....	7,000	492	....
" "	50.0;	"	50.0....	7,000	492	....
Tin (Banca),	90.9;	Antimony,	9.1....	11,000	773	7.36
" "	88.9;	"	11.1....	10,000	703	7.28
" "	85.7;	"	14.3....	13,000	914	7.23
" "	80.0;	"	20.0....	13,000	914	7.19
" "	66.7;	"	33.3....	12,000	874	7.11
" "	50.0;	"	50.0....	3,000	211	7.06
Tin (Banca),	90.9;	Bismuth,	9.1....	13,000	914	7.58
" "	80.0;	"	20.0....	8,000	562	7.61
" "	66 7;	"	33.0....	14,000	984	8.08
" "	50.0;	"	50.0....	12,000	844	8.15
" "	33.3;	"	66.7....	10,000	703	8.58
" "	20 0;	"	80 0....	8,000	562	9.01
" "	9.1;	"	90.9....	4,000	281	9.44
Lead,	50.0;	Bismuth,	50.0....	7,000	492	10.93
"	66.7;	"	33.3....	6,000	422	11.09
"	9.1;	"	90.9....	3,000	211	10.83

267. **The Records of Experiments** upon the copper-tin-zinc alloys which follow are selected from those reported by the Author to the Committee on Alloys of the U. S. Board as representative of the more successful mixtures. These alloys have been already described at some length, and further

* Introd. ad Phil. Nat.; *Phil. Mag.*, 1817, Vol. L.; Tredgold.

description in detail is here unnecessary.* Although selected examples, some considerable part of the variation observed among them is probably due to the varying conditions met with in ordinary foundry work; the principal cause of these great differences of strength and ductility is, however, to be attributed to differences in composition. It will be observed that the strongest of these alloys are not distinguished by great ductility, a fact already frequently illustrated in earlier portions of this work.

Examining the records of test by tension, it is seen that the better class of alloys exhibit a great regularity of elongation under increasing loads. Comparing the tenacities of the best specimens with the moduli of rupture, it is seen that the latter exceed the former by about fifty per cent. In ductile metals the resistances to compression and to extension do not greatly differ where, as in a bent bar of the proportions here adopted, the compressed metal is not confined. The modulus of rupture for a beam of rectangular section when the material is elastic and brittle is that given in the common theory of resistance of materials, $R = \frac{6M}{bd^2}$, in which M, b, d, are the bending moment, the breadth and the depth of the bar. When the material is ductile, $R_1 = \frac{4M}{bd^2}$, and, therefore, $R = \frac{3}{2} R_1$ when the bar is of the same dimensions and the same bending moment is attained at rupture, assuming the same theory applied to each case and the apparent modulus to be accepted.†

In the cases of some of the valuable alloys of which the records of test are here given, the moduli of rupture are often in excess of the tenacities by fifty per cent., or in the same proportion as in wrought iron,‡ proving them to belong to the class to which the second of the expressions just given belongs. This is best illustrated by bar No. 12 (copper, 58.22; tin, 2.30; zinc, 39.48).

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* Vide Report of the U. S. Board, Vol. II., Washington, 1881.

† Part II., p. 487, § 263, Eq. (113).

‡ Part II., p. 491.

TABLE LXXXII.

TESTS BY TENSILE STRESS.

ALLOYS OF COPPER, TIN, AND ZINC.

DIMENSIONS.—Length = 5″ (12.7 cm.); diameter = .798″ (2 cm.).

BAR NO. 1 B-D.

COMPOSITION.—Original mixture: Cu, 70; Sn, 8.75; Zn, 20.25.

LOAD PER SQUARE INCH.	ELONGATION.	SET.	ELONGATION IN PER CENT. OF LENGTH.	LOAD PER SQUARE INCH.	ELONGATION.	SET.	ELONGATION IN PER CENT. OF LENGTH.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
1,400	.0001	.....	.002	16,000	.0046	.....	.092
1,600	.0001	.....	.002	18,000	.0052	....	.104
1,800	.0002	.....	.004	20,000	.0061	.....	.122
2,000	.0002	.....	.004	3 0	.....	.0001	.002
2,500	.0003	.....	.006	10,000	.0010	.....	.020
3,000	.0004	.....	.008	20,000	.0053	.....	.106
3,500	.0005	.....	.010	22,000	.0064	.....	.128
4,000	.0007	.....	.014	24,000	.0084	.....	.168
5,000	.0009	.....	.018	28,000	.0142	.....	.284
6,000	.0012	.....	.024	32,000	.0217	.....	.434
7,000	.0014	.....	.028	36,000	.0316	.....	.632
8,000	.0016	.....	.032	Broke.			
9,000	.0022	.....	.044	Tenacity per square inch, original section,			
10,000	.0024	.....	.048	36,000 pounds (2,531 kilogs. per sq. cm.).			
11,000	.0028	.....	.056	Tenacity per square inch, fractured section,			
12,000	.0031	.....	.062	36,080 pounds (2,536 kilogs. per sq. cm.).			
13,000	.0035	.....	.070	Diameter of fractured section, 0.797″ (2 cm.).			
14,000	.0038	.....	.076				

BAR NO. 5 B-D.

COMPOSITION.—Original mixture: Cu, 88.135; Sn, 1.865; Zn, 10.

3,200	.0014	.....	.035	7,000	.0040	.....	.100
4,000	.0018	.....	.045	8,000	.0042	.....	.105
4,500	.0020	.....	.050	9,000	.0044	.....	.110
5,000	.0023	.....	.057	10,000	.0050	.....	.125
5,500	.0026	.....	.065	11,000	.0054	.....	.135
6,000	.0028	.....	.070	12,000	.0058	.....	.145
7,000	.0033	.....	.082	13,000	.0088	.....	.220
8,000	.0036	.....	.090	14,000	.0121	.....	.302
9,000	.0039	.....	.097	15,000	.0161	.....	.402
10,000	.0043	.....	.107	16,000	.0252	.....	.630
11,000	.0047	.....	.117	18,000	.0548	.....	1.370
12,000	.0052	.....	.130	20,000	.0987	.....	2.460
300	....	.0008	....	22,000	.1595	.....	3.987
100	.0011	.....	.027	26,000	.3118	.....	7.795
1,400	.0013	.....	.032	30,000	.5177	.....	12.942
1,800	.0015	.....	.037	33,000	.7818	.....	19.545
2,200	.0017	.....	.042	Broke.			
2,600	.0019	.....	.047	Tenacity per square inch, original section,			
3,000	.0022	.....	.055	33,000 pounds (21.30 kgs. per sq. cm.).			
4,000	.0028	.....	.070	Tenacity per square inch, fractured section,			
5,000	.0033	.....	.082	47,649 pounds (33.52 kgs. per sq. cm.).			
6,000	.0037	.....	.092	Diameter of fractured section, 0.664″ (1.7 cm.).			

TABLE LXXXII.—*Continued.*

BAR NO. 7 B-D.

COMPOSITION.—Original mixture: Cu, 66.885; Sn, 1.865; Zn, 31.25.

LOAD PER SQUARE INCH.	ELONGATION.	SET.	ELONGATION IN PER CENT. OF LENGTH.	LOAD PER SQUARE INCH.	ELONGATION.	SET.	ELONGATION IN PER CENT. OF LENGTH.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
300	.....	.....	....	6,000	.0029	.....	.058
1,000	.0002	.....	.004	8,000	.0033	.....	.066
2,000	.0004	.....	.008	10,000	.6042	.....	.084
3,000	.0006	.....	.012	12,000	.0055	.....	.110
4,000	.0008	.....	.016	14,000	.0069	.....	.138
4,200	.0008	.....	.016	16,000	.0089	.....	.178
4,400	.0009	.....	.018	18,000	.0113	.....	.226
4,600	.0010	.....	.020	20,000	.0209	.....	.418
5,000	.0011	.....	.022	22,000	.0309	.....	.618
5,400	.0012	.....	.024	24,000	.0444	.....	.888
6,000	.0013	.....	.026	26,000	.0589	.....	1.178
7,000	.0015	.....	.030	28,000	.0779	.....	1.558
8,000	.0017	.....	.054	30,000	.1019	.....	2.038
9,000	.0022	.....	.044	32,000	.1391	.....	2.782
11,000	.0029	.....	.058	34,000	.1171	.....	2.342
12,000	.0036	.....	.072	36,000	.2181	.....	4.362
14,000	.0050	.....	.100	36,540	Broke.		
15,000	.0060	.....	.120	Tenacity per square inch, original section,			
16,000	.0070	.....	.140	36,540 pounds (24.68 kgs. per sq. cm.).			
17,000	.0082	.....	.164	Tenacity per square inch, fractured section,			
300	.....	0016	.032	41,028 pounds (28.84 kgs. per sq. cm.).			
2,000	.0020	.....	.040	Diameter of fractured section, 0.753″ (1.9 cm.).			
4,000	.0025	.....	.050				

BAR NO. 12 B-D.

COMPOSITION.—Original mixture: Cu, 58.22; Sn, 2.30; Zn, 39.48.

300	.....	.....	....	30,000	.0240	.....	.48
1,000	.0012	.....	.024	32,000	.0254	.....	.508
2,000	.0022	.....	.044	34,000	.0268	.....	.536
2,200	.0024	.....	.048	36,000	.0282	.....	.564
2,400	.0026	.....	.052	38,000	.0297	.....	.594
2,600	.0028	.....	.056	40,000	.0313	.....	.626
2,800	.0030	.....	.060	300	.....	.0150	.030
3,000	.0032	.....	.064	10,000	.0215	.....	.430
3,200	.0034	.....	.068	20,000	.0279	.....	.558
3,400	.0036	.....	.072	30,000	.0345	.....	.690
3,600	.0038	.....	.076	40,000	.0299	.....	.798
3,800	.0041	.....	.082	42,000	.0423	.....	.846
4,000	.0044	.....	.088	44,000	.0447	.....	.894
5,000	.0054	.....	.108	46,000	.0473	.....	.946
6,000	.0064	.....	.128	48,000	.0494	.....	.988
7,000	.0074	.....	.148	50,000	.0527	.....	1.054
8,000	.0081	.....	.162	52,000	.0568	.....	1.136
9,000	.0098	.....	.176	54,000	.0615	.....	1.23
10,000	.0085	.....	.190	56,000	.0674	.....	1.348
300	.....	.0022	.044	58,000	.0771	.....	1.542
10,000	.0113	.....	.226	60,000	.0873	.....	1.746
12,000	.0125	.....	.25	62,000	.0958	.....	1.916
14,000	.0137	.....	.274	64,000	.1277	.....	2.554
16,000	.0150	.....	.30	66,000	.1577	.....	3.154
18,000	.0165	.....	.33	67,000	Broke.		
20,000	.0176	.....	.352	Tenacity per square inch, original section,			
22,000	.0189	.....	.378	67,600 pounds (47.52 kgs. per sq. cm.).			
24,000	.0202	.....	.404	Tenacity per square inch, fractured section,			
26,000	.0213	.....	.426	73,160 pounds (51.43 kgs. per sq. cm.).			
28,000	.0226	.....	.452	Diameter fractured section, 0.767″ (1.9 cm.).			

TABLE LXXXII.—*Continued.*

BAR NO. 40 B.

COMPOSITION.—Original mixture: Cu, 50; Sn, 5; Zn, 45.

Load per Square Inch.	Elongation.	Set.	Elongation in per Cent. of Length.	Load per Square Inch.	Elongation.	Set.	Elongation in per Cent. of Length.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
300	.....	.....	....	14,000	.0126	.....	.252
1,000	.0009	.....	.018	16,000	.0141	.....	.282
2,000	.0018	.....	.036	18,000	.0155	.....	.310
2,500	.0022	.....	.044	20,000	.0169	.....	.338
3,000	.0025	.....	.050	300	.....	.0005	....
3,500	.0028	.....	.056	1,000	.....	.0013	....
4,000	.0022	.....	.064	22,000	.0184	.....	.368
300	.....	.0000	....	24,000	.....	.0195	.390
1,000	.....	.0009	....	26,000	.....	.0205	.410
4,000	.0032	.....	.064	28,000	.....	.0215	.430
6,000	.0051	.....	.102	30,000	.....	.0225	.450
8,000	.0069	.....	.138	31,300	Broke.		
10,000	.0087	.....	.174				
300	.....	.0002	...				
1,000	.....	.0011	....				
10,000	.0092	.....	.186				
12,000	.0107	.....	.214				

Tenacity per square inch, original section, 31,300 pounds (22.00 kgs. per sq. cm.).
Tenacity per square inch, fractured section, 31,300 pounds (22.00 kgs. per sq. cm.).
Diameter of fractured section, 0.798″ (2 cm.).

BAR NO. 52 B.

COMPOSITION.—Original mixture: Cu, 60; Sn, 5; Zn, 35.

300	.....	......	....	300	.....	.0007	....
1,000	.0006	......	.012	20,000	.0092	.....	.184
2,000	.0018	. ....	.036	22,000	.0098	.....	.196
2,500	.0023	......	.046	24,000	.0105	.....	.210
3,000	.0026	......	.052	26,000	.0114	.....	.228
3,500	.0030	......	.060	28,000	.0125	.....	.250
4,000	.0033	......	.066	30,000	.0138	.....	.276
300	.....	.00005	....	300	.....	.0026	....
1,000	.....	.0006	....	30,000	.0144	.....	....
4,000	.0027	......	....	32,000	.0153	.....	.306
6,000	.0035	......	.070	34,000	.0165	.....	.330
8,000	.0046	......	.092	36,000	.0182	.....	.364
10,000	.0054	......	.108	38,000	.0199	.....	.398
300	.. ..	.0001	....	38,330	Broke.		
10,000	.0019	......	....				
12,000	.0058	......	.116				
14,000	.0068	......	.136				
16,000	.0076	......	.152				
18,000	.0083	......	.166				
20,000	.0090	......	.180				

Tenacity per square inch, original section, 38,300 pounds (26.95 kgs. per sq. cm.).
Tenacity per square inch, fractured section, 38,534 pounds (24.84 kgs. per sq. cm.).
Diameter of fractured section, 0.797″ (2 cm.).

TABLE LXXXII.—*Continued.*

BAR NO. 59 A.

COMPOSITION.—Original mixture: Cu, 70; Sn, 5; Zn, 25.

LOAD PER SQUARE INCH.	ELONGATION.	SET.	ELONGATION IN PER CENT. OF LENGTH.	LOAD PER SQUARE INCH.	ELONGATION.	SET.	ELONGATION IN PER CENT. OF LENGTH.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
300	.....	.....	....	300	.....	.0004	.....
1,000	.0004	.....	.008	20,000	.0133	.....	.....
2,000	.0009	.....	.018	22,000	.0171	.....	.342
2,500	.0012	.....	.024	24,000	.0233	.....	.466
3,000	.0014	.....	.028	26,000	.0296	.....	.596
3,500	.0016	.....	.032	28,000	.0376	.....	.752
4,000	.0018	.....	.036	30,000	.0472	.....	.944
300	.....	.0000	....	300	.....	.0078	.....
1,000	.....	.0004	....	30,000	.0470	.....	.....
4,000	.0018	.....	....	32,000	.0517	.....	1.034
6,000	.0023	.....	.046	34,000	.0684	.....	1.368
8,000	.0029	.....	.058	36,000	.0838	.....	1.676
10,000	.0036	.....	.072	38,000	.1028 ?	.....	2.056
300	.....	.0002	....				
10,000	.0038	.....	....				
12,000	.0046	.....	.092				
14,000	.0059	.....	.118				
16,000	.0079	.....	.158				
18,000	.0098	.....	.196				
20,000	.0129	.....	.258				

Broke just after reading was taken.
Tenacity per square inch, original section, 38,000 pounds (26.61 kgs. per sq. cm.).
Tenacity per square inch, fractured section, 39,014 pounds (27.43 kgs. per sq. cm.).
Diameter of fractured section, 0.788″ (2 cm.).

BAR NO. 67 A.

COMPOSITION.—Original mixture: Cu, 80; Sn, 5; Zn, 15.

300	....	.....	....	20,000	.0632	.....	1.264
1,000	.0012	.....	.024	300	.....	.0518	......
2,000	.0027	.....	.054	20,000	.0638	.....	......
2,500	.0036	.....	.072	22,000	.0847	.....	1.694
3,000	.0044	.....	.088	24,000	.1150	.....	2.300
3,500	.0050	.....	.100	26,000	.1582	.....	3.164
4,000	.0056	.....	.112	28,000	.2650	.....	4.100
300	.....	.0003	....	30,000	.2642	.....	5.284
4,000	.0059	.....	....	300	....	.2502	5.004
5,000	.0069	.....	.138	30,000	.2682	.....	5.364
6,000	.0081	.....	.162	32,000	.3422	.....	6.844
8,000	.0111	.....	.222	34,000	.4127	.....	8.254
10,000	.0150	.....	.300	36,000	.5022	.....	10.044
300	.....	.0038	....	37,500	.5804	.....	11.608
1,000	.....	.0052	....				
10,000	.0157	.....	....				
12,000	.0198	.....	.396				
14,000	.0271	.....	.542				
16,000	.0346	.....	.692				
18,000	.0469	.....	.938				

Broke.
Tenacity per square inch, original section, 37,560 pounds (26.40 kgs. per sq. cm.).
Tenacity per square inch, fractured section, 48,905 pounds (34.38 kgs. per sq. cm.).
Diameter of fractured section, 0.700″ (1.78 cm.).

TABLE LXXXII.—*Continued.*

BAR NO. 73 A.

COMPOSITION.—Original mixture: Cu, 55; Sn, 0.5; Zn, 44.5.

Load per Square Inch.	Elongation and Set in Inches.	Elongation and Set in per Cent. of Length.	Modulus of Elasticity.	Load per Square Inch.	Elongation and Set in Inches.	Elongation and Set in per Cent. of Length.	Modulus of Elasticity.
Pounds.	*Inch.*			*Pounds.*	*Inch.*		
300	......	....	....	36,000	.0473	.946	....
1,000	.00025	.005	....	38,000	.0586	1.172	....
2,000	.00065	.013	15,383,076	40,000	.0748	1.496	2,673,796
3,000	.0011	.022	13,636,363	300	Set .05535	Set 1.107	....
4,000	.00155	.031	12,903,258	40,000	.07815	1.563	....
5,000	.00195	.039	12,820,512	42,000	.09025	1.805	....
6,000	.0024	.048	12,500,000	44,000	.1197	2.394	....
7,000	.00295	.059	11,868,474	46,000	.1393	2.786	....
8,000	.0035	.070	11,428,571	48,000	.16255	3.251	....
9,000	.0038	.076	11,842,105	50,000	.2006	4.014	1,245,762
10,000	.0042	.084	11,904,761	52,000	.2259	4.518	....
300	Set .00005	Set .001	....	300	Set .19825	Set 3.965	....
10,000	.0042	.084	....	52,000	.22955	4.591	....
12,000	.0052	.104	11,538,461	54,000	.26605	5.321	....
14,000	.0062½	.120	11,200,000	56,000	.29875	5.975	....
16,000	.0072	.144	11,111,111	58,000	.3263	6.526	....
18,000	.0082	.164	10,975,668	60,000	.3720	7.440	....
20,000	.0089½	.179	11,172,184	300	Set .3496	Set 6.992	....
300	Set .00055	Set .011	....	60,000	.3991	7.982	....
20,000	.0095	.190	....	62,000	.4636	9.272	....
22,000	.0109	.218	10,009,082	64,000	.4714	9.428	....
24,000	.01265	.253	9,494,071	68,900	Broke.		
26,000	.01485	.297	8,755,555				
28,000	.0178	.356	7,865,168				
300	Set .00515	Set .103	....				
28,000	.01815	.363	....				
30,000	.02235	.447	....				
32,000	.02755	.511	....				
34,000	.03625	.725	....				

Tenacity per square inch, original section, 68,900 pounds (48.44 kgs. per sq. cm.).
Tenacity per square inch, fractured section, 92,136 pounds (64.77 kgs. per sq. cm.).
Diameter of fractured section, .6900″ (1.75 cm.).

TABLE LXXXIII.

TESTS BY TRANSVERSE STRESS.

ALLOYS OF COPPER, TIN AND ZINC.

DIMENSIONS.—Length, $l = 22''$ (55.88 cm.); breadth, $b = 1.00''$ (2.54 cm.); depth, $d = 1.00''$ (2.54 cm.).

BAR NO. I.

COMPOSITION.—Original mixture: Cu, 70; Sn, 8.75; Zn, 21.25. Analysis: Cu, 70.22; Sn, 8.90; Zn, 20.68.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.	LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
3	.....	.....	....	10	.....	.0132	....
6	.0004	.....	....	3	.....	.0098	....
10	.0018	.....	....	Left 10 min.; showed very slight increase of			
20	.0067	.....	7,820,389	resistance.			
40	.0125	.....	8,383,457	1,000	.....	.....	....
60	.0172	.....	9,138,945	Left under strain.			
80	.0215	.....	9,748,166	Resistance diminished in 5 min. to 996 lbs.			
100	.0250	.....	10,498,644	Resistance diminished in 20 min. to 990 lbs.			
120	.0287	.....	10,953,995	Resistance diminished in 1 hr. 55 m. to 985 lbs.			
160	.0359	.....	11,948,989	1,000	.1951	.....	....
200	.0437	.....	11,990,718	1,010	.1967	.....	....
10	.....	.0018	....	1,020	.1994	.....	....
3	.....	.0003	....	1,040	.2033	.....	....
200	.0435	.....	....	1,060	.2081	.....	....
240	.0500	.....	12,575,185	1,080	.2145	.....	....
280	.0568	.....	12,914,657	1,120	.2259	.....	....
320	.0635	.....	13,202,297	1,160	.2373	.....	....
360	.0702	.....	13,434,278	1,200	.2515	.....	12,500,184
400	.0764	.....	13,716,389	10	.....	.0291	....
10	.....	.0050	....	3	.....	.0261	....
4	.....	.0009	....	Resistance increased in 20 min. to 9 lbs.			
400	.0764	.....	....	3	.....	.0257	....
440	.0825	.....	13,972,399	Decrease of set, .0004″.			
480	.0891	.....	14,113,565	1,200	.2536	.....	....
520	.0960	.....	14,190,748	1,240	.2634	.....	....
560	.1022	.....	14,355,235	1,280	.2785	.....	....
600	.1086	.....	14,474,203	1,320	.2962	.....	....
10	.....	.0054	....	1,360	.3143	.....	....
3	.....	.0001	....	1,400	.3351	.....	10,945,277
600	.1084	.....	....	10	.....	.0721	....
640	.1157	.....	14,491,715	3	.....	.0681	....
680	.1234	.....	14,436,664	10	.....	.0697	....
720	.1305	.....	14,454,236	1,400	.3351	.....	....
760	.1380	.....	14,428,053	1,440	.3516	.....	....
800	.1468	.....	14,277,003	1,480	.3713	.....	....
10	.....	.0056	....	1,520	.4019	.....	....
3	.....	.0026	....	1,550	Broke suddenly in middle, with		
800	.1464	.....	....	ringing sound.			
840	.1549	.....	14,206,957	Breaking load, $P = 1{,}550$ lbs.			
880	.1627	.....	14,169,948	Modulus of rupture, $R = \frac{3Pl}{2bd^2} = 50{,}541$ (3,553			
920	.1716	.....	14,045,709				
960	.1808	.....	13,910,603	metric).			
1,000	.1905	.....	13,752,390				

TABLE LXXXIII.—*Continued.*

BAR NO. 5.

COMPOSITION.—Original mixture: Cu, 88.135; Sn, 1.865; Zn, 10. Analysis: Cu, 89.56; Sn, 2.07; Zn, 8.11.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*	
3	.....	.....	....
10	.0018	.....	....
20	.0071	.....	5,325,416
40	.0119	.....	6,354,696
60	.0162	.....	7,001,935
80	.0190	.....	7,960,094
100	.0224	.....	8,439,831
120	.0255	.....	8,896,573
160	.0314	.....	9,633,235
200	.0379	.....	9,976,370
10	.....	.0101	....
3	.....	.0059	....
200	.0381	.....	....
240	.0436	.....	....
280	.0511	.....	10,359,026
320	.0584	.....	10,359,028
360	.0658	.....	10,343,283
400	.0727	.....	10,401,776
10	.....	.0204	....
3	.....	.0162	....
400	.0749	.....	....
440, beam sinks.	.0830	.....	10,022,046
480	.0921	.....	9,852,884
520	.1086	.....	....
560	.1309	.....	....
600	.1631	.....	6,954,660
10	.....	.0849	....
3	.....	.0820	....
600	.1695	.....	....

Left under strain.
Resistance diminished in 1 min. to 584 lbs.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inches.*	*Inch.*	
Resistance diminished in 4 min. to 578 lbs.			
Resistance diminished in 41 min. to 570 lbs.			
600	.1749	.....	....
620	.1854	.....	....
640	.2089	.....	....
680	.2896	.....	....
720	.3767	.....	....
760	.5394	.....	....
800	.6984	.....	2,164,546
10	.....	.5811	....
3	.....	.5681	....
800	.7154	.....	....
840	.9199	.....	....
860	.9859	.....	....
880	1.1389	.....	....
900	1.26	.....	....
920	1.36	.....	....
940	1.56	.....	....
960	1.74	.....	....
980	1.92	.....	....
1,000	2.12	.....	....
1,020	2.32	.....	....
1,040	2.52	.....	....
1,060	2.72	.....	....
1,080	2.92	.....	....
1,100	3.27	.....	....
1,120	3.67	.....	....

Bar removed.
Breaking load, $P = 1,120$ pounds
Modulus of rupture, $R = \frac{3Pl}{2bd^2} = 31,986$ (metric, 2,250).

BAR NO. 7.

COMPOSITION.—Original mixture: Cu, 66.885; Sn, 1.865; Zn, 31.25.

3	.....	.....	....
10	.0024	.....	....
20	.0055	.....	9,699,400
40	.0114	.....	9,359,172
80	.0201	.....	10,616,259
120	.0281	.....	11,390,754
160	.0367	.....	11,628,709
200	.0447	.....	11,934,387
10	.....	.0060	....
3	.....	.0041	....
200	.0443	.....	....
240	.0513	.....	12,478,758
280	.0603	.....	12,385,635
320	.0678	.....	12,589,165
360	.0748	.....	12,837,309
400	.0831	.....	12,839,159
10	.....	.0091	....
3	.....	.0066	....
400	.0836	.....	....

440	.0920	.....	12,756,821
480	.1012	Beam sinks.	12,651,391
520	.1109	.....	....
560	.1239	.....	....
600	.1402	.....	11,415,131
10	.....	.0257	....
3	.....	.0233	....
600	.1433	.....	....
Left under strain.			
Resistance diminished in 3 min. to 596 lbs.			
Resistance diminished in 10 min. to 594 lbs.			
Resistance diminished in 16 h. 15m. to 581 lbs.			
10	.....	.0290	....
3	.....	.0274	....
Left under strain.			
Resistance increased in 10 min. to 5 lbs.			
3	.....	.0273	....
581	.1400	.....	....
600	.1440	.....	....

TABLE LXXXIII. (Bar No. 7).—*Continued.*

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.	LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inches.*	*Inches.*	
620	.1496	.....	....	1,040	.7799	.....	....
640	.1575	.....	....	1,080	.9498	.....	....
680	.1836	.....	....	1,120	1.0549	.....	....
720	.2128	.....	....	1,160	1.19	.....	....
760	.2642	.....	....	1,200	1.37	.....	....
720	.....	.....	....	1,240	1.57	.....	....
760	.....	.....	....	1,280	1.73	.....	....
800	.3069	.....	6,952,976	1,320	1.93	.....	....
10	.....	.1387	....	1,360	2.13	.....	....
3	.....	.1343	....	1,400	2.33	.....	....
3	.....	.1334	....	1,440	2.61	.....	....
800	.3099	.....	....	1,480	3.11	.....	....
840	.3471	.....	....	1,500	3.76	.....	....
880	.4296	.....	....	3	.....	3.32	....
920	.5156	.....	....				
960	.6145	.....	....				
1,000	.7117	.....	3,747,836				
10	.....	.4714	....				
3	.....	.4668	....				
1,000	.7169	.....	....				

Bar removed.
Breaking load, $P=1{,}500$.
Modulus of rupture, $R = \frac{3\,Pl}{2\,bd^2} = 49{,}599$
(metric, 3,417).

BAR NO. 12.

COMPOSITION.—Original mixture: Cu, 58.22; Sn, 2.30; Zn, 39.48.

3	.....	.....	....	10	.....	.0043	....
10	.0024	.....	....	3	.....	.0032	....
20	.0046	.....	11,760,504	800	.2028	.....	....
40	.0098	.....	11,040,471	840	.2142	.....	10,607,511
80	.0202	.....	11,712,535	880	.2247	.....	10,593,349
120	.0296	.....	10,965,874	920	.2344	.....	10,616,562
160	.0418	.....	10,353,743	960	.2433	.....	10,672,909
200	.0517	.....	10,463,891	1,000	.2550	.....	10,607,511
10	.....	.0032	....	10	.....	.0064	....
3	.....	.0011	....	3	.....	.0046	....
200	.0532	....	....	1,000	.2544	.....	....
240	.0612	.....	10,607,511	1,040	.2642	.....	10,647,661
280	.0712	.....	10,637,306	1,080	.2764	.....	10,569,132
320	.0802	.....	10,792,679	1,120	.2847	.....	10,641,044
360	.0908	.....	10,724,336	1,160	.2951	.....	10,632,674
400	.1000	.....	10,819,661	1,200	.3062	.....	10,600,509
10	.....	.0027	....	10	.....	.0114	....
3	.....	.0008	....	3	. .	.0093	....
400	.1010	.....	....	1,200	.3069	.....	....
440	.1095	.....	10,869,067	Left under strain.			
480	.1197	.....	10,846,777	Resistance diminished in 55 min. to 1,194 lbs.			
520	.1294	.....	10,869,829	1,240	.3170	.....	....
560	.1403	.....	11,578,364	1,280	.3276	.....	....
600	.1511	.....	14,321,101	1,320	.3398	.....	....
10	.....	.0032	....	1,360	.3528	.....	....
3	.....	.0015	....	1,400	.3673	.....	....
600	.1515	.....	....	10	.....	.0210	....
640	.1629	.....	10,627,046	3	.....	.0193	....
680	.1740	.....	10,570,934	1,400	.3695	.....	10,310,049
720	.1846	.....	10,550,048	1,440	.3817	.....	....
760	.1944	.....	10,574,771	1,480	.3959	.....	....
800	.2038	.....	10,617,922	1,520	.4102	.....	....

TABLE LXXXIII. (Bar No. 12).—*Continued.*

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*	
1,560	.4236	.....	....
1,600	.4395	.....	9,847,245
10	.....	.0407	....
3	.....	.0387	....
1,600	.4405	.....	....
1,640	.4537	.....	....
1,680	.4704	.....	....
1,720	.4882	.....	....
1,760	.5042	.....	....
1,800	.5205	.....	9,354,174
10	.....	.0743	....
3	.....	.0727	....
1,800	.5230	.....	....
1,840	.5383	.....	....
1,880	.5586	.....	....
1,920	.5823	.....	....
1,960	.6076	.....	....
2,000	.6343	.....	8,955,262
10	.....	.1340	....
3	.....	.1326	....

Left under strain.
Resistance increased in 10 min. to 8 lbs.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
3	.....	.1320	....
2,000	.6390	.....	....
2,040	.6594	.....	....
2,080	.6856	.....	....
2,120	.7140	.....	....
2,160	.7486	.....	....
2,200	.7777	.....	7,651,812
2,240	.8106	.....	....
2,280	.8621	.....	....

Left under strain.
Resistance decreased in 1 min. to 2,272 lbs.
Resistance decreased in 3 min. to 2,268 lbs.
Resistance decreased in 25 min. to 2,260 lbs.
Resistance decreased in hr. to 2,256 lbs.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
2,280	.8665	.....	....
2,290	.8685	.....	....
2,300	.8-22	.....	....
2,310	.8763	.....	....
2,320	.8843	.....	....

Left under strain.
Resistance decreased in 3 min. to 2,312 lbs.
Resistance decreased in 10 min. to 2,308 lbs.
Resistance decreased in 66 hr. 13 m. to 2,260 lbs.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
2,270	.8867	.....	....
2,280	.8893	.....	....
2,290	.8919	.....	....
2,300	.8948	.....	....
2,310	.8967	.....	....
2,320	.8990	.....	....
2,330	.9019	.....	....
2,340	.9063	.....	....
2,350, beam sinks.	.9165	.....	....

Left under strain.
Resistance decreased in 10 min. to 2,342 lbs.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
2,350	.9189	.....	....
2,360	.9239	.....	....
2,370	.9418	.....	....
Pounds.	*Inches.*	*Inch.*	
2,380	.9529	.....	....
2,390	.9650	.....	....
2,400	.9764	.....	....
2,410	.9888	.....	....
2,420	1.0048	.....	....
2,430	1.0189	.....	....
2,440	1.0333	.....	....
2,450	1.0438	.....	....
2,460	1.0553	.....	....
2,470	1.0755	.....	....
2,480	1.0865	.....	....
2,490	1.1013	.....	....
2,500	1.1265	.....	....
2,510	1.1341	.....	....
2,520	1.1475	.....	....
2,530	1.1647	.....	....
2,540	1.1818	.....	....
2,550	1.1918	.....	....
2,560	1.2073	.....	....
2,570	1.2293	.....	....
2,580	1.2445	.....	....
2,590	1.2585	.....	....
2,600	1.2851	.....	5,472,552
2,610	1.3063	.....	....
2,620	1.3288	.....	....
2,630	1.3406	.....	....
2,640	1.3556	.....	....
2,650	1.3747	.....	....
2,660	1.3973	.....	....
2,670	1.4178	.....	....
2,680	1.4447	.....	....
2,690	1.4665	.....	....
2,700	1.4898	.....	....
2,710	1.5057	.....	....
2,720	1.5303	.....	....
2,730	1.5437	.....	....
2,740	1.5603	.....	....
2,750	1.6106	.....	....
2,760	1.6279	.....	....
2,770	1.6395	.....	....
2,780	1.6581	.....	....
2,790	1.6899	.....	....
2,800	1.7285	.....	4,331,697
2,810	1.7599	.....	....
2,820	1.7793	.....	....
2,830	1.8111	.....	....
2,840	1.8553	.....	....
2,850	1.8807	.....	....
2,860	1.8936	.....	....
2,870	1.9453	.....	....
2,880	1.9881	.....	....
2,890	Broke gradually in the middle.		

While putting on strain a slight crackling sound was heard a few seconds before breaking.

Breaking load, $P = 2{,}880$ pounds.

Modulus of rupture,

$$R = \frac{3Pl}{2bd^2} = 95{,}623 \text{ (metric, 6,722).}$$

TABLE LXXXIII.—*Continued.*

BAR NO. 52.

COMPOSITION.—Original mixture: Cu, 60; Sn, 5; Zn, 35.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.	LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
3	.....	.....	....	10	.....	.0058	....
10	.0017	.....	....	3	.....	.0036	....
20	.0036	.....	14,805,645	800	.1495	.....	....
40	.0073	....	14,602,823	840	.1555	.....	14,395,261
80	.0148	.....	14,389,192	Beam sinking a little.			
120	.0237	.....	13,477,585	880	.1626	.....	14,423,245
160	.0327	.....	13,039,862	920	.1698	.....	14,439,425
200	.0408	.....	13,063,832	960	.1774	.....	14,421,764
10	.....	.0022	....	1,000	.1857	.....	14,351,218
3	.....	.0006	....	10	.....	.0063	....
200	.0411	.....	....	3	.....	.0039	....
240	.0497	.....	12,869,320	1,000	.1858	.....	....
280	.0583	.....	12,704,416	1,040	.1935	.....	14,324,630
320	.0656	.....	12,704,190	1,080	.2032	.....	....
360	.0713	.....	13,455,931	1,120	.2126	.....	....
400	.0770	.....	13,844,270	1,160	.2221	.....	....
10	.....	.0026	....	1,200	.2324	.....	13,760,839
3	.....	.0008	....	10	.....	.0098	....
400	.0777	.....	....	3	.....	.0072	....
440	.0839	.....	13,975,955	1,200	.2330	.....	....
480	.0915	.....	13,980,442	1,240	.2426	.....	....
520	.0993	.....	13,955,804	1,280	.2547	.....	....
560	.1068	.....	13,973,864	1,320	.2639	.....	....
600	.1137	.....	14,063,440	1,360	.2722	.....	....
10	.....	.0047	....	1,400	.2804	.....	13,275,464
3	.....	.0026	....	10	.....	.0157	....
600	.1148	.....	....	3	.....	.0136	....
640	.1216	.....	14,626,432	1,402	Broke about 1 inch from the middle.		
680	.1285	.....	14,102,841				
720	.1353	.....	14,181,934				
760	.1420	.....	14,263,500				
800	.1487	.....	14,336,709				

Breaking load, $P = 1,402$ pounds.
Modulus of rupture, $R = \frac{3Pl}{2bd^2} = 46,076$ (metric, 3,239).

BAR NO. 55.

COMPOSITION.—Original mixture: Cu, 65; Sn, 5; Zn, 30.

3	.....	.....	....	440	.0856	.....	14,191,208
10	.0018	.....	....	480	.0931	.....	14,234,223
20	.0037	.....	14,923,498	520	.0988	.....	14,530,772
40	.0081	.....	13,633,811	560	.1058	.....	14,613,175
80	.0168	.....	13,146,888	600	.1129	.....	14,672,351
120	.0253	.....	13,094,906	10	.....	.0038	....
160	.0341	.....	12,954,119	3	.....	.0026	....
200	.0422	.....	13,084,581	600	.1129	.....	....
10	.....	.0020	....	640	.1195	.....	14,786,125
3	.....	.0001	....	680	.1265	.....	14,840,914
200	.0431	.....	....	720	.1342	.....	14,812,293
240	.0506	.....	13,094,924	760	.1420	.....	14,776,364
280	.0581	.....	13,305,285	800	.1495	.....	14,776,762
320	.0649	.....	13,612,805	10	.....	.0064	....
360	.0715	.....	13,900,769	3	.....	.0042	....
400	.0781	.....	14,172,658	800	.1498	.....	....
10	.....	.0028	....	840	.1586	.....	14,622,290
3	.....	.0015	....	880	.1680	.....	14,461,578
400	.0781	.....	....	920	.1796	.....	14,142,41[illegible]

TABLE LXXXIII. (Bar No. 55).—*Continued.*

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.	LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
960	.1906	.....	13,905,628	1,320	.3716	.....	....
1,000	.2047	.....	13,487,282	1,360	.4039	.....	....
10	.....	.0196	....	1,400	.4433	.....	8,719,012
3	.....	.0177	....	10	.....	.1421	....
1,000	.2072	.....	....	3	.....	.1397	....
1,040	.2185	.....	....	1,400	.4508	.....	....
1,080	.2382	.....	....	1,440	.4704	.....	....
1,120	.2579	.....	....	1,480	.5165	.....	....
1,160	.2789	.....	....	1,520	.5608	.....	....
1,200	.3014	.....	....	1,525	Broke in the middle.		
10	.....	.0597	....				
3	.....	.0576	....				
1,200	.3036	.....	10,912,409				
1,240	.3272	.....	....				
1,280	.3580	.....	....				

Breaking load, $P = 1{,}525$ pounds.

Modulus of rupture, $R = \frac{3Pl}{2bd^2} = 51{,}369$ (metric, 3614).

BAR NO. 64.

COMPOSITION.—Original mixture: Cu, 75; Sn, 10; Zn, 15.

3	.....	.....	....	960	.1847	.....	14,148,277
10	.0019	.....	....	1,000	.1979	.....	13,754,775
20	.0036	.....	15,122,613	10	.....	.0224	....
40	.0068	.....	16,012,177	3	.....	.0195	....
80	.0143	.....	15,228,364	1,000	.2001	.....	....
120	.0229	.....	14,264,121	1,040	.2113	.....	....
160	.0313	.....	13,914,737	1,080	.2258	.....	....
200	.0389	.....	13,995,219	1,120	.2438	.....	....
10	.....	.0024	....	1,160	.2661	.....	....
3	.....	.0002	....	1,200	.2858	.....	11,429,344
200	.0390	.....	....	10	.....	.0637	....
240	.0468	.....	13,959,331	3	.....	.0607	....
280	.0549	.....	13,883,543	1,200	.2927	.....	....
320	.0627	.....	13,892,545	1,240	.3077	.....	....
360	.0702	.....	13,959,331	1,280	.3286	.....	....
400	.0776	.....	14,031,290	2,320	.3536	.....	....
10	.....	.0026	....	1,360	.3816	.....	....
3	.....	.0003	....	1,400	.4111	.....	9,270,002
400	.0775	.....	....	10	.....	.1473	....
440	.0843	.....	14,207,721	3	.....	.1443	....
480	.0907	.....	14,405,661	1,400	.4186	.....	....
520	.0971	.....	14,577,511	1,440	.4413	.....	....
560	.1035	.....	14,728,108	1,480	.4795	.....	....
600	.1107	.....	14,752,853	1,520	.5234	.....	....
10	.....	.0049	....	1,560	.5598	.....	....
3	.....	.0021	....	1,600	.5947	.....	....
600	.1115	.....	....	10	.....	.2840	....
640	.1179	.....	14,776,293	3	.....	.2798	....
680	.1251	.....	14,796,224	1,600	.6090	.....	....
720	.1323	.....	14,813,990	1,640	.6399	.....	....
760	.1395	.....	14,829,914	1,680	.6755	.....	....
800	.1472	.....	14,793,825	1,720	.7339	.....	....
10	.....	.0081	....	1,750	Broke near the middle.		
3	.....	.0057	....				
800	.1482	.....	....				
840	.1557	.....	14,685,542				
880	.1647	.....	14,544,151				
920	.1738	.....	14,409,115				

Breaking load, $P = 1{,}750$ pounds.

Modulus of rupture,

$$R = \frac{3Pl}{2bd^2} = 58{,}345 \text{ (metric, 4,102).}$$

TABLE LXXXIII.—*Continued.*

BAR NO. 68.

COMPOSITION.—Original mixture: Cu, 80; Sn, 10; Zn, 10.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.	LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inches.*	*Inch.*	
3	.....	.....	....	1,200	.3325	.....	9,372,595
10	.0019	.....	....	10	.....	.1171	....
20	.0038	.....	13,668,369	3	.....	.1153	....
40	.0072	.....	14,427,725	1,200	.3419	.....	....
80	.0132	.....	15,739,337	1,240	.3627	.....	....
120	.0210	.....	14,839,942	1,280	.4037	.....	....
160	.0291	.....	14,278,983	1,320	.4400	.....	....
200	.0374	.....	13,887,648	1,360	.4934	.....	....
10	.....	.0025	....	1,400	.5647	.....	6,438,437
3	.....	.0006	....	10	.....	.2951	....
200	.0374	.....	....	3	.....	.2934	....
240	.0456	.....	13,668,369	1,400	.5720	.....	....
280	.0536	.....	13,566,365	1,440	.6010	.....	....
320	.0617	.....	13,468,990	1,480	.6449	.....	....
360	.0699	.....	13,379,554	1,520	.7143	.....	....
400	.0786	.....	13,266,871	1,560	.7921	.....	....
440	.0853	.....	13,395,961	1,600	.8645	.....	4,806,460
480	.0921	.....	13,534,458	10	.....	.5468	....
520	.0991	.....	13,626,987	3	.....	.5432	....
560	.1063	.....	13,681,226	1,600	.8808	.....	....
600	.1120	.....	13,911,448	1,640	.9409	.....	....
10	.....	.0067	....	1,680	1.0216	.....	....
3	.....	.0053	....	1,720	1.1157	.....	....
600	.1137	.....	....	1,760	1.2321	.....	....
640	.1208	.....	13,759,793	1,800	1.3417	.....	3,484,072
680	.1286	.....	13,732,139	10	.....	.9589	....
720	.1365	.....	13,698,407	3	.....	.9546	....
760	.1444	.....	13,668,368	1,800	1.3689	.....	....
800	.1526	.....	13,614,630	1,840	1.4464	.....	....
10	.....	.0150	....	1,880	1.5879	.....	....
3	.....	.0130	....	1,920	1.7029	.....	....
800	.1528	.....	....	1,960	1.8499	.....	....
840	.1625	.....	....	2,000	2.0079	.....	2,586,772
880	.1725	.....	....	2,040	2.2849	.....	....
920	.1839	.....	....	2,060	2.4479	.....	....
960	.1955	.....	....				
1,000	.2126	.....	12,215,380				
10	.....	.0417	....				
3	.....	.0405	....				
1,000	.2166	.....	....				
1,044	.2323	.....	....				
1,080	.2527	.....	....				
1,120	.2789	.....	....				
1,160	.3066	.....	....				

Rollers flew apart. Continued tests on cast-iron supports. The bar broke at 2,320 pounds with a total deflection of 2.797″.

Coefficient of elasticity, 2,154,099.

Breaking load, $P = 2{,}060$ pounds.

Modulus of rupture,

$$R = \frac{3Pl}{2bd^2} = 67{,}117 \text{ (metric, 4,718).}$$

TABLE LXXXIII.—*Continued.*

BAR NO. 71.

COMPOSITION.—Original mixture: Cu, 85; Sn, 10; Zn, 5.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*	
3	.....	.....	....
10	.0013	.....	....
20	.0031	.....	15,737,217
40	.0064	.....	15,245,428
90	.0131	.....	14,896,295
120	.0201	.....	14,562,759
160	.0275	.....	14,192,108
200	.0355	.....	13,742,357
10	.....	.0024	....
3	.....	.0015	....
200	.0364	.....	....
240	.0426	.....	13,742,357
280	.0508	.....	13,444,786
320	.0589	.....	13,252,393
360	.0670	.....	13,106,516
400	.0752	.....	12,974,833
10	.....	.0042	....
3	.....	.0026	....
400	.0759	.....	....
440	.0842	.....	12,746,771
480	.0919	.....	12,740,466
520	.0998	.....	12,709,614
560	.1073	.....	10,730,571
600	.1135	.....	12,906,151
10	.....	.0068	....
3	.....	.0051	....
600	.1141	.....	....
640	.1138	.....	13,031,152
680	.1270	.....	13,060,650
720	.1347	.....	13,038,405
760	.1425	.....	13,009,431
800	.1501	.....	13,000,763
10	.....	.0134	....
3	.....	.0116	....
800	.1506	.....	....
840	.1598	....	....
880	.1691	.....	....
920	.1787	.....	....
960	.1894	.....	....

Left under strain.
Resistance decreased in 1 min. to 944 lbs.
Resistance decreased in 2 min. to 940 lbs.
Resistance decreased in 3 min. to 938 lbs.
Resistance decreased in 4 min. to 937 lbs.
Resistance decreased in 9 min. to 932 lbs.
Resistance decreased in 14 min. to 930¼ lbs.
Resistance decreased in 29 min. to 926 lbs.
Resistance decreased in 44 min. to 925 lbs.
Resistance decreased in 1 hr. 14 min. to 923 lbs.
Resistance decreased in 1 hr. 44 min. to 922 lbs.
Resistance decreased in 2 hr. 44 min. to 920 lbs.
Resistance decreased in 2 hr. 74 min. to 920 lbs.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
920	.1896	.....	....
940	.1914	.....	....
945	.1920	.....	....
950	.1943	.....	....
955	.1951	.....	....

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*	
960	.1958	.....	....
965	.1969	.....	....
970	.1983	.....	....
975	.1994	.....	....
980	.2005	.....	....
985	.2017	.....	....
990	.2031	.....	....
1,000	.2066	.....	11,806,720
10	.....	.0397	....
3	.....	.0382	....
1,000	.2078	.....	....
1,040	.2166	.....	....
1,080	.2306	.....	....
1,120	.2537	.....	....
1,160	.2832	.....	....

Left under strain.
Resistance decreased in 2 min. to 1,118 lbs.
Resistance decreased in 3 min. to 1,112 lbs.
Resistance decreased in 4 min. to 1,110 lbs.
Resistance decreased in 7 min. to 1,104 lbs.
Resistance decreased in 12 min. to 1,100 lbs.
Resistance decreased in 27 min. to 1,093 lbs.
Resistance decreased in 42 min. to 1,090 lbs.
Resistance decreased in 1 hr. 12m. to 1,087 lbs.
Resistance decreased in 2 hr. 12m. to 1,082 lbs.
Resistance decreased in 16 hr. 12m. to 1,066 lbs.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
1,066	.2833	.....	....
1,100	.2897	.....	....
1,110	.2914	.....	....
1,120	.2937	.....	....
1,130	.2958	.....	....
1,135	.2970	.....	....
1,140	.2986	.....	....
1,145	.3005	.....	....
1,150	.3023	.....	....
1,155	.3045	.....	....
1,160	.3076	.....	....
1,165	.3110	.....	....
1,170	.3141	.....	....
1,175	.3175	.....	....
1,180	.3221	.....	....
1,200	.3304	.....	8,859,329
10	.....	.1166	....
3	.....	.1141	....
1,200	.3305	.....	....
1,240	.3511	.....	....
1,280	.3691	.....	....
1,320	.4204	.....	....
1,360	.4704	.....	....
1,400	.5296	.....	6,448,116
10	.....	.2794	....
3	.....	.2764	....
1,400	.5500	.....	....
1,440	.6052	.....	....
1,480	.6534	.....	....
1,520	.7356	.....	....
1,560	.8214	.....	....

TABLE LXXXIII. (Bar No. 71).—*Continued.*

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inches.*	*Inch.*	
1,600	.9206	.....	....
10	.....	.6169	....
3	.....	.6132	....
1,600	.9486	.....	....
1,640	1.0198	.....	....
1,680	1.1191	.....	....
1,720	1.2726	.....	....
1,760	1.3791	.....	....
1,800	1.5061	.....	....
1,840	1.6896	.....	....
1,880	1.8556	.....	....

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inches.*	*Inch.*	
1,920	2.0401	.....	....
1,960	2.3676	.....	....
2,000	2.5621	.....	....

The beam could not be raised with an increase of load.
Breaking load, $P = 2{,}000$ pounds.
Modulus of rupture,

$$R = \frac{3Pl}{2bd^2} = 62{,}470 \text{ (4,392 metric).}$$

BAR NO. 72.

COMPOSITION.—Original mixture: Cu, 90; Sn, 5; Zn, 5.

3	.....	.....	....
10	.0018	.....	....
20	.0036	.....	14,309,323
40	.0069	.....	14,862,866
80	.0145	.....	14,145,348
120	.0221	.....	13,921,359
160	.0297	.....	13,811,961
200	.0374	.....	13,710,398
10	.....	.0035	....
3	.....	.0019	....
200	.0376	.....	....
240	.0461	.....	13,347,532
280	.0535	.....	13,418,250
320	.0608	.....	13,493,919
360	.0681	.....	13,553,364
400	.0754	.....	13,601,300
10	.....	.0071	....
3	.....	.0049	....
400	.0757	.....	....
440	.0827	.....	13,640,770
480	.0907	.....	13,568.306
520	.0992	.....	13,439,504
560	.1092	.....	13,180,961
600	.1202	.....	12,797,923
10	.....	.0246	....
3	.....	.0233	....
600	.1246	.....	....
640	.1342	.....	....

Left under strain.
Resistance decreased in 1 m. to 628 lbs.
Resistance decreased in 2 m. to 626 lbs.
Resistance decreased in 3 m. to 624 lbs.
Resistance decreased in 4 m. to 623 lbs.
Resistance decreased in 5 m. to 622 lbs.
Resistance decreased in 6 m. to 621 lbs.
Resistance decreased in 11 m. to 618 lbs.
Resistance decreased in 16 m. to 617 lbs.
Resistance decreased in 19 hrs. 51 m. to 596 lbs.
Resistance decreased in 40 hrs. 36 m. to 591 lbs.
Resistance decreased in 42 hrs. 11 m. to 591 lbs.

591	.1342	.....	....
620	.1387	.....	....
625	.1392	.....	....
630	.1397	.....	....
635	.1406	.....	....
640	.1415	.....	....
645	.1426	.....	....
650	.1441	.....	....
655	.1456	.....	....
660	.1473	.....	....
680	.1525	.....	....
720	.1701	.....	....
760	.1969	.....	....
800	.2287	.....	8,968,410
10	.....	.0997	....
3	.....	.0979	....
800	.2451	.....	....
840	.2814	.....	....

Left under strain.
Resistance decreased in 1 m. to 800 lbs.
Resistance decreased in 2 m. to 795 lbs.
Resistance decreased in 3 m. to 792 lbs.
Resistance decreased in 4 m. to 790 lbs.
Resistance decreased in 5 m. to 789 lbs.
Resistance decreased in 6 m. to 788 lbs.
Resistance decreased in 13 m. to 782 lbs.
Resistance decreased in 21 m. to 779 lbs
Resistance decreased in 31 m. to 777 lbs.
Resistance decreased in 46 m. to 774 lbs.
Resistance decreased in 1 hr. 1 m. to 772 lbs.
Resistance decreased in 1 hr. 16 m. to 771½ lbs.
Resistance decreased in 1 hr. 46 m. to 770 lbs.
Resistance decreased in 3 hr. 1 m. to 766 lbs.
Resistance decreased in 4 hr. 1 m. to 764 lbs.
Resistance decreased in 5 hr. 31 m. to 763 lbs.
Resistance decreased in 21 hr. 15 m. to 752½ lbs.
Resistance decreased in 23 hr. 45 m. to 752 lbs.
Resistance decreased in 24 hr. 36 m. to 752 lbs.

752	.2814	.....	....
780	.2865	.....	....
800	.2900	.....	....
820	.2951	.....	....
825	.2973	.....	....
830	.3006	.....	....
835	.3050	.....	....
840	.3094	.....	....

TABLE LXXXIII. (Bar No. 72).—*Continued.*

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.	LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inches.*	*Inch.*		*Pounds.*	*Inches.*	*Inch.*	
845	.3175	.....	....	1,120	1.3085	.....	....
850	.3237	.....	....	1,160	1.5835	.....	....
860	.3317	.....	....	1,200	1.8925	.....	1,629,090
880	.3510	.....	....	1,240	2.1905	.....	....
920	.4320	.....	....	1,280	2.6325	.....	....
960	.5587	.....	....				
1,000	.7191	.....	3,565,351				
10	.....	.5485	....				
3	.....	.5455	....				
1,000	.7567	.....	....				
1,040	.8634	.....	....				
1,080	1.1001	.....	....				

The beam could not be raised with an increase of weight.
Breaking load, $P =$ 1,280 pounds.
Modulus of rupture,

$$R = \frac{3Pl}{2bd^2} = 41{,}334 \text{ (2,906 metric).}$$

BAR NO. 73.

COMPOSITION.—Original mixture: Cu, 55; Sn, 5; Zn, 44.5.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
3	.....	.....	....
10	.0021	.....	....
20	.0051	.....	11,125,506
40	.0122	.....	9,301,654
80	.0217	.....	10,459,002
120	.0321	.....	10,605,623
160	.0417	.....	10,885,388
200	.0519	.....	10,932,579
10	.....	.0024	....
3	.....	.0024	....
200	.0520	.....	....
240	.0631	.....	10,790,506
280	.0734	.....	10,822,358
320	.0813	.....	11,166,563
360	.0899	.....	11,360,639
400	.1001	.....	11,336,420
10	.....	.0028	....
3	.....	.0008	....
400	.0997	.....	....
440	.1102	.....	11,327,423
480	.1199	.....	11,357,480
520	.1300	.....	11,348,016
560	.1402	.....	11,331,828
600	.1516	.....	11,228,276
10	.....	.0046	....
3	.....	.0018	....
600	.1518	.....	....
640	.1623	.....	11,187,203
680	.1745	.....	11,055,376
720	.1881	.....	10,859,347
760	.2024	.....	10,652,784
800	.2164	.....	10,015,963
10	.....	.0140	....
3	.....	.0119	....
800	.2167	.....	....
840	.2296	.....	10,379,284
880	.2443	.....	10,229,254
920	.2585	.....	10,996,882
960	.2758	.....	9,874,995
1,000	.2923	.....	9,705,798
10	.....	.0440	....
3	.....	.0417	....
1,000	.2948	.....	....
1,040	.3146	.....	9,378,526
1,080	.3338	.....	9,179,045
1,120	.3571	.....	8,897,912
1,160	.3851	.....	....
1,200	.4271	.....	7,970,978

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
10	.....	.1286	....
3	.....	.1265	....
1,200	.4284	.....	....
1,240	.4575	.....	....
1,280	.4973	.....	....
1,320	.5390	.....	....
1,360	.5876	.....	....
1,400	.6419	.....	6,187,577
10	.....	.2986	....
3	.....	.2965	....

Left under strain.
Resistance increased in 20 m. to 5¼ lbs.
Resistance increased in 15 hrs. 45 m. to 10 lbs.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
10	.2970	.....	....
3	.2933	.....	....
1,400	.6508	.....	....
1,440	.7197	.....	....
1,480	.7853	.....	....
1,520	.8571	.....	....
1,560	.9485	.....	....
1,600	1.0361	.....	4,381,050
1,640	1.1295	.....	....
1,680	1.2316	.....	....
1,720	1.3347	.....	....
1,760	1.4535	.....	....
1,800	1.5744	.....	3,243,526
10	.....	1.1384	....
3	.....	1.1358	....
1,800	1.5866	.....	....
1,840	1.7459	.....	....
1,880	1.8619	.....	....
1,920	2.0244	.....	....
1,960	2.2087	.....	....
2 000	2.3178	.....	2,448,014
10	.....	1.9144	....
3	.....	1.9096	....
2,000	2.3513	.....	....
2,000	2.7738	.....	....
2,040	3.0498	.....	....
2,080	3.0498	.....	....
2,100	Beam could not be raised after this pressure was attained.		

Breaking load, $P =$ 2,100 pounds.
Modulus of rupture,

$$R = \frac{3Pl}{2bd^2} = 72{,}308 \text{ (metric, 5,083).}$$

TABLE LXXXIII.—*Continued.*

BAR NO. 74.

COMPOSITION.—Original mixture: Cu, 67.5; Sn, 5; Zn, 27.5.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*	
3	.....	.....	....
10	.0016	.....	....
20	.0033	.....	16,821,775
40	.0070	.....	17,390,724
80	.0146	.....	15,208,723
120	.0218	.....	15,278,489
160	.0294	.....	15,105,267
200	.0393	...	14,125,146
10	.....	.0025	....
3	.....	.0009	....
200	.0396	.....	....
240	.0482	.....	13,820,378
280	.0562	.....	13,828,573
320	.0642	.....	13,834,729
360	.0727	.....	13,712,725
400	.0809	.....	13,723,572
10	.....	.0028	....
3	.....	.0013	....
400	.0807	.....	....
440	.0886	.....	13,783,981
480	.0963	.....	13,834,726
520	.1037	.....	13,918,109
560	.1107	.....	14,040,945
600	.1180	.....	14,113,185
10	.....	.0039	....
3	.....	.0024	....
600	.1177	.....	....
640	.1255	.....	14,154,417
680	.1315	.....	14,352,805
720	.1379	.....	14,491,853
760	.1442	.....	14,628,641
800	.1508	.....	14,724,630
10	.....	.0044	....
3	.....	.0032	....
800	.1514	.....	....
840	.1577	.....	14,784,385
880	.1644	.....	14,857,187

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*	
920	.1721	.....	14,871,767
960	.1801	.....	14,794,934
1,000	.1888	.....	14,701,230
10	.....	.0083	....
3	.....	.0068	....
1,000	.1898	.....	....
1,040	.1980	.....	14,578,869
1,080	.2083	.....	14,390,973
1,120	.2211	.....	....
1,160	.2333	.....	....
1,200	.2469	.....	13,490,121
10	.....	.0190	....
3	.....	.0175	....
1,200	.2498	.....	....
1,240	.2632	.....	....
1,280	.2791	.....	....
1,320	.3013	.....	12,159,913
1,360	.3183	.....	....
1,400	.3360	.....	....
10	.....	.0521	....
3	.....	.0503	....
1,400	.3396	.....	....
1,440	.3521	.....	....
1,480	.3727	.....	....
1,520	.4013	.....	10,513,107
1,560	.4301	.....	....
1,600	.4620	.....	....
10	.....	.1167	....
3	.....	.1151	....
1,600	.4621	.....	9,610,361
1,640	.4874	.....	....
1,660	Broke.		

Breaking load, $P = 1,660$ pounds.
Modulus of rupture,

$$R = \frac{3Pl}{2bd^2} = 55,976 \text{ (metric, 3,935)}.$$

BAR NO. 76.

COMPOSITION.—Original mixture: Cu, 80; Sn, 12.5; Zn, 7.5.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
3	.....	.....	....
10	.0021	.....	....
20	.0053	.....	9,996,061
40	.0109	.....	9,720,941
80	.0193	.....	10,980,131
120	.0271	.....	11,729,695
160	.0361	.....	11,740,527
200	.0463	.....	11,442,576
10	.....	.0040	....
3	.....	.0016	....
200	.0468	.....	....
240	.0546	.....	11,643,764
280	.0614	.....	12,079,930
320	.0682	.....	12,429,120

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
360	.0750	.....	12,714,988
400	.0826	.....	12,827,876
10	.....	.0046	....
3	.....	.0022	....
400	.0824	.....	....
440	.0897	.....	12,993,767
480	.0964	.....	13,189,824
520	.1031	.....	13,360,397
560	.1101	.....	13,473,348
600	.1166	.....	13,630,993
10	.....	.0057	....
3	.....	.0035	....

Left under strain.
Resistance increased in 1 hour to 6 pounds.

TABLE LXXXIII. (Bar No. 76).—*Continued.*

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.	LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
3	.....	.0031	....	3	.....	.0964	....
600	.1167	.....	....	1,400	.3626	.....	....
640	.1232	.....	13,760,813	1,440	.3791	.....	....
680	.1301	.....	13,845,426	1,480	.4036	.....	....
720	.1366	.....	13,962,296	1,520	.4364	.....	....
760	.1440	.....	13,980,603	1,560	.4656	.....	....
800	.1506	.....	14,071,480	1,600	.5081	.....	....
10	.....	.0081	....	10	.....	.2011	....
3	.....	.0064	....	3	.....	.1983	....
800	.1506	.....	....	1,600	.5163	.....	8,209,046
840	.1587	.....	14,020,942	1,640	.5364	.....	....
880	.1675	.....	13,950,222	1,680	.5706	.....	....
920	.1767	.....	13,791,965	1,720	.5986	.....	....
960	.1860	.....	13,671,035	1,760	.6559	.....	....
1,000	.1954	.....	13,556,581	1,800	.6990	.....	6,821,346
10	.....	.0182	....	10	.....	.3462	....
3	.....	.0156	....	3	.....	.3425	....
1,000	.1976	.....	....	1,800	.7148	.....	....
1,040	.2064	.....	13,347,452	1,840	.7579	.....	....
1,080	.2173	.....	....	1,880	.7965	.....	....
1,120	.2299	.....	....	1,920	.8485	.....	....
1,160	.2434	.....	....	1,960	.9090	.....	....
1,200	.2594	.....	12,254,229	2,000	.9652	.....	5,508,330
10	.....	.0447	....	10	.....	.5518	....
3	.....	.0428	....	3	.....	.5473	....
1,200	.2646	.....	....				
1,240	.2766	.....	....				
1,280	.2926	.....	....				
1,320	.3126	.....	....				
1,360	.3313	.....	....				
1,400	.3529	.....	10,508,678				
10	.....	.0991	....				

Broke while putting strain on and before it had reached 1,950 pounds.
Breaking load, $P = 2{,}000$ pounds.
Modulus of rupture,

$$R = \frac{3Pl}{2bd^2} = 66{,}073 \text{ (metric, 4,645).}$$

BAR NO. 77.

COMPOSITION.—Original mixture: Cu, 82.5; Sn, 15; Zn, 25.

3	.....	.....	....	600	.1155	.....	13,774,451
10	.0012	.....	....	10	.....	.0027	....
20	.0031	.....	17,107,474	3	.....	.0014	....
40	.0071	.....	14,938,924	600	.1161	.....	....
80	.0154	.....	13,774,851	640	.1217	.....	13,944,630
120	.0235	.....	13,540,381	680	.1286	.....	14,021,209
160	.0307	.....	13,819,719	720	.1361	.....	14,027,877
200	.0421	.....	12,596,953	760	.1437	.....	14,024,081
10	.....	.0021	....	800	.1506	.....	14,085,034
3	.....	.0006	....	10	.....	.0046	....
200	.0422	.....	....	Left under strain.			
240	.0498	.....	12,779,076	Resistance increased in 27 hrs. 50 m to 14 lbs.			
280	.0575	.....	12,912,424	14	.0046	.....	....
320	.0655	.....	12,954,669	10	.....	.0043	....
360	.0732	.....	13,040,943	3	.....	.0027	....
400	.0800	.....	13,258,292	800	.1463	.....	....
10	.....	.0025	....	840	.1562	.....	14,259,881
3	.....	.0012	....	880	.1627	.....	14,342,099
400	.0802	.....	....	920	.1691	.....	14,425,528
440	.0874	.....	13,349,313	960	.1775	.....	14,341,363
480	.0950	.....	13,396,852	1,000	.1857	.....	14,279,259
520	.1017	.....	13,558,134	10	.....	.0125	....
560	.1090	.....	13,623,198	3	.....	.0105	....

TABLE LXXXIII. (Bar No. 77).—*Continued.*

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.	LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inches.*	*Inch.*	
1,000	.1862	.....	....	1,640	.5167	.....	....
1,040	.1940	.....	14,215,075	1,680	.5528	.....	....
1,080	.2049	... .	....	1,720	.5847	.....	....
1,120	.2165	.....	....	1,760	.6287	.....	....
1,160	.2310	.....	....	1,800	.6807	.....	7,011,877
1,200	.2447	.....	13,003,632	10	.....	.3181	....
10	.....	.0311	....	3	.....	.3156	....
3	.....	.0275	... .	1,800	.6950	.....	....
1,200	2473	.....	....	1,840	.7356	....	....
1,240	.2615	.....	....	1,880	.7842	....	....
1,280	.2791	.....	....	1,920	.8311	.....	....
1,320	.2992	.....	....	1,960	.8924	.....	....
1,360	.3174	.....	....	2,000	.9558	.....	5,548,564
1,400	.3390	.....	10,823,095	10	.....	.5305	....
10	.....	.0822	....	3	.....	.5247	....
3	.....	.0800	....	2,000	.9762	.....	....
1,400	.3430	.....	....	2,040	1.0197	.....	....
1,440	.3599	.....	....	2,080	1.0895	.....	....
1,480	.3860	.....	.. ..	2,090	Broke.		
1,520	.4150	.....	....	Breaking load, $P = 2{,}090$ pounds.			
1,560	.4472	.....	....	Modulus of rupture,			
1,600	.4823	.....	....				
10	.....	.1730	... .	$R = \frac{3Pl}{2bd^2} = 69{,}045$ (metric, 4,854).			
3	.....	.1705	....				
1,600	.4929	.....	8,607,535				

BAR NO. 78

COMPOSITION.—Original mixture: Cu, 60; Sn, 2.5; Zn, 37.5.

3	.....	.....	....	680	.1307	....	13,698,602
10	.0014	.....	....	720	.1489	.....	13,608,229
20	.0079	.....	7,124,701	760	.1581	.....	13,528,371
40	.0119	.....	9,459,685	800	.1676	.....	13,432,210
80	.0197	.....	11,428,458	10	.....	.0083	....
120	.0284	.....	11,891,227	3	.....	.0070	....
160	.0357	.....	12,612,918	800	.1683	.....	....
200	.0431	.....	13,059,198	840	.1785	.....	13,243,564
10	.....	.0019	....	880	.1887	.....	13,124,254
3	. ...	.0001	....	920	.2010	.....	....
200	.0446	.....	....	960	.2137	.....	....
240	.0513	.....	13,166,112	1,000	.2256	.....	12,474,544
280	.0600	.....	13,133,199	10	.....	.0215	....
320	.0683	.....	13,185,394	3	.....	.0201	....
360	.0756	.....	13,401,225	1,000	.2244	.....	....
400	.0839	.....	13,417,197	1,040	.2426	.....	....
10	.....	.0013	....	1,080	.2595	.....	....
3	.....	.0002	....	1,120	.2791	.....	....
400	.0840	.....	....	1,160	.2998	.....	....
440	.0917	.....	13,503,526	1,200	.3244	.....	10,410,323
480	.0996	.....	13,562,685	10	.....	.0566	....
520	.1079	.....	13,562,685	3	.....	.0546	....
560	.1158	.....	13,609,517	1,200	.3245	.....	....
600	.1235	.....	13,672,506	1,240	.3419	.....	....
10	.....	.0032	....	1,280	.3676	.....	... .
3	.....	.0012	....	Left under strain.			
600	.1239	.....	....	Resistance decreased in 2 min. to 1,265 lbs.			
640	1319	.....	13,655,229	Resistance decreased in 4 min. to 1,260 lbs.			

TABLE LXXXIII. (Bar No. 78).—*Continued.*

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.	LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inches.*	*Inch.*	
Resistance decreased in 7 min. to 1,257½ lbs.				1,640	.7345	.....	....
Resistance decreased in 22 min. to 1,253½ lbs.				1,680	.7979	.....	....
Resistance decreased in 4 h. 52 m. to 1,245½ lbs.				1,720	.8654	.....	....
Resistance decreased in 12 h. 32 m. to 1,244 lbs.				1,760	.9268	.....	....
1,260	.3699	.....	....	1,800	1.0156	.....	4,987,853
1,270	.3718	.....	....	10	.....	.5333	....
1,280	.3741	.....	....	3	.....	.5306	....
1,290	.3762	.....	....	1,800	1.0181	.....	....
1,300	.3788	.....	....	1,840	1.0456	.....	....
1,320	.3852	.....	....	1,880	1.1513	.....	....
1,360	.4311	.....	....	1,920	1.2366	.....	....
1,400	.4760	.....	8,277,226	1,960	1.3206	.....	....
10	.....	.1381	....	2,000	1.4426	.....	3,901,644
3	.....	.1360	....	10	.....	.8821	....
1,400	.4775	.....	....	3	.....	.8800	....
1,440	.5017	.....	....	2,000	1.4574	.....	....
1,480	.5430	.....	....	2,030	Broke in the middle.		
1,520	.5965	.....	....				
1,560	.6476	.....	....				
1,600	.7044	.....	6,392,409				
10	.....	.2942	....				
3	.....	.2921	....				
1,600	.7064	.....	....				

Breaking load, $P = 2{,}030$ pounds.
Modulus of rupture,

$$R = \frac{3Pl}{2bd^2} = 69{,}508 \text{ (metric, 4,886).}$$

BAR NO. 80.

COMPOSITION.—Original mixture: Cu, 77.5; Sn, 10; Zn, 12.5.

3	.....	.....	....	680	.1315	.....	....
10	.0014	.....	....	720	.1364	.....	13,871,289
20	.0083	.....	6,332,141	760	.1445	.....	13,821,159
40	.0111	.....	9,469,689	800	.1515	.....	13,876,377
80	.0208	.....	10,107,072	10	.....	.0104	....
120	.0290	.....	10,873,815	3	.....	.0085	....
160	.0368	.....	11,425,387	800	.1524	.....	....
200	.0448	.....	11,731,423	840	.1601	.....	13,787,536
10	.....	.0019	....	880	.1690	.....	13,683,421
3	.....	.0005	....	920	.1809	.....	13,364,351
200	.0449	.....	....	960	.1959	.....	....
240	.0523	.....	12,058,914	1,000	.2099	.....	12,519,481
280	.0585	.....	12,577,687	10	.....	.0297	....
320	.0661	.....	12,721,759	3	.....	.0279	....
360	.0740	.....	12,784,079	1,000	.2130	.....	....
400	.0814	.....	12,913,211	1,040	.2251	.....	....
10	.....	.0024	....	1,080	.2419	.....	....
3	.....	.0010	....	1,120	.2613	.....	....
400	.0810	.....	....	1,160	.2824	.....	....
440	.0884	.....	13,079,741	1,200	.3023	.....	10,431,381
480	.0955	.....	13,207,981	10	.....	.0770	....
520	.1025	.....	13,331,472	3	.....	.0752	....
560	.1095	.....	13,439,173	1,200	.3086	.....	....
600	.1165	.....	13,533,934	1,240	.3249	.....	....
10	.....	.0045	....	1,280	.3445	.....	....
3	.....	.0029	....	1,320	.3765	.....	....
600	.1165	.....	....	1,360	.4039	.....	....
640	.1235	.....	13,617,950	1,400	.4475	.....	8,221,172
680	.1304	.....	13,703,452	10	.....	.1776	....
Left under strain.				3	.....	.1747	....
Resistance decreased in 43 min. to 672 pounds.				1,400	.4595	.....	....

TABLE LXXXIII. (Bar No. 80).—*Continued.*

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.	LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inches.*	*Inch.*	
1,440	.4880	.....	....	10	.....	.5756	....
1,480	.5215	.....	....	3	..	.5718	....
1,520	.5710	.....	....	1,800	.9777	.....	....
1,560	.6148	.....	....	1,840	1.0177	.....	....
1,600	.6675	.....	6,293,140	1,880	1.0903	.....	....
10	....	.3435	....	1,920	1.1930	.....	....
3	.....	.3410	....	1,960	Broke just after beam rose.		
1,600	.6760	.....	....				
1,640	.7096	.....	....				
1,680	.7573	.....	....				
1,720	.8255	.....	....				
1,760	.8785	.....	....				
1,800	.9628	.....	4,912,868				

Breaking load, $P = 1{,}960$ pounds.
Modulus of rupture,

$$R = \frac{3Pl}{2bd^2} = 63{,}849 \text{ (metric, 4,489).}$$

BAR NO. 87.

COMPOSITION.—Original mixture: Cu, 77.5; Sn, 12.5; Zn, 10.

3	.....	.....	....	3	.....	.0106	....
10	.0018	.....	....	1,000	.1912	.....	....
20	.0063	.....	8,550,829	1,040	.2004	.....	....
40	.0108	.....	9,975,965	1,080	.2113	.....	....
80	.0185	.....	11,647,614	1,120	.2225	.....	....
120	.0263	.....	12,289,782	1,160	.2377	.....	....
160	.0336	.....	12,826,242	1,200	.2570	.....	12,576,762
200	.0415	.....	12,980,775	10	.....	.0380	....
10	.....	.0021	....	3	.....	.0348	....
3	.....	.0006	....	1,200	.2592	.....	....
200	.0427	.....	....	1,240	.2705	.....	....
240	.0520	.....	12,431,587	1,280	.2845	.....	....
280	.0603	.....	12,507,172	1,320	.3029	.....	....
320	.0675	.....	12,769,235	1,360	.3240	.....	....
360	.0743	.....	12,050,657	1,400	.3493	.....	10,795,632
400	.0816	.....	13,203,483	10	.....	.0912	....
10	.....	.0035	....	3	.....	.0892	....
3	.....	.0018	....	1,400	.3553	.....	....
400	.0817	.....	....	1,440	.3690	.....	....
440	.0887	.....	13,361,271	1,480	.3905	.....	....
480	.0958	.....	13,495,668	1,520	.4134	.....	....
520	.1025	.....	13,664,637	1,560	.4597	.....	....
560	.1089	.....	13,850,926	1,600	.4950	.....	8,706,298
600	.1153	.....	14,016,565	10	.....	.1865	....
10	.....	.0043	....	3	.....	.1830	....
3	.....	.0021	....	1,600	.5043	.....	....
600	.1161	.....	....	1,640	.5225	.....	....
640	.1219	.....	14,141,485	1,680	.5513	.....	....
680	.1284	.....	14,264,731	1,720	6008	.....	....
720	.1348	.....	14,386,704	1,760	.6490	.....	....
760	.1413	.....	14,486,388	1,800	.6885	.....	7,041,858
800	.1485	.....	14,510,495	10	.....	.3288	....
10	.....	.0055	....	3	.....	.3245	....
3	.....	.0038	....	1,800	.7050	.....	....
800	.1493	.....	....	1,825	Broke.		
840	.1557	.....	14,531,465				
880	.1630	.....	14,541,654				
920	.1707	.....	14,516,869				
960	.1794	.....	14,413,435				
1,000	.1897	.....	....				
10	.....	.0119	....				

Breaking load, $P = 1{,}825$ pounds.
Modulus of rupture,

$$R = \frac{3Pl}{2bd^2} = 61{,}705 \text{ (metric, 4,538).}$$

TABLE LXXXIII.—*Continued*

BAR NO. 88.

COMPOSITION.—Original mixture: Cu, 82.5; Sn, 12.5; Zn, 5.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.	LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
3	.....	.....	....	10	.....	.0520	....
10	.0020	.....	....	3	.....	.0494	....
20	.0047	.....	11,327,661	1,200	.2726	.....	....
40	.0090	.....	11,831,112	1,240	.2864	.....	....
80	.0075	.....	12,169,145	1,280	.3065	.....	....
120	.0254	.....	12,576,378	1,320	.3258	.....	....
160	.0338	.....	12,601,287	1,360	.3487	.....	....
200	.0410	.....	12,985,365	1,400	.3730	.....	9,991,423
10	.....	.0023	....	10	.....	.1153	....
3	.....	.0003	....	3	.....	.1124	....
200	.0411	.....	....	1,400	.3825	.....	....
240	.0509	.....	12,551,671	1,440	.4017	.....	....
280	.0590	.....	....	1,480	.4326	.....	....
320	.0666	.....	12,790,394	1,520	.4733	.....	....
360	.0739	.....	12,967,797	1,560	.5062	.....	....
400	.0810	.....	13,145,680	1,600	.5520	.....	7,715,943
10	.....	.0038	....	10	.....	.2431	....
3	.....	.0017	....	3	.....	.2399	....
400	.0816	.....	....	1,600	.5649	.....	....
440	.0888	.....	13,190,091	1,640	.5875	.....	....
480	.0958	.....	13,377,788	1,680	.6242	.....	....
520	.1021	.....	13,557,691	1,720	.6828	.....	....
560	.1097	.....	13,589,062	1,760	.7412	.....	....
600	.1171	.....	13,639,627	1,800	.8048	.....	5,953,778
10	.....	.0050	....	10	.....	.4380	....
3	.....	.0039	....	3	.....	.4328	....
600	.1169	.....	....	Left under strain.			
640	.1231	.....	13,839,806	Resistance increased in 1 hour to 23 pounds.			
680	.1310	.....	13,818,016	10	.....	.4306	....
720	.1373	.....	13,959,508	3	.....	.4287	....
760	.1451	.....	13,942,939	1,800	.8168	.....	....
800	.1528	.....	13,937,173	1,840	.8490	.....	....
10	.....	.0098	....	1,880	.9086	.....	....
3	.....	.0075	....	1,920	.9788	.....	....
800	.1534	.....	....	1,960	1.0520	.....	....
840	.1608	.....	13,905,974	2,000	1.1326	.....	4,700,689
880	.1693	.....	13,836,741	10	......	.7059	....
920	.1783	.....	13,735,503	3	......	.7014	....
960	.1880	.....	13,593,199	2,000	1.1576	.....	....
1,000	.1983	.....	13,424,108	2,040	1.2173	.....	....
10	.....	.0215	....	2,080	1.2980	.....	....
3	.....	.0194	....	2,120	1.6100	.....	....
1,000	.1988	.....	....	Broke just after beam rose.			
1,040	.2090	.....	....	Breaking load, $P = 2,120$ pounds.			
1,080	.2206	.....	....	Modulus of rupture,			
1,120	.2341	.....	....				
1,160	.2502	.....	....				
1,200	.2675	.....	10,791,095				

$$R = \frac{3Pl}{2bd^2} = 69,960 \text{ (metric, 4,918).}$$

TABLE LXXXIII.—*Continued.*

BAR NO. 89.

COMPOSITION.—Original mixture: Cu, 85; Sn, 12.5; Zn, 2.5.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.	LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inches.*	*Inch.*	
3	.....	.....	....	1,080	.2647	.....	....
10	.0021	.....	....	1,120	.2880	.....	....
20	.0067	.....	7,877,604	1,160	.3193	.....	....
40	.0112	.....	9,424,989	1,200	.3505	.....	9,035,081
80	.0207	.....	10,199,024	10	......	.1245	....
120	.0292	.....	10,845,190	3	......	.1214	....
160	.0367	.....	11,505,164	1,200	.3625	.....	....
200	.0444	.....	11,886,372	1,240	.3993	.....	....
10	.....	.0031	....	1,280	.4435	.....	....
3	.....	.0010	....	1,320	.5130	.....	....
200	.0450	.....	....	1,360	.5783	.....	....
240	.0536	.....	11,816,403	1,400	.6527	.....	5,660,481
280	.0620	.....	11,918,049	10	......	.3707	....
320	.0694	.....	12,168,285	3	......	.3671	....
360	.0765	.....	12,419,811	1,400	.6743	.....	....
400	.0840	.....	12,566,652	1,440	.7230	.....	....
10	.....	.0053	....	1,480	.8345	.....	....
3	.....	.0031	....	1,520	.9425	.....	....
400	.0844	.....	....	1,560	1.0777	.....	....
440	.0915	.....	12,690,260	1,600	1.2199	.....	3,461,264
480	.0981	.....	12,915,497	10	......	.8472	....
520	.1055	.....	13,007,377	3	......	.8423	....
560	.1131	.....	13,066,650	1,600	1.2255	.....	....
600	.1208	.....	13,107,604	1,640	1.3145	.....	....
10	.....	.0084	....	1,680	1.4685	.....	....
3	.....	.0049	....	1,720	1.6595	.....	....
600	.1210	.....	....	1,740	1.7665	.....	....
640	.1279	.....	13,205,304	1,760	1.8645	.....	....
680	.1352	.....	13,273,061	1,780	1.9655	.....	....
720	.1427	.....	13,315,159	1,800	2.0745	.....	2,257,161
760	.1504	.....	13,335,359	1,820	2.1805	.....	....
800	.1594	.....	13,244,652	1,840	2.2995	.....	....
10	.....	.0172	....	1,860	2.4075	.....	....
3	.....	.0143	....	1,880	2.5425	.....	....
800	.1606	.....	....	1,900	2.6985	....	....
840	.1692	.....	13,101,403	1,920	2.8285	.....	....
880	.1798	.....	....				
920	.1930	.....	....				
960	.2095	.....	....				
1,000	.2265	.....	11,651,201				
10	.....	.0438	....				
3	.....	.0410	....				
1,000	.2307	.....	....				
1,040	.2460	.....	....				

The beam could not be raised with an increase of load.

Breaking load, $P = 1,920$ pounds.

Modulus of rupture,

$$R = \frac{3Pl}{2bd^2} = 62,405 \text{ (metric, 4,387).}$$

CHAPTER XIII.

CONDITIONS AFFECTING STRENGTH OF NON-FERROUS METALS AND ALLOYS.

268. **The Conditions Affecting the Strength of the Non-Ferrous Metals** are precisely such as have been found to modify the valuable properties of iron and steel, and of other materials of construction used by the engineer. The effect of every change, whether chemical or physical, of internal or of external conditions, affecting the metal is seen in a modification of its strength, elasticity, ductility and resilience. Change of temperature, either gradual or sudden, alteration of methods of manufacture, differences, however slight, of composition and of density, and every variation of the magnitude, and of the number of applications, of the load has an effect, more or less marked and important, upon the value and reliability of the metal as a structural material.

The effect of heat and of variation of temperature upon the non-ferrous metals and upon the alloys has been but little studied; but some important facts have become well ascertained.

269. **The Strength of Copper** is modified by temperature in the same general way as iron (Part II., Arts. 285–288). It is reduced steadily, and according to a simple law, as temperature rises, finally becoming zero at the point of fusion. Decrease of temperature causes increase of strength.

A committee of the Franklin Institute, of the State of Pennsylvania, consisting of Professor W. R. Johnson, Benjamin Reeves, and Professor A. D. Bache, were engaged, during a period extending from April, 1832, to January, 1837, in experiments upon the tenacity of iron and of copper, under the varying conditions of ordinary use.

The effect of change of temperature upon those metals was investigated with equal intelligence and thoroughness, and most valuable results were obtained.

Upward of one hundred experiments upon copper, at temperatures ranging from the freezing point up to 1,000° Fahrenheit, exhibited plainly the fact that a gradual diminution of strength occurs with increase of temperature, and *vice versa*, and that the change is as uniform as the unavoidable irregularities in the structure of the metal would allow.

The law of this variation of tenacity, within the limits between which the experiments were made, was found to be closely represented by the formula,

$$D^2 = C\ T^3,$$

i. e., the squares of the diminutions of tenacity vary as the cubes of the observed temperatures measured from the freezing point.

The following are the tenacities of copper at various temperatures, as determined by experiment, to the nearest round numbers (see Appendix):

TABLE LXXXIV.

TENACITIES OF COPPER WITH VARYING TEMPERATURES.

TEMPERATURE.		TENACITY.		TEMPERATURE.		TENACITY.	
F.	C.	Lbs. per sq. in.	Kilogs. per sq. cm.	F.	C.	Lbs. per sq. in.	Kilogs. per sq. cm.
122°	50°	33,000	231	602°	316°	22,000	...
212	100	32,000	225	801	427	19,000	144
302	150	31,000	218	912	490	15,000	105
482	250	27,000	190	1 016	546	11,000	77
545	290	25,000	176	2,032	1,111	0	0

270. The Effect of Heat on Bronze and the kalchoid alloys of copper, tin and zinc was determined by the British Admiralty at Portsmouth in the year 1877.*

* London Engineering, Oct. 5, 1877.

The metal was cast in the form of rods one inch in diameter, and composed of five different alloys as follows:

No. 1. Copper, 87.75; tin, 9.75; zinc, 2.5.
No. 2. Copper, 91; tin, 7; zinc, 2.
No. 3. Copper, 85; tin, 5; zinc, 10.
No. 4. Copper, 83; tin, 2; zinc, 15.
No. 5. Copper, 92.5; tin, 5; zinc, 2.5.

The specimens were heated in an oil bath near the testing machine, and the operation of fixing and breaking was rapidly and carefully performed, so as to prevent, as far as possible, loss of heat by radiation. The strength and ductility of the above test-pieces, at atmospheric temperature, were as follows: No. 1, 535 pounds, 12.5 per cent.; No. 2, 825 pounds, 16 per cent.; No. 3, 525 pounds, 21 per cent.; No. 4, 485 pounds, 26 per cent. and No. 5, 560 pounds, 20 per cent. As the heat increases a gradual loss in strength and ductility occurs, up to a certain temperature, at which, within a few degrees, a great change takes place, the strength falls to about one half the original, and the ductility is wholly gone. Thus in alloy No. 1, at 400° F. (204° C.) the tensile strength had fallen to 245 lbs., and the ductility to 0.75 per cent.; the precise temperature at which the change took place was ascertained to be about 370° F. (188° C.). At 350° F. (177° C.), the tensile strength was 450 lbs., and ductility 8.25 per cent. At temperatures above the point where this change begins and up to 500° F. (260° C.) there is little if any loss of strength.

Phosphor-bronze was less affected by heat, and at 500° F. (260° C.) retained two-thirds its tenacity and one-third its ductility. Muntz metal (copper, 62; zinc, 38) was found reliable up to the limit, and iron and steel were not injured.

The following table exhibits the results of these experiments in convenient shape.

Bach finds bronze sensitive to change of temperature, in some cases losing 6 per cent. tenacity at 400° F. and 50 per cent. at 600°. The alloy Cu. 91, Sn. 5, Zn. 4, useful with low steam-pressures, is not probably reliable with high pressure or superheat.

TABLE LXXXV.

THE EFFECT OF HEAT ON TENACITY OF KALCHOID ALLOYS.

TEMPERATURE.		GUN-METAL RODS 1 INCH DIAMETER.												PHOSPHOR-BRONZE RODS 1 INCH DIAMETER.		MUNTZ-METAL RODS .74 INCH DIAMETER.	
		1. Copper ....87.75 Tin........ 9.75 Zinc 2.90		2. SECOND SET. Copper ....87.75 Tin........ 9.75 Zinc 2.50		3. Copper ...... 91 Tin.......... 7 Zinc 2		4. Copper ...... 85 Tin.......... 5 Zinc 10		5. Copper ...... 83 Tin.......... 2 Zinc 15		6. Copper .....92.5 Tin......... 5 Zinc 2.5		Copper.... 92.5 Tin........ 7 Zinc....... .5		Copper ...... 62 Zinc......... 38	
		Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.
Cent.	*Fahr.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*
	Atmospheric.	535	12.5	575	8.75	525	16.	525	21.	485	26.	560	20.	609	17.5	700	2.5
37.7°	100°	505	10.	....	....	525	15.5	550	18.	480	26.	....	....	614	17.	680	2.5
65.5	150	525	11.	....	....	525	14.	530	19.5	450	25.5	....	....	610	18.	720	3.9
93.3	200	485	10.	535	8.75	460	9.	523	19.	460	26.25	440	11.	605	18.	685	3.9
121.1	250	505	10.	385	5.	255	3.	515	16.	440	26.	360	6.	580	15.	670	5.
148.9	300	500	10.	295	.66	265	nil.	531	18.25	435	23.	255	.66	575	12.	650	2.5
176.7	350	450	8.25	295	nil.	....	....	495	17.	435	25.	....	....	470	7.	650	2.25
210.0	400	245	.75	....	....	260	nil.	260	2.	435	25.	....	....	424	5.	600	2.25
232.2	450	265	nil.	....	....	....	....	250	2.	152	1.2	....	....	380	4.	615	3.75
260.0	500	250	nil.	....	....	275	nil.	230	2.	152	nil.	....	....	420	5.	620	5.

271. Various Metals.—Variations of temperature, according to Baudrimont,* produce alterations of the tenacity of metals, as below. The metals were in the form of wire, nearly 0.4 millimetre (0.0158 inch) in diameter, except the iron, which was 0.175 mm. (0.0067 inch), and the copper, 0.48 mm. (0.0189 inch). The tenacity is reduced to kilogrammes per square centimetre. All, except iron, are weakened by increase of temperature.

TABLE LXXXVI.

TENACITIES OF METALS AT VARYING TEMPERATURES.

	TENACITY IN KILOGS. PER SQ. CM.		
	0° C. (32° F.)	100° C. (212° F.)	200° C. (392° F.)
Gold	1,840	1,522	1,288
Platinum	2,263	1,928	1,728
Copper	2,510	2,187	1,822
Silver	2,832	2,327	1,858
Palladium	3,648	3,248	2,708
Iron	20,540	19,173	21,027

272. The Modulus of Elasticity of hard-drawn iron, copper, and brass wires was found by Loomis and Kohlrausch † to vary with temperature according to a law expressed by the equation

$$E = E_0(1 - at - bt^2),$$

in which E is the modulus at the temperature t, E_0 that at 0° and a and b experimentally determined co-efficients; for the Centigrade scale, their values are

	a	b
Iron	0.000 483	0.000 000 12
Copper	0.000 572	0.000 000 28
Brass	0.000 485	0.000 001 36

* Annales de Chimie et de Physique, 1850.

† Am. Jour. Science and Arts, vol. l., Nov., 1870.

Thus, the reduction of the value of the modulus between the melting point of ice and the boiling point of water is, for iron 4.6 to 5 per cent.; for copper, 5.5 to 6 per cent.; for brass, 5.6 to 6.2 per cent., and this variation is most rapid at the highest temperature. The values of the moduli were found to be very closely proportional to the co-efficients of expansion.

The following determinations were made by Wertheim:

TABLE LXXXVII.

VARIATION OF MODULI OF ELASTICITY WITH TEMPERATURE.

	S. G.	15° C., 59° F.		100° C., 212° F.		200° C., 392° F.	
		Metric.	British.	Metric.	British.	Metric.	British.
Lead	11.232	173	2.4	163	2.3	....	....
Gold	18.035	558	7.9.	531	7.6	548	7.9
Silver	10.304	715	10.2	727	10.4	637	9.1
Palladium	11.225	979	14.0	....	....	....	....
Copper	8.936	1,052	15.0	983	14.0	786	11.2
Platinum	21.083	1,552	22.2	1,418	20.3	1,296	18.5
Steel (wire)	7.622	1,728	24.9	2,129	30.4	1,928	27.5
Steel (cast)	7.919	1,956	26.5	1,901	27.1	1,792	25.6
Iron	7.757	2,079	26.8	2,188	31.2	1,770	25.2

The metric values are in thousands of kilogrammes per square centimetre; the British in millions of pounds per square inch.

273. The Stress produced by Change of Temperature is easily calculated when the modulus of elasticity and the coefficient of expansion are known, thus:

Let E = the modulus of elasticity;
λ = the change of length per degree and per unit of length;
Δt° = the difference of initial and final temperatures;
p = the stress produced.

Then:

$$p : E :: \lambda \, \Delta t^\circ : 1,$$

$$\therefore p = \lambda E \, \Delta t^\circ \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

For good wrought iron and steel, taking E as 28,000,000 pounds on the square inch, or 2,000,000 kilogrammes on the square centimetre, and λ as 0. 0000068 for Fahrenheit, and as 0.0000120 for Centigrade degrees:

$$\left. \begin{aligned} p &= 190 \, \Delta t^\circ \text{ Fahr., nearly} \\ &= \;\; 25 \, \Delta t^\circ \text{ Cent., nearly} \end{aligned} \right\} \quad . \quad . \quad . \quad . \quad (2)$$

For cast iron, taking $E = 16.000,000$; $\lambda = 0.0000062$:

$$\left. \begin{aligned} p &= 100 \, \Delta t^\circ \text{ Fahr., nearly} \\ &= \;\; 12 \, \Delta t^\circ \text{ Cent., nearly} \end{aligned} \right\} \quad . \quad . \quad . \quad . \quad (3)$$

This force must be allowed for as if a part of the tension, T, or compression, C, produced by the working load when the parts are not free to expand.

274. **Sudden Variation of Temperature** has an effect, very usually, upon the non-ferrous metals, which is afterward seen in a permanent alteration of their properties. Repeated heating and cooling causes a permanent change of form, and sudden cooling from high temperatures causes a modification of the tenacity and ductility of the kalchoids and the metals composing such alloys, which is precisely the opposite of that produced on steel. Thus copper, brass, and bronze, suddenly cooled from a low red heat, are softened and weakened and greatly improved in malleability and ductility. This process, which is one of hardening and tempering with steels, is thus one of softening with other metals. On the other hand, very slow cooling softens or "anneals" steels, while it hardens the non-ferrous metals and alloys. Thus, also, casting bronze ordnance or other castings in chills increases the value of the metal by preventing liquation and securing homogeneousness and maximum density.

275. **The Effect of Chill-casting** is exhibited in the following tables of tests by tension furnished to the Author by the U. S. N. Department in the course of a series of investigations in 1877. The metal has the composition, copper (Lake Superior), 9; tin, 1; it was cast either in chills or in sand as specified, after having been melted in a reverberatory furnace, the copper first and the tin three hours later. The specimens tested were of the "short" pattern, and the reduction of section, rather than the elongation recorded, is the measure of relative ductility. The tables also exhibit the method of testing usual in the Ordnance Department of the U. S. Navy in 1875–6. British measures are here used.

TABLE LXXXVIII.

EFFECT OF CASTING BRONZE IN "CHILLS."

Navy Ordnance-Bronze.

MARK.	TENSILE STRENGTH PER SQUARE INCH OF—		PERMANENT ELONGATION IN PARTS OF ORIGINAL LENGTH.	PERMANENT REDUCTION OF AREA IN PARTS OF ORIGINAL.	SPECIFIC GRAVITY.	
	Original section.	Fractured section.				
M 1, 3-4-75.....	42,037	70,000	.4795	.40	.....	
M 2, 3-4-75.....	41,768	71,600	.478	.417	.... .	
BB IX.........	22,385	......	.100	....	.....	Full of large tin spots.
M 2, 5-6-75.....	45,737	......	.522	.470	.....	
No. 3, 8-21-75 ..	49,772	65,600	.2603	.240	8.878	Cast in chill mould.
No. 2, 8-21-75 ..	48,000	60,000	.211	.20	.....	Cast in chill mould.
GB 2, 5-6-75 ...	35,820	......	.4075	.50	.....	
GB 3, 5-6-75 ...	29,818	......	.0291	....	8.392	Flaw in the breaking portion.
B 3 L, 12-70-75.	33,630	39,000	.135	.134	.....	Cast in chill mould.
M 1 C, 3-11-76.	51,459	91,600	.580	.438	.....	
B 2 C, 3-11-76..	45,837	73,450	.396	.376	.....	Cast in chill mould.
B 3 C, 3-11-76..	44,869	71,600	.415	.373	8.853	Cast in chill mould.

The guns cast in chill moulds were composed of 10 parts of copper to 1 part of tin; the others were of 9 parts of copper to 1 part of tin.

In the course of experiments made by Major Wade,* three

* Report on Ordnance.

howitzers, Nos. 27, 28, and 29, were cast from the same liquid metal. No. 27 was cast when the metal was at the highest temperature, No. 28 was cast fifteen minutes later, and No. 29 fourteen minutes after No. 28. The following results were obtained:

NUMBER.	TIME OF METAL IN LADLE, MINUTES.	TEMPERATURE OF METAL AT CASTING.	SPECIFIC GRAVITY—				TENACITY—		
			Of gun-heads.	Of entire gun.	Of small bars cast in—		Of gun-heads.	Of small bars cast in—	
					Gun mould.	Separate mould.		Gun mould.	Separate mould.
27	0	Highest	7.986	8.195	8.686	8.554	17,761	50,973	31,132
28	15	Mean.......	8.351	8.551	8.823	8.447	28,995	52,330	28,153
29	29	Lowest	8.538	8.752	8.816	8.376	23,722	56,786	28,082

In casting another howitzer, No. 30, small test-bars were cast in separate moulds, one of which was of cast iron, to ascertain the effect of sudden cooling, and the others were of clay, similar to the gun-mould. The tests of all the samples from this casting were as follows:

	SPECIFIC GRAVITY.	TENACITY.
Small bars cast separately in iron mould..	8.953	37,688
Small bars cast separately in clay mould..	8.313	25,783
Small bar cast in gun mould	8.896	53,798
Gun-head samples	8.490	35,578
Finished howitzer	8.733	

The effect of the chill is evidently very beneficial, and iron moulds should, therefore, always be used where possible in the casting of bronze; with brass they are less necessary.

276. **Effect of Tempering and Annealing.**—Riche determined the effect of tempering and annealing upon the

density of the bronzes, finding that tempering increased the density of those rich in tin but not of others, as gun-bronzes; and that annealing reduces the density of tempered bronze although it does not entirely destroy that effect. Density is increased to a considerable degree by mechanical action as well as by tempering.

Successive temperings and annealings produce, on the whole, an increase of density. Tempering, according to both Darcet and Riche, softens the bronzes rich in tin, *i.e.*, those containing about 20 per cent. tin. Thus, Riche obtained the result that such bronzes, tempered, can be moulded in the press, while they will crack if untempered or annealed. Bronze and steel exhibit opposite behavior in this respect. The same author finds that working hot does not increase the density more than working at low temperature. The metal increases in density very rapidly by working hot, and without danger of rupture; while cold the action is extremely slight and very difficult.

There is evidence that the method of making gongs by the Chinese involves working hot under the hammer.*

Riche, reaches the following conclusions: †

"The bronzes rich in tin (18 to 22 per cent.) increase in density with tempering; and annealing lessens the density of tempered bronze, but in a less proportion. The density is considerably increased by the alternate action of tempering and annealing, and of the press. These effects, the reverse of those in steel, coincide with the fact that tempering softens bronze while it hardens steel.

"This softening, discovered by Darcet, is not sufficient to allow of this bronze being worked cold for industrial purposes. It was shown that this metal—extremely hard when cold and pulverizable at red heat—is forged and rolled at dark red heat with remarkable facility. This fact enabled me, in common with M. Champion, to succeed in the manufacture of tamtams, and other sonorous instruments, by the method followed in the East.

* Industries Anciennes, etc. Lacroix, Paris, 1869.

† Annales de Chimie et de Physique, vol. xxx., 1873.

"Tempering produced no apparent softening in the bronzes less rich in tin (12 to 6 per cent.); and if they are tempered for industrial uses it is more especially in order to detach the oxide produced during the reheating of the matter in the course of the operations.

"It was found that in the axis of a cannon, and especially toward the muzzle, there are some parts very rich in tin and in zinc.

"The density of copper, subjected alternately to mechanical action, then to tempering or annealing, displays inverse variations according as it is exposed to the air or sheltered from it during the reheating; while in the first case the mechanical action increases the density, in the second mechanical action diminishes the density.

"Mechanical action increases the density of yellow brass, and this effect is counteracted in part by tempering, and especially by annealing. It is thought that annealing is preferable to tempering in working with brass.

"Mechanical action, tempering, and annealing, do not sensibly change the volume of similor and of the bronzes of aluminium, alloys remarkable for the facility with which they can be worked.

"While repeated mechanical action increases the density of the bronzes rich in tin, especially of porous copper, of copper alloyed with iron, of brass, it evidently diminishes the density of copper exposed to the air during reheating, and it produces no noticeable alteration in the volume of similor or of aluminium bronze. Tempering produces on brass, and especially on the bronzes rich in tin previously annealed, an increase in density, contrary to what takes place in steel, copper and glass.

"It will be perceived that tempering diminishes the density of a body, because the surface, cooled before the centre, cannot contract freely by reason of the resistance that the interior parts dilated at this moment offer to contraction."

The following are some of the results of Riche's experiments.

BRASS.	DENSITY.	
	I.	II.
After rolling	8.409	8.412
After tempering	8.410	8.411
After rolling	8.414	8.415
After tempering	8.431	8.427
After rolling	8.443	8.436
After tempering	8 433	8.436
After rolling	8 439	8.444
After tempering	8.437	8.437
After rolling	8.439	8.437
After tempering	8.445	8.443

The metal was a yellow brass containing copper, 65; zinc, 35. The same general effect was seen when the brass contained, copper, 91; zinc, 9.

It is to be noted that there is a great difference between the effect on copper protected from the air while heating it, as should always be done, and on copper exposed to the air; annealing and tempering diminished density in the one case and increased it in the other, although the latter modification is not important. The increase of density resulting from the heat is very nearly compensated by the tempering, so that the plate, after being made considerably thinner, is found to have the same density as before the operation. Cast at a high temperature, the density became 8.939, in Riche's experiments, and was but 8.039 when poured at a low heat.

277. **The Effect of Annealing on Tenacity** is seen in the following experiments:

Wertheim obtained for the tenacity of copper wire,

	T.	T_m.	ELON.
Copper, hard drawn	58,600	4,100	0.0033
" annealed	45,100	3,160	0.0030

Kirkaldy, testing wire, obtained the following results:

TABLE LXXXIX.

TENACITY OF WIRE, HARD AND ANNEALED.

	HARD WIRE (A).		ANNEALED WIRE (B).		COMPLETE TURNS IN 5 IN. (12.8 CM.).		FINAL ELONGATION PER CENT.
	Lbs. per sq. in.	Kilogs. per sq. cm.	Lbs. per sq. in.	Kilogs. per sq. cm.	A.	B.	
Phosphor-bronze.	102,750	7,224	49,351	3,470	6.7	87	37.5
" "	120,957	8,504	47,787	1,360	22.3	52	34.1
" "	120,950	8,503	53,381	3,753	13.0	124	42.4
" "	139,141	9,872	54,153	3,807	17.3	53	44.9
" "	159,515	11,212	58,853	4,138	13.3	66	46.6
" "	151,119	10,625	64,569	4,340	15.8	60	42.8
Copper..........	63,122	4,438	37,002	2,602	86.7	96	34.1
Steel............	120,976	8,506	74,637	5,248	22.4	79	10.9
Best charcoal iron.	65,834	4,629	46,160	3,245	48.0	87	28.0

These figures are considerably in excess of those ordinarily obtained for bronzes into which no phosphorus has been introduced. The effect of annealing is remarkably great.

Other illustrations of this and related phenomena are given elsewhere, as, *e.g.*, in Art. 247, where they are well exhibited in Anderson's experiments on sterro-metal.

278. **The Effect of Temperature of Casting** and cooling upon zinc has been studied by Bolley as illustrative of this effect generally.* He finds that zinc may solidify in either of two forms, the one finely crystalline, the other coarsely crystalline with lamellar structure. He finds these conditions to be determined, not by the presence of other elements, but by the temperature of casting. When cast at the lowest temperature at which it will "pour," it takes the first form, with a density of 7.18; when cast at a full red heat, it takes the second form, with a lower density, 6.86. In the first case, it is comparatively malleable, remains malleable throughout a wide range of temperature, and is not as readily soluble in acids as when in the second condition. In

* Annalen der Chimie und Pharm., xcv., p. 294.

the latter form it is not malleable, and is more soluble. These conditions have not been studied with other metals.

279. **The Effect of Time, and Velocity of Rupture,** on the action of stress is not less important with the non-ferrous than with the ferrous metals. A very important difference is found to exist between the two classes. (See Part II., Art. 295, *et seq.*) The rupture of the non-ferrous metals takes place under lower stresses, as the time of operation is greater, and the fracture is more slowly produced. The contrary is the case with iron and steel. With non-ferrous metals, the piece strained may give way, ultimately, under static loads greatly less than those required to produce immediate rupture. This occurs to a less extent with soft annealed iron, and still less with harder irons and steels. Cast iron is stated by Hodgkinson to be capable of sustaining, indefinitely, loads closely approaching the breaking load under test. Some of the alloys will probably exhibit similar differences.

With rapid distortion, the resistance is increased with non-ferrous metals, decreased with iron.

The Author has, therefore, enunciated a principle which had been deduced from experiments on wrought iron, which is, evidently, of vital importance to the engineer, viz.: "That the time during which applied stress acts is an important element in determining its effects, not only as an element which modifies the effect of the *vis viva* of the attacking mass and the action of the inertia of the piece attacked, but also as modifying seriously the conditions of production and relief of internal strain by even simple stresses." *

Should it be true, as suggested by the Author, that the cause of the variation of resistance, sometimes observed with increased velocity of distortion, is closely related to the cause of the variation of the elastic limit by strain,† it would seem to be a corollary that materials so inelastic and so viscous as to be incapable of becoming internally strained during distortion, should offer greater resistance to rapid than to

* Trans. American Society of Civil Engineers, vol. iv., p. 334.

† See Part II., pp. 588–604; figures 135–138.

slowly-produced distortion, in consequence of their inability to "flow" so rapidly as to reduce resistance by such fluxion at the higher speed, or by correspondingly reducing the fractured section. This principle has been shown, by a large number of experiments, to be frequently, if not invariably, the fact. Copper, tin, and other inelastic and ductile metals and alloys, were found by the author to exhibit this behavior, and are therefore quite opposite in this respect to commercial wrought iron and worked steel.

The records of the Mechanical Laboratory of Sibley College, Cornell University, frequently illustrate the proposition that metals which gradually yield under a constant load offer increased resistance with increased rapidity of rupture.

The curves of deflections of a considerable number of ductile metals and alloys are very smooth when the time during which each load has been left upon them is the same; but whenever that time has been variable the curve has been irregular. Bars of such metals broken by transverse stress give a greater resistance to rapidly increasing stress than to stress slowly intensified. Two pieces of tin, as described in Article 280, were broken by tension, the one rapidly and the other slowly. The first broke under a load of 2,100 and the latter of 1,400 pounds. The example illustrates well the very great difference which is possible in such cases, and seems to the writer to indicate the possibility, in extreme cases, of obtaining results which may be fatally deceptive when the time of rupture is not noted.

The depression of the elastic limit has been observed previously in materials, but less attention has been paid to it than the importance of the phenomenon would seem to demand.

The strain diagram of a bronze bar is nearly hyperbolic; but the law of Hooke, *ut tensio sic vis*, holds good, as usual, up to a point at which the load is about one-half the maximum. The curve of times and loads exhibits the rate of loss of effort while the bar was finally held at a deflection of 0.5456 inch, the load being carefully and regularly reduced, as the effort diminished, from 1,233 to 911 pounds, at which latter figure the bar broke. The curve is a very smooth one.

TABLE XC.

EFFECT OF TIME ON BRASS.

BAR NO. 599.

90 parts zinc, 10 parts copper: 1 × 0.992 × 22 inches.

LOAD.	DEFLECTION.	SET.	LOAD.	DEFLECTION.	SET.	LOAD.	DEFLECTION.	SET.
Pounds.	*Inch.*	*Inch.*	*Pounds.*	*Inch.*	*Inch.*	*Pounds.*	*Inch.*	*Inch.*
23	0.0033	......	363	0.0781	......	3	......	0.0336
43	0.0078	......	403	0.0881	......	643	0.1641	......
63	0.0127	......	3	......	0.0079	803	0.2149	......
103	0.0225	......	403	0.0886	......	1,003	0.3178	......
143	0.031	......	Resistance fell in 8 h. 30 m.			1,103	0.3921	......
163	0.0347	......	to 333	0.0886	......	1,203	0.481	......
Resistance fell in 15 h. 25 m.			3	......	0.0246	1,233	0.5209	......
to 143	0.0347	......	333	0.0896	......	Resistance fell in 15 m.		
3	......	0.0039	Resistance fell in 15 h.			to 1,137	0.5209	......
163	0.0391	......	to 302	0.0896	......	3	......	0.2736
203	0.0471	......	303	0.0876	......	1,137	0.5131	......
243	0.0544	......	403	0.1072	......	1,233	0.5456	......
283	0.0611	......	503	0.1282	......			
323	0.0692	......	603	0.1521	......			

The bar was left under strain at $11^h\ 22^m$ A.M., and the effort to restore itself measured at intervals, as follows:

HOUR.—11:37	11:50 A.M.	12:2	12:8	12:25	12:39½	12:53½	12:58½	1:20 P.M.
EFFORT.—1,133	1,093	1,070	1,063	1,043	1,023	1,003	993	911 pounds.

At $1^h\ 23^m$ P.M. the bar broke.

BAR NO. 596.

75 parts zinc, 25 parts copper; second casting · 0.985 × 0.985 × 22 inches.

LOAD.	DEFLECTION.	SET.	LOAD.	DEFLECTION.	SET.	LOAD.	DEFLECTION.	SET.
Pounds.	*Inch.*	*Inch.*	*Pounds.*	*Inch.*	*Inch.*	*Pounds.*	*Inch.*	*Inch.*
23	0.0057	......	463	0.0799	......	503	0.0894	......
63	0.0142	......	503	0.0866	......	543	0.0952	......
103	0.0207	......	3	......	0.0014	583	0.1012	......
143	0.0275	......	503	0.0866	......	603	0.1042	......
183	0.0346	......	Resistance fell in 5 h.			623	0.1075	......
223	0.0414	......	to 489	0.0866	......	643	0.1102	......
263	0.0485	......	3	......	0.0074	663	0.1136	......
303	0.0549	......	489	0.0866	......	Broke 5 seconds after with ringing sound.		
343	0.0610	......	Resistance fell in 13 h. 30 m.					
383	0.0669	......	to 473	0.0866	......			
423	0.073	......	3	......	0.0092			

An example of somewhat similar behavior, but exhibited by a metal of very different quality, is shown above.

This bar was hard, brittle, and elastic, but must apparently be classed with tin in its behavior under either continued or intermitted stress.

These latter specimens were broken; one in each set by adding weight steadily until the end of the test, so as to give as little time for elevation of elastic limit as was possible; and one in each set by intermittent stress, observing sets, and the elevation of the elastic limit.

There seems to the Author to exist a distinction, illustrated in these cases, between that "flow" which is seen in these metals, and that to which has been attributed the relief of internal stress and the elevation of the elastic limit by strain and with time.

If the long-known effects of cold-hammering, cold-rolling, and wire-drawing in stiffening, strengthening, and hardening some metals can be, as the Author is inclined to believe, attributed in part to this molecular change, as well as to simple condensation and closing up of cavities and pores, this variation of the elastic limit by distortion under externally applied force has been shown to occur in iron and in metals of that class in tension, torsion, compression, and under transverse strain.

280. Effect of Prolonged Stress on Tin and Zinc.—In testing a bar of tin, in work done as described in earlier chapters, the Author studied this phenomenon. An experiment on No. 29 A (a bar of pure tin) was made to determine the difference in resistance to slow and rapid rupture. This bar was a good casting, and tests of the two pieces, one from the upper and one from the lower end of the bar, should show little, if any, difference in strength. No. 29 A was tested with a load of 1,700 pounds, which caused an elongation of 0.15 inch. This load was then reduced to 1,250 pounds, and the reading again taken, showing an elongation of 0.19 inch, which increased in two minutes to 0.27 inch. The load was then increased to 1,400 pounds, and the elongation was 0.32 inch. The load was allowed to remain on the bar for ten minutes, and the elongation gradually increased to 1.7 inches, when the bar broke. It seems probable from this test that the load of 1,400 pounds would have broken the piece, even if the load of 1,700 pounds had not been placed on it at the beginning of the test.

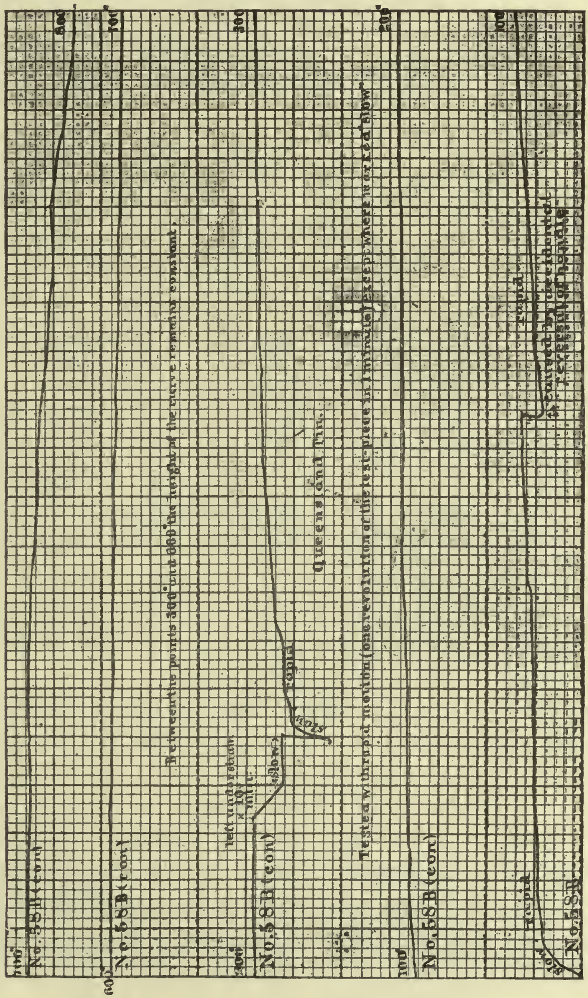


FIG. 30.—AUTOGRAPHIC STRAIN DIAGRAM OF TIN.

Bar No. 29 B was tested in a different manner. The load was gradually, but rapidly, increased to 2,100 pounds, without stopping longer than was necessary to take the reading of the elongations at 975, 1,180, 1,290, 1,600, and 2,000 pounds. At 2,100 pounds, the elongation read 1.88 inches. The piece then extended very rapidly, and, at the same time, its resistance, as measured by the scale-beam, reduced to 1,700 pounds. The pump of the hydraulic press was worked as fast as possible, but the beam could not be balanced beyond 1,700 pounds. The piece sustained this load a few seconds, then broke after an elongation of 2.58 inches.

Comparing the tests, it is seen that the resistance of No. 29 A to an elongation greater than 0.19 inch was never greater than 1,400 pounds, while that of No. 29 B was 2,100 pounds, or 50 per cent. more than the former; which 50 per cent. apparent increase of strength was evidently due to the greater rapidity of the test of No. 29 B. The fact that the difference in strength is only apparent is confirmed by the experiments by torsional stress on pieces from the same bar. These showed that torsion-pieces No. 29 A and No. 29 B, from the top and from the bottom of the bar, tested by moderately slow motion, each gave a resistance of 14.2 foot-pounds torsional moment; piece No. 29 C, from the middle of the bar, tested in the same manner, resisted 13.2 foot-pounds, while No. 29 D, a piece taken from the middle of the bar and adjoining No. 29 C, tested by very slow motion and left under stress for hours, resisted only 9.2 foot-pounds or some 30 per cent. less than either of the other pieces.

The effect of slow and rapid test is shown by both bars in the tensile test. The average tenacity of all the pieces tested is given as 3,130 pounds per square inch, but it is probable that all the pieces would have broken at as low as 2,000 pounds if the test had been of long duration, say one hour, or as high as 4,000 pounds if each test had been made in, say, five minutes. The records of several tests follow.

The effect of time is also shown in the autographic strain-diagrams (Fig. 30), and in the records calculated from them.

TABLE XCI.

STRENGTH OF TIN AS VARYING WITH TIME OF TESTING.

Tests by Tensile Stress.

QUEENSLAND TIN, CAST.

No. 58 A.—Material: Tin cast in iron mould. Dimensions: Length, 5″ (12.7 cm.); Diameter, 0.798″ (2 cm.).

LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	SET.	ELONGATION IN PARTS OF ORIGINAL LENGTH.
Pounds.	*Inch.*	*Inch.*	
400	0.0002	......	.00004
600	0.0027	......	.0005
800	0.0081	......	.0016
1,000	0.0175	......	.0035
240	......	0.0159	......
1,200	0.0309	.....	.0062
1,400	0.0433	......	.0086
1,600	0.0517	......	.0103
1,800	0.0630	......	.0126
2,000	0.0745	......	.0149
240	......	0.0756	......
2,000	0.0860	......	.0172

2,000 pounds per square inch kept constant for 14 minutes, elongation increasing as follows:

LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	SET.	ELONGATION IN PARTS OF ORIGINAL LENGTH.
Minutes.	*Inch.*	*Pounds.*	
1	0.1070	......	......
2	0.1156	......	......
3	0.1298	......	......
4	0.1437	......	......
5	0.1580	......	......
6	0.1709	......	......
7	0.1861	......	......
8	0.1997	......	.....
9	0.2176	......	.....
10	0.2328	......	.....
11	0.2490	......	.....
12	0.2687	......	.....
13	0.2929	......	.....
14	0.3311	......	.....

Resistance reduced to 1,700 pounds per square inch, and a crack was observed on one side.

1,700 lbs.	0.3610	......	.0722
1 min.	0.4315	......	.0863

Resistance decreased gradually, and piece broke 2 inches from A end.

The fractured surface had an irregular boundary nearly elliptical; two diameters measured 0.580 and 0.685 inch.

Tensile strength per square inch, original section, under slow strain, 2,000 pounds (141 kilogs. per sq. cm.).

Total time of test, 30 minutes.

No. 58 B.

400	0.0005	......	.0001
600	0.0029	......	.0006
800	0.0051	......	.0010
1,000	0.0108	......	.0022
1,200	0.0184	......	.0037
1,400	0.0293	......	.0059
1,600	0.0394	......	.0079
1,800	0.0484	......	.0097
2,000	0.0566	......	.0113
240	......	0.0557	.....
2,000	0.0631	......	.0126

Stress kept constant for 2 minutes.

1 min.	0.0724	......	.0145
2 min.	0.0821	......	.0164

Increased stress rapidly for 1 minute, and piece broke at 3,520 pounds per square inch.

Total time of test, 8 minutes.

Diameter of fractured section, 0.542 inch.

Tensile strength per square inch, original section under rapid strain, 3,520 pounds (248 kilogs. per sq. cm.).

TABLE XCI.—*Continued.*

TEST BY TRANSVERSE STRESS.

No. 58.—Material: Queensland tin cast in iron mould.—Dimensions: l = 22″ (55.9 cm.); b = 1″ (2.54 cm.); d = 1″ (2.54 cm.).

LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*	
10	0.0082	......	....
20	0.0118	......	5,574,991
3	......	0.0009	....
10	0.0087	......	....
20	0.0129	......	....
30	0.0173	......	5,310,020
40	0.0241	......	5,635,593
50	0.0333	......	3,596,764
3	......	0.0126	....
60	0.0502	......	....
70	0.0600	......	....
80	0.0859	......	....
90	0.1416	......	....
100	0.2109	......	....
3	......	0.1753	....
100	0.2415	......	....

Resistance decreased in 1 minute to 70 pounds.

Resistance decreased in 3 minutes to 62 pounds.

LOAD PER SQUARE INCH.	ELONGATION IN 5 INCHES.	SET.	MODULUS OF ELASTICITY.
Pounds.	*Inch.*	*Inch.*	
Resistance decreased in 8 minutes to 56 pounds.			
100	0.3033	......	......
110	0.3827	......	......
120	0.6403	......	......
130	0.8091	......	......
130 Cont'd 1 min.	1.07	......	......
140	1.36	......	......
150	Ran pressure-screw down slowly till deflection was more than 3 inches; the scale-beam vibrating all the time about 150 pounds.		

Bent without breaking.

Breaking load, P = 150 pounds.

Modulus of rupture, $R = \frac{3Pl}{2bd^2}$ = 4,559 (metric, 321).

The effect of prolonged stress on cast zinc is exhibited by the following memorandum of test:

No. 21 (cast zinc).—Four pieces were tested by torsion, which gave results nearly agreeing, the torsional moments varying from 34.42 to 37.83 foot-pounds, and the angles of torsion from 123 to 163 degrees. The strain diagrams of these pieces exhibit marked peculiarities. No. 21 D was left for fourteen hours under stress, just before reaching its maximum resistance. In this time the resistance decreased 15 per cent. On resuming the test, the piece slowly resumed its maximum resistance, which it held for some time. It was then left under stress, and in about 30 seconds the resistance decreased about 15 per cent. The piece then broke partly through, and the resistance decreased to less than one-half the maximum. On continuing the torsion, the piece held by the unbroken side exhibited a constant resistance till it was twisted through about 80 degrees further, when it broke entirely across.

On No. 21 B experiments were made to determine the effect of rapid and of slow stress and of resting under stress. They indicated a decrease of resistance when resting under stress, a uniform resistance to very slow motion, and a rapid increase of resistance to rapid motion, except after the resistance has reached the maximum, when rapid motion then keeps the resistance constant.

It was observed that very ductile metals, such as tin itself and alloys containing a large amount of tin, all exhibit different amounts of resistance to slow and to rapid stress, and a decrease of resistance on resting under stress. The same phenomenon is exhibited by cast zinc, which is much less ductile than the copper-tin alloys, and is less ductile than several of the alloys of copper and zinc (those containing from 20 to 40 per cent. of zinc), which either did not show the phenomenon at all, or but slightly.

281. The Effect on Bronze of long continued stress in producing continuous distortion, even when the loads are far within those required to produce the same effect on first application, is well exhibited below.

TABLE XCII.

EFFECT OF TIME ON BRONZE.

Tests by Transverse Stress—With Dead Loads.

Samples 1 × 1 × 22 inches.

NO. OF TEST.	MATERIAL PARTS.		LOAD.	DEFLECTION.	TIME.	INCREASED DEFLECTION.	BREAKING WEIGHT.
	Tin.	Copper.					
			Pounds.	*Inches.*		*Inches.*	*Pounds.*
7	.....	100	600	0.534	5 minutes	0.009	650
8	1.9	98.1	475	1.762	3 minutes	0.291	....
			500	2.108	3 minutes	0.488	500
9	7.2	92.8	950	0.348	5 minutes	0.081	1,350
10	10.	90.	950	0.395	5 minutes	0.021	....
			1,485	3.447	13 minutes	4.087	1,485
11	90.3	9.7	100	0.085	10 minutes	0.021	....
			120	0.140	10 minutes	0.055	....
			140	0.221	10 minutes	0.098	....
			140	0.319	10 minutes	0.038	....
			140	0.357	40 hours	0.920	....

TABLE XCII.—*Continued.*

NO. OF TEST.	MATERIAL PARTS.		LOAD.	DEFLECTION.	TIME.	INCREASED DEFLECTION.	BREAKING WEIGHT.
	Tin.	Copper.					
			Pounds.	*Inches.*		*Inches.*	*Pounds.*
			160	1.294	10 minutes	0.025	....
			160	1.320	1 day	1.000	....
			160	2.320	1 day	1.000	....
			160	3.320	1 day	1.000	160
12	98.89	1.11	90	0.243	5 minutes	0.063	....
			120	0.736	15 minutes ...	1.055	....
			120	1.791	30 minutes	0.748	....
			120	2.539	45 minutes	0.595	....
			120	3.134	12 hours	8.000	120
13	100	.....	80	0.218	5 minutes	0.064	110

Metals having a composition intermediate between these extremes have not been observed to exhibit flow or to increase deflection under a constant load.

The same phenomena are exhibited by tests made in the autographic testing machine,* thus :

NO. OF TEST.	MATERIAL.		TIME UNDER STRESS.	ANGLE OF TORSION.	FALL OF PENCIL.	REMARKS.
	Tin.	Copper.				
				°		
†1	.....	....	40 hours ...	65	0.06 inch...	Recovered after further distortion of 1°.
†2	100	....	1 hour	180	0.1 inch...	Recovered in 8°.
†3	.....	....	2 hours ...	280	0.1 inch...	Recovered in 80°.
4	99.44	0.56	12 minutes .	‡380	50 per cent.	Did not recover.
5	98.89	1.11	....	....	....	Behaved like No. 4.
6	Alloy.		....	58	0.2 inches.	Did not recover.

Tests by tension with similar materials exhibit similar results, and these observations and experiments thus seem to indicate that, under some conditions, the phenomena of flow, and of variation of the elastic limit by strain, may be co-existent, and that progressive distortion may occur with "viscous" metals.

282. A Fluctuation of Resistance with Time, illustrated in the table here given, is a singular phenomenon which has been observed by the Author, but the causes of which remain

* Part II., p. 379. † Same piece. ‡ Taking "elasticity line."

TABLE XCIII.

FLUCTUATION OF RESISTANCE.

Test by Transverse Stress.

ALLOY OF COPPER AND TIN.

No. 47.—Material: Alloy.—Original mixture: 17.5 Cu, 82.5 Sn.—Dimensions: Length between supports, 22″; Breadth, 0.996″; Depth, 0.983″.

LOAD.	DEFLECTION. Δ	SET.	MODULUS OF ELASTICITY. $\frac{Pl^3}{4\,\Delta\,bd^3}$
Pounds.	*Inch.*	*Inch.*	
10	0.0027	......	....
20	0.0070	......	8,039,339
40	0.0153	......	7,356,258
60	0.0256	......	6,594,770
80	0.0365	......	6,167,163
Beam sinks slowly.			
100	0.0499	......	5,638,814
5	.....	0.0092	....
120	0.0617	......	5,472,481
140	0.0804	......	4,899,597
160	0.1042	......	4,320,565
180	0.1343	......	3,771,245
200	0.1666	......	3,377,873
5	......	0.0821	....
200	0.1798	......	....
220	0.2145	......	....
240	0.2503	......	2,697,980
260	0.3021	......	....
270	0.3367	......	....
280	0.3762	......	832,406
290	0.4147	......	....
300	0.4597	......	....
5	......	0.3084	....

The beam was observed to rise, and another reading of set was taken in 2 minutes.

5	......	0.3022	....

The beam rose again, pushed forward the poise till beam balanced at 10 pounds. Time 2 minutes.

In 2 minutes more, beam balanced at 14 pounds. The pressure-screw was then run back till beam balanced again at 5 pounds, and another reading of set taken.

Pounds.	*Inches.*	*Inch.*	
5	......	0.2998	....

Beam rose again.
In 2 minutes balanced at 10 pounds.
In 10 minutes balanced at 16 pounds.
In 39 minutes balanced at 23 pounds.
Ran back pressure-screw till beam balanced again at 5 pounds.

5	......	0.2902	....

In 4 minutes beam rose again.
In 23 minutes beam balanced at 14 pounds.
In 1 hour and 36 minutes beam balanced at 20 pounds.
Ran back pressure-screw till beam balanced again at 5 pounds.

5	.....	0.2845	....

Total *decrease of set* in 2 hours and 20 minutes 0.3084 − 0.2845 = 0.0239 inch.
Replaced load of 280 pounds.

280	0.4849	......	....
300	0.5332	......	....
310	Broke on applying strain.		

Breaking load, 300 pounds.

Modulus of rupture, $R = \frac{3Pl}{2bd^2} = 10{,}288.$

No. 48.—Material: Alloy.—Original mixture: 12.5 Cu, 87.5 Sn.—Dimensions: Length between supports, 22″; Breadth, 0.985″; Depth, 0.990″.

LOAD.	DEFLECTION.	SET.	MODULUS OF ELASTICITY.
10	0.0025	......	....
20	0.0050	......	....
40	0.0141	......	7,901,458
60	0.0230	......	7,249,195
80	0.0352	......	6,330,144
Beam sinks slowly.			
100	0.0508	......	5,482,803
5	......	0.0120	....
120	0.0760	......	4,397,784
140	0.0969	......	4,024,116
160	0.1262	......	3,531,237
180	0.1592	......	....
200	0.2044	......	2,725,307
5	......	0.1238	....
200	0.2268	......	....
220	0.2916	......	....
240	0.4078	......	1,639,194
260	0.5210	......	....
270	0.5763	......	....
280	0.6458	......	1,207,609
290	0.7185	......	....
300	0.8025	......	1,041,220
5	......	0.6742	....

Scale beam rose.
In 2 minutes balanced at 20 pounds.
In 4 minutes balanced at 29 pounds.
In 15 minutes balanced at 34 pounds.
Ran back pressure-screw till beam balanced again at 5 pounds.

5	......	0.6555	....

Beam rose again, balanced at 12 pounds in 5 minutes.

5	......	0.6508	....

Total decrease of set in 20 minutes, 0.6742 − 0.6508 = 0.0234 inch.
Beam rose again, but test was continued without further waiting.

260	0.8304	......	....
280	0.9018	......	....
300	1.0760	Beam sank rapidly.	
300	Repeated.	Bar broke just as beam rose.	

Breaking load, 300 pounds.

Modulus of rupture, $R = \frac{3Pl}{2bd^2} = 10{,}254.$

to be determined. The bars tested as shown were not perfect in structure, and do not exhibit any considerable strength; they consist principally of tin (82.5 and 87.5 per cent.) and are valueless for the ordinary work of the constructor, although useful "white metals." It is seen that the resistance of both bars was, at times, overcome by the load, but, on balancing the weigh-beam, the bar each time gradually re-acquired a power of raising the load which had deformed it, and straightened itself sufficiently to raise the beam against the upper "chock." A *decrease of set* took place of 0.02 inch—in the first beam in two hours and twenty minutes, and in the second in twenty minutes. In two minutes, recovery occurred to such an extent that the bar exerted an effort of 20 pounds tending to straighten itself, and in 15 minutes of 34 pounds. The phenomenon is one which will demand careful investigation.

283. **The Effect of Unintermitted and Heavy Stress on Resistance** is well exhibited on the two sets of strain-diagrams* here reproduced from Part II. of this work. The first series of tests exhibited *decrease of resistance* with time

No. 655 was a bar of Queensland tin, presented to the Author by the Commissioner of that country at the Centennial Exhibition, and which was found to be remarkably pure. A load of 100 pounds gave a deflection of 0.2109 inch, and produced a set of 0.1753 inch. The same load restored deflected the bar 0.2415 inch, which deflection being retained, the effort to regain the original shape decreased in one minute from 100 to 70 pounds, in 3 minutes to 62, and in 8 minutes to 56 pounds. The original load of 100 pounds then brought the deflection to 0.3033 inch, nearly 50 per cent. more than at first.

A bar, No. 599, of copper-zinc alloy, similarly tested, deflected 0.5209 inch under 1,233 pounds, and took a set of 0.2736 inch after being held at that deflection 15 minutes, the effort falling meantime to 1,137 pounds. Restoring the load of 1,137 pounds, the deflection became 0.5131 inch, and the original load of 1,233 pounds brought it to 0.5456 inch.

* Trans. American Society of Civil Engineers, 1877.

The bar was now held at this deflection and the set gradually took place, the effort falling in 15 minutes to 1,132 pounds (4 per cent. more than at the first observation), in 22 minutes to 1,093, in 46 minutes to 1,063, in 63 minutes to 1,043, in 91½ minutes to 1,003, and in 118 minutes to 911 pounds, at which last strain the bar broke 3 minutes later, the deflection remaining unchanged up to the instant of fracture. This remarkable case has already been referred to in an earlier article, when treating of the effect of time in producing variation of resistance and of the elastic limit.

Nos. 561, copper-tin, and 612, copper-zinc, were compositions which behaved quite similarly to the iron bar at its first trial, the set apparently becoming nearly complete, in the first after 1 hour, and in the second after 3 or 4 hours.

In all of these metals, the set and the loss of effort to resume the original form were phenomena requiring time for their progress, and in all, except in the case of No. 599—which was loaded heavily—the change gradually became less and less rapid, tending constantly toward a maximum.

So far as the observation of the Author has yet extended, the latter is always the case under light loads. As heavier loads are added, and the maximum resistance of the material is approached, the change continues to progress longer, and, as in the case of the brass above described, it may progress so far as to produce rupture, when the load becomes heavy, up to a limit, which closely approaches maximum tenacity in the "iron class." The brass broke under a stress 25 per cent. less than it had actually sustained previously.

The records are herewith presented, and the curves representing them shown in the figures which follow.

TABLE XCIV.

DECREASE OF RESISTANCE AND INCREASE OF SET OF METALS, WITH TIME.

Bars 1 inch square; 22 inches between supports.

TIME.	LOAD.	LOSS OF LOAD.	DEFLECTION.	SET.
	No. 648 Wrought iron.			
	First Trial.			
Min.	*Pounds.*	*Pounds.*	*Inches.*	*Inch.*
.....	1,003	...	0.0995	.. ...
.....	3	...	......	0.0049
.....	1,003	...	0.1001	......
25	999	4	0.1001	......
100	991	12	0.1001	......
275	987	16	0.1001	......
320	987	16	0.1001	.. ...
320	3	...	......	0.007
322	987	...	0.9910	......
322	1,003	...	0.1003	......
.....	2,720	...	2.6400	......
	Second Trial.			
.....	1,003	...	2.2548	......
No. 561.—27.5 parts copper, 72.5 parts tin.				
.....	160	...	0.0696	......
.....	5	...	......	0.0145
.....	160	...	0.072	......
1	154	6	0.072	......
3	150	10	0.072	......
2,640	104	56	0.072	......
4,140	100	60	0.072	......
.....	5	...	......	0.04
.....	100	...	0.0763	......
.....	160	...	0.0970	.....
.....	320	...	0.2200	Broke
No 599.—10 parts copper, 90 parts zinc.				
.....	1,233	...	0.5209	......
15	1,137	...	0.5209	......
.....	3	...	......	0.2736
.....	1,137	...	0.5131	......
.....	1,233	...	0.5456	......
15	1,133	100	0.5456	......
28	1,093	140	0.5456	......
40	1,070	163	0.5456	......
46	1,063	170	0.5456	......
63	1,043	190	0.5456	......
77.5	1,023	210	0.5456	......
91.5	1,003	230	0.5456	......

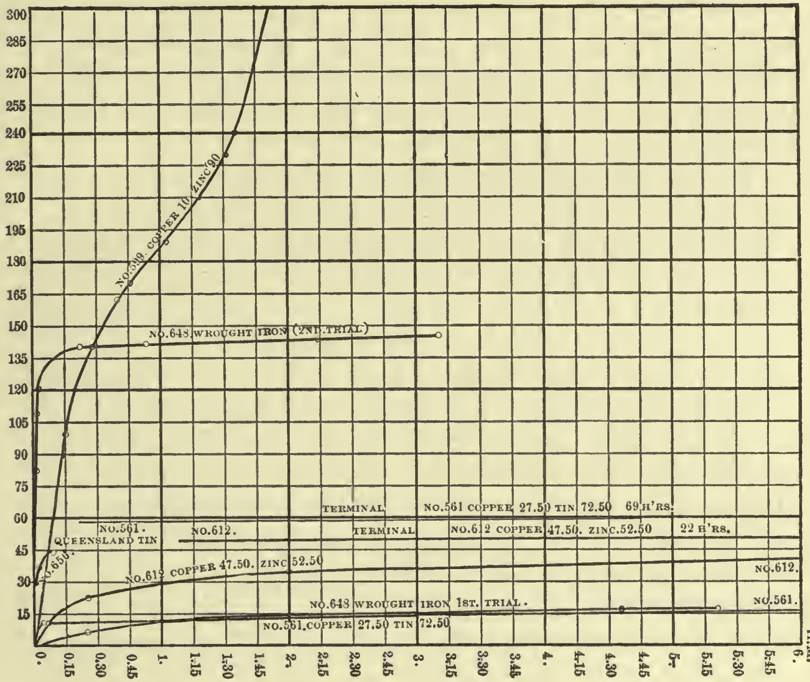
TIME.	LOAD.	LOSS OF LOAD.	DEFLECTION.	SET.
Min.	*Pounds.*	*Pounds.*	*Inches.*	*Inch.*
....	3	...	......	0.1091
....	1,603	...	0.287	......
1	1,521	82	0.287	......
2	1,493	110	0.287	......
3	1,483	120	0.287	......
23	1,463	140	0.287	.. ...
53	1,461	142	0.287	......
133	1,459	144	0.287	......
193	1,457	146	0.287	......
363	1,457	146	0.287	......
363	3	...	......	0.1481
....	1,457	...	0.2863	......
....	1,603	..	0.3016	......
....	2,720	...	2.6400	......
....	.....	...	.. ...	......
96.5	993	240	0.5456	......
118	911	322	......	......
121	911	326	... ..	Broke
No. 612.—47.5 parts copper, 52.5 parts zinc.				
.....	800	...	0.3332	......
.....	3	...	......	0.1478
.....	800	...	0.3366	.....
5	790	10	0.3366	......
25	778	22	0.3366	......
120	766	34	0.3366	... .
480	756	44	0.3366	......
1,320	751	49	0.3366	......
.....	3	...	......	0.1688
.....	751	...	0.3364	......
.....	800	...	0.3490	......
.....	1,100	...	......	Broke
	No. 655.—Queensland tin.			
.....	100	...	0.2109	......
.....	3	...	......	0.1752
.....	100	...	0.2415	......
1	70	30	0.2415	......
3	62	38	0.2415	......
8	56	44	0.2415	......
.....	100	...	0.3033	......
.....	150	...	Bent rapidly.	

284. The Observed Increase of Deflection Under Static Load.—In the preceding article the writer presented results of an investigation made to determine the time required to produce "set" in metals belonging to the two typical classes, which exhibit, the one exaltation, and the other a depression of the elastic limit under strain.

The experiments there described were made by means of

FIG. 31.—DECREASE OF RESISTANCE WITH TIME.

Rate of set of Bars 1 inch square 22 inches between supports.



a testing-machine, in which the test-piece could be securely held at a given degree of distortion, and its effort to recover its form measured at intervals, until the progressive loss of effort could no longer be detected, and until it was thus indicated that set had become complete.

The deductions were:

That in metals of all classes under light loads this decrease of effort and rate of set become less and less noticeable until, after some time, no further change can be observed, and the set is permanent.

That in metals of the "tin class," or those which had been found to exhibit a depression of the elastic limit with intermitted strain, under a heavy load, *i. e.*, a load considerably exceeding the proof strain, the loss of effort continued, until, before the set had become complete, the test-piece yielded entirely.

And that in the metals of the "iron class," or those exhibiting an elevation of elastic limit by strain, the set became a maximum and permanent, and the test-piece remained unbroken, no matter how near the maximum load the strain may have been.

The experiments here described were conducted with the same object as those above referred to. In these experiments, however, the load, instead of the distortion, was made constant, and deflection was allowed to progress, its rate being observed, until the test-piece either broke under the load or rapidly yielded, or until a permanent set was produced. The results of these experiments are in striking accordance with those conducted in the manner previously described. They exhibit the fact of a gradually-changing rate of set for the several cases of light or heavy loads, and illustrate the striking and important distinctions between the two classes of metals even more plainly than the preceding. The accompanying record and the strain-diagrams, which are its graphical representation, will assist the reader in comprehending the method of research and its results. All test-pieces were of one inch square section, and loaded at the middle. The bearings were 22 inches apart.

No. 651 was of wrought iron from the same bar with No. 648.* This specimen subsequently gave way under a load of 2,587 pounds. Its rate of set was determined at about 60 per cent. of its ultimate resistance, or at 1,600 pounds. Its deflection, starting at 0.489 inch, increased in the first minute, 0.1047; in the second minute, 0.026; in the third minute,

* Trans. Am. Soc., C. E., vol. v., page 208.

0.0125; in the fourth minute, 0.0088; in the fifth minute, 0.0063; and in the sixth minute, 0.0031 inch; the total deflections being 0.5937, 0.6197, 0.6322, 0.641, 0.6473, and 0.6504, inch. In the succeeding 10 minutes the deflection only increased 0.0094 inch, or to 0.6598 inch, and remained at that point without increasing so much as 0.0001 inch, although the load was allowed to remain 344 minutes untouched. The bar had evidently taken a permanent set, and it seems to the writer probable that it would have remained at that deflection indefinitely, and have been perfectly free from liability to fracture for any length of time.

This bar finally yielded completely, under a load of 2,589 pounds, deflecting 4.67 inches.

No. 479 was a bronze bar containing 3¾ per cent. of tin. Its behavior may be taken as typical of that of the whole "tin class" of metals, as the preceding illustrates the behavior of the "iron class" under heavy loads. It was subjected to two trials, the one under a load of 700 and the other of 1,000 pounds, and broke under the latter load, after having sustained it 1¼ hours. The behavior of this bar will be considered especially interesting, if its record and strain-diagram are compared with those of No. 599, previously given, which latter specimen broke after 121 minutes, when held at a constant deflection of 0.5456 inch; its resistance gradually falling from an initial amount of 1,233 pounds, to 911 pounds at the instant before breaking.

This bar, No. 479, was loaded with 700 pounds "dead weight," and at once deflected 0.441 inch. The deflection increased 0.118 inch in the first five minutes, 0.024 in the second five minutes, 0.018 in the second ten minutes, 0.17 in the fourth, 0.012 in the fifth, and 0.008 inch in the sixth ten minute period, the total set increasing from 0.441 to 0.65 inch. The record and the strain-diagram show that at the termination of this trial the deflection was regularly increasing. The load was then removed and the set was found to be 0.524 inch, the bar springing back 0.126 inch on removal of the weight.

The bar was again loaded with 1,000 pounds. The first deflection which could be measured was 3.118 inches and the increase at first followed the parabolic law noted in the preceding cases, but quickly became accelerated; this sudden change of law is best seen on the strain-diagram. The new rate of increase continued until fracture actually occurred, at the end of 1¼ hours, and at a deflection of 4.506 inches.

This bar was of very different composition from No. 599; it is a member of the "tin class," however, and it is seen, by examining their records and strain-diagrams, that these specimens, tested under radically different conditions, both illustrate the peculiar characteristics of the class, by similarly exhibiting its treacherous nature.

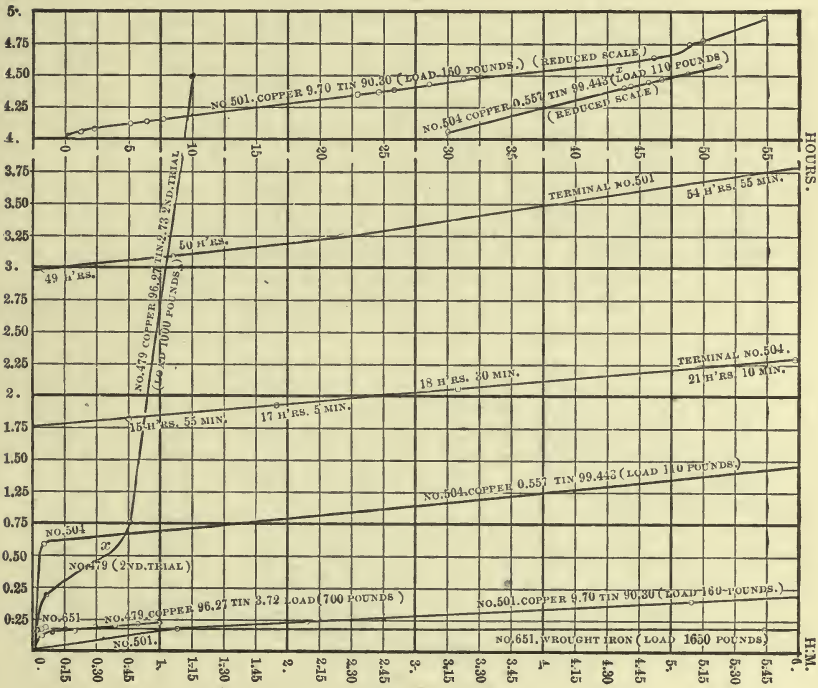
No. 504 was a bar of tin containing about 0.6 per cent. of copper—the opposite end of the scale—and exhibited precisely similar behavior, taking a set of 0.323 inch under 110 pounds and steadily giving way and deflecting uninterruptedly until the trial ended at the end of 1,270 minutes, over 21 hours. This bar, subsequently, was, by a maximum stress of 130 pounds, rapidly broken down to a deflection of 8.11 inches.

No. 501 presents the finest illustration of this phenomenon yet met with by the Author. The test extended over nearly 2½ days under observation, and the bar left for the night was found next morning broken. The time of fracture is therefore unknown, as is the ultimate deflection. The record is, however, sufficient to determine the law, and the strain-diagram is seen to be similar to that of the second test of No. 479, exhibiting the same tendency to the parabolic shape and the same change of law and reversal of curvature preceding final rupture, and illustrates, even more strikingly, the fact that this class of metals is not safe against final rupture, even though the load may have been borne a considerable time, and have apparently been shown, *by actual test*, to be capable of sustaining it. A strain-diagram of each of the latter two bars is exhibited on a reduced scale to present to the eye more strikingly this important characteristic.

A comparison of the records and the strain-diagrams with those of the preceding article, in illustration of the behavior of the two classes of metals under constant deflection, is most

FIG. 32.—INCREASE OF DEFLECTION WITH TIME.

Rate of Set of Bars 1 Inch Square 22 Inches Between Supports.



instructive. It will still be necessary to make many experiments to determine under what fraction of their ultimate resistance to rapidly applied and removed loads, the members of the "tin class"—the viscous metals—will be safe under static permanent loads. The records in Table LXXXIII., Art. 267, present many illustrations of the phenomenon here considered.

TABLE XCV.

INCREASE OF DEFLECTION WITH TIME.

Bars, 1 inch square; 22 inches between supports. Load applied at the middle.

No. 651.—WROUGHT IRON.

Load, 1,600 *pounds.*

TIME.	DEFLECTION.	INCREASE.	
		Difference.	Total.
Min.	*Inches.*	*Inches.*	*Inches.*
0	0.4890	......	......
1	0.5937	0.1047	0.1047
2	0.6197	0.0260	0.1307
3	0.6322	0.0125	0.1432
4	0.6410	0.0088	0.1520
5	0.6473	0.0063	0.1583
6	0.6504	0.0031	0.1614
16	0.6598	0.0094	0.1708
344	0.6598	0.0000	0.1708

Maximum load, 2,589 pounds; maximum deflection, 4.67 inches.

TIME.	DEFLECTION.	INCREASE.	
		Difference.	Total.
Min.	*Inches.*	*Inches.*	*Inches.*
30	0.618	0.017	0.177
40	0.630	0.012	0.189
50	0.642	0.012	0.201
60	0.650	0.008	0.209
Set	0.524	.....	.....

Second Trial.—Load, 1,000 *pounds.*

TIME.	DEFLECTION.	Difference.	Total.
0	3.118	.....	.....
5	3.540	0.422	0.422
15	3.660	0.120	0.542
45	4.102	0.442	0.984
75	7.634	3.522	4.506

Broke bar under 1,000 pounds.

No. 504.—0.557 PARTS COPPER, 99.443 PARTS TIN.

Load, 110 *pounds.*

TIME.	DEFLECTION.	Difference.	Total.
0	0.323	......	......
5	0.406	0.083	0.083
845	1.945	1.539	1.622
865	2.005	0.059	1.681
895	2.138	0.134	1.815
1,025	2.248	0.110	1.925
1,110	2.378	0.130	2.055
1,270	2.626	0.248	2.303

Maximum load, 130 pounds; maximum deflection, 8.11 inches.

No. 479.—96.27 PARTS COPPER, 3.73 PARTS TIN.

Load, 700 *ponnds.*

TIME.	DEFLECTION.	Difference.	Total.
0	0.441	......	......
5	0.559	0.118	0.118
10	0.583	0.024	0.142
20	0.601	0.018	0.160

No. 501.—9.7 PARTS COPPER, 90.3 PARTS TIN.

Load, 160 *pounds.*

TIME.	DEFLECTION.	Difference.	Total.
0	1.294	.....	.....
10	1.319	0.025	0.025
70	1.463	0.144	0.169
130	1.530	0.067	0.236
310	1.691	0.161	0.397
400	1.766	0.075	0.472
460	1.811	0.045	0.517
1,360	2.534	0.723	1.240
1,475	2.697	0.163	1.403
1,565	2.782	0.085	1.488
1,730	2.938	0.156	1.644
1,880	3.136	0.198	1.842
2,780	3.798	0.662	2.504
2,940	4.274	0.476	2.980
3,000	4.349	0.075	3.055
3,295	5.097	0.748	3.803

Bar left under strain at night and found broken in the morning.

285. Depression of Elastic Limits.—The effects of intermitted stress and of interrupted strain are of peculiar interest and importance with the non-ferrous metals and the alloys. So far as they have been observed by the Author, they are often precisely the opposite of those noted in experiments on merchant iron and commercial grades of steel. They are well illustrated in Fig. 33, which is here reproduced from Part II.

These strain-diagrams are obtained by transverse test, from bars of common iron, Nos. 648, 649, 650, 651, and from two specimens of bronzes, Nos. 596, 599, all of the same size,

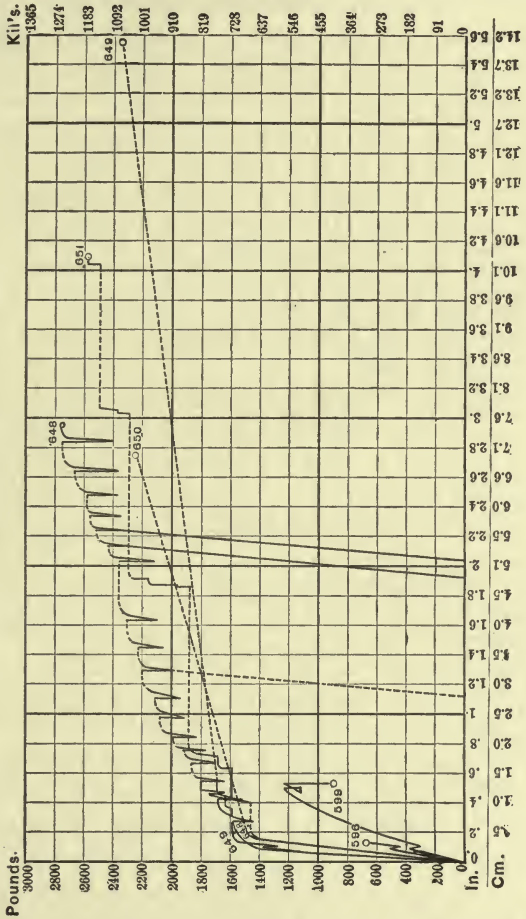


FIG. 33.—VARIATION OF ELASTIC LIMITS.

1 inch (2.54 cm.) square and 22 inches (55.9 cm.) between supports.

The first strain diagram to be studied is that of a bar of the most ductile metal (No. 599, copper, 10; zinc, 90). It exhibits clearly the phenomenon of flow with a depression of the elastic limit under constant load.

This bar was left deflected under a load of 163 pounds (74 kgs.). It gradually lost its power of restoration until it only exhibited an effort of 143 pounds (65 kgs.). The curve exhibits the relation of deflection to deflecting force. The resistance gradually increased as deflection progressed until the load—403 pounds (183 kgs.)—produced a deflection of 0.09 inch (0.23 cm.). The bar was again left, and, under a fixed deflection, again lost resisting power, and the effort to straighten itself fell to 333 pounds (151 kgs.).

Finally, the bar offered its maximum resistance of 1,233 pounds (560 kgs.) under a deflection of 0.545 inches (1.3 cm.), and was then held in its flexed position. Gradually its effort to restore itself grew less and less, until, when it had fallen to 911 pounds (414 kgs.), the bar suddenly snapped and the two halves fell to the floor.

No. 596 (copper 25, zinc 75) similarly exhibited a depression of the elastic limit by strain, but, vastly harder, more elastic and brittle, it broke under 663 pounds (301 kgs.) and at a deflection of 0.1136 inch (0.3 cm.), before apparently passing the point termed the primitive or apparent limit of elasticity by the Author, *i. e.*, that point at which the sets become nearly proportional to the strains, and at which the line of the strain-diagram turns sharply away from the vertical.

The strain-diagram No. 648, common iron, is that of the type of that class in which the elevation of the elastic limit has been detected by the Author.

The bar was like the preceding, of 1 inch (2.54 cm.) square section and 22 inches (55.88 cm.) in length between bearings. It reached its elastic limit at 1,450 pounds (659 kgs.) and at a deflection of 0.15 inch (0.4 cm.). Passing this point, and at a deflection of 0.287 inch (0.7 cm.), the bar was held at a constant deflection, under a load of 1,600 pounds (727 kgs.). Flow occurring, the effort to regain its original shape became less and less, until in six hours it had fallen to 1,457 pounds (662 kgs.). Continuing the test, resistance and deflection increased as indicated by the curve, instead of following the original direction.

Similar increase of resisting power under strain is seen at other points on the curve, and whenever the process of distortion was interrupted long enough to permit flow and that re-arrangement of particles which has been described. An hour or two usually gave time enough to bring out this remarkable phenomenon.

This action has been discovered in iron and steel, and under every form of strain—tension, torsion, compression and cross-breaking—and it would seem that aside from accidental overstrain, producing incipient rupture or loss of strength due to such action as abrasion or corrosion, length of life of iron structures under strain was in itself, apparently, a source of increased safety. On the other hand, as is here seen, the behavior of non-ferrous metals is precisely the opposite, and the engineer is compelled to use them with greater caution and to base his calculations upon a higher factor of safety, a conclusion fully corroborated by the work of Wöhler.

Recurring to Fig. 33, a resemblance is to be noted in the behavior of both classes of metals.

The bars No. 649, 650 and 651 were tested by rapidly increased load up to the breaking point, allowing no time for reading of sets.

The first of this set deflected 0.014 inch (0.04 cm.) under 100 pounds (45 kgs.), 0.052 under 500 pounds, 0.098 under 1,000 pounds, and 0.18 under 1,500 pounds. At 1,600 pounds the deflection was 0.2854 inch, and the bar yielded to the stress, and the deflection became 0.363 in 2¾ minutes. Under 1,640 pounds the deflection increased in six minutes from 0.383 to 0.440 inch, and a maximum resistance was recorded of 2,350 pounds (1,070 kgs.), and a deflection of 5.577 inches (15 cm.). This bar was tested in a similar manner to the preceding, and in the same machine.

Numbers 650 and 651 were tested by dead loads—*i. e.*, by laying upon them heavy weights. By this method the deflection could increase to a maximum under each load, instead of being kept constant, as in the testing machine. No. 650 was rapidly broken without allowing time for completion of set or any considerable exaltation of the elastic limit. The plotted curves of results exhibited well the striking difference of behavior between this bar and 651, which was purposely given time for set and for exaltation of the elastic limit. At 1,500 pounds (682 kgs.) each had deflected nearly the same amount, and had passed the elastic limit, as usually called. The first, however, gave way completely with 2,260.5 pounds (1,027 kgs.), while the second, after several times exhibiting an elevation of the elastic limit—as at 1,500, 1,600, 1,700, 1,900, 2,300, 2,400 and at 2,500 pounds—finally only yielded entirely at 2,589. The first only deflected 2¾ inches (7 cm.); the second, 4.67 inches (11.9 cm.); although when the latter was loaded with about the weight at which the first yielded, it deflected about the same amount.

The last bar was left two and a half days under its final load, and its deflection increased from 4.275 inches (10.9 cm.) to 4.67 (11.9 cm.), when the weights reached the supports of the frame and the test was ended. The other bar sank rapidly after being loaded with 1,600 pounds (726 kgs.).

Both classes of metals, when flexed, were shown to exhibit less and less effort to restore themselves to their original form. In the case of the tin class, as the Author has called it, this continues indefinitely. With the iron group this loss of effort gradually becomes less and less and reaches a limit at which the bar is found to become stronger than at first. The two classes are thus seen to be affected by time in precisely the same manner initially, but finally in exactly opposite ways.

286. The Effect of Variable Stress *in causing variation of the normal series of elastic limits* observed during ordinary tests is well shown by the records of test of the copper-zinc alloys. The following are extracts from the memoranda taken during tests made for the U. S. Board to which frequent references are made. Similar illustration may be found among the records of tests, both of bronzes and of brasses, already given.

Bar No. 8 (60.94 copper, 38.65 zinc) bent to a deflection of 3½ inches under a load of 1,140 pounds. The apparent elastic limit was reached at about 640 pounds. At 400 pounds the bar was left under stress for eighteen hours, at the end of which time the scale-beam was found still balanced, the resistance to a constant deflection being unchanged. At 800 pounds the scale beam dropped and the resistance decreased 18 pounds in one hour.

After leaving the bar under a stress of 800 pounds for one hour, taking the reading of a set, then applying a stress of 840 pounds, the deflection was 0.0185 inch over the deflection produced by 800 pounds. The load was increased to 880 pounds, and the deflection increased 0.441 inch. An additional 20 pounds then increased the deflection only 0.020 inch, and another 20 pounds only 0.0515 inch. Successive additions of 20 pounds at a time were applied, and the increased amounts of deflection were as follows: 0.22, 0.07, 0.20, 0.09, 0.25, 0.10, 0.25, 0.10 inch. The time occupied in applying the load was as regular as possible, about 30 seconds. This irregularity of resistance to distortion has been also observed both in tensile and torsional tests of pieces obtained from the same bar, and of other bars of nearly similar compositions.

Bar No. 10 (49.66 copper, 50.14 zinc) broke at a load of 940 pounds after a deflection of 1.257 inches. The weakness was due to unfavorable conditions of casting. The fractured surface showed a finely porous or spongy surface, and the composition was not homogeneous. The limit of elasticity was passed at 320 pounds. At 200 pounds the scale beam was observed to sink very slowly.

After 200 pounds had been applied, a slight crackling sound like the "cry of tin" was heard to proceed from the bar, which continued for two or three minutes, while the deflection was held constant by the pressure-screw. After it had ceased to be distinctly audible it could be heard on applying the ear to the bar. With every increase of load the same phenomenon took place till the bar broke.

After 940 pounds had been applied, slight cracks were heard and the scale-beam dropped. The poise was pushed back and the beam balanced at 580 pounds. No crack could be perceived in the bar, and no indication of fracture. After reading the deflection the pressure was then taken off the bar and a reading of set taken. The pressure was again gradually applied, and when it reached 500 pounds the bar broke.

The sudden decrease of resistance from 940 to 580 pounds without visible appearance of breaking cannot be explained. The crackling sound emitted by the bar during the whole test after passing a load of 200 pounds, and when it was held at a constant deflection for several minutes, is evidence of molecular change, probably the "flow of metals" described by Tresca.

Bar No. 11 (47.56 copper, 52.28 zinc) behaved much like No. 10, but was much stronger, breaking at 1,360 pounds. The elastic limit was passed at 450 pounds. At 460 pounds the scale-beam sank about 16 seconds after it balanced. At 560 pounds a crackling sound was heard from the bar like that emitted from bar No. 10, which continued for 10 minutes, gradually growing fainter. With the same deflection, the resistance decreased 50 pounds in 15 hours. On proceeding with the test the next day, the crackling sound was again given out by the bar, and continued till the bar broke at 1,360 pounds, after a deflection of 1.17 inches.

Bar No. 19 (10.30 copper, 88.88 zinc) was similar in character to other bars containing a large proportion of zinc, but was stronger, sustaining a load of 1,233 pounds before rupture. It broke, however, at 911 pounds, two hours after it had sustained the load of 1,233 pounds. The total deflection before breaking was 0.5456 inch. The record of this test is given in full in the tables, and is entirely unlike that of any other bar tested. Three "time tests" were made at 163, 403, and 1,233 pounds, which showed the common phenomenon of decrease of resistance with time. In the last case the resistance decreased from 1,233 to 1,137 pounds in fifteen minutes. After taking a reading of the set, the load of 1,233 pounds was again applied and the decrease of resistance with time noted at intervals during a period of two hours.

The decrease of resistance was at first rapid, 100 pounds in the first fifteen minutes, and then much slower. In the fifteen minutes, commencing at one hour and three minutes after the beginning of the "time test," the decrease was 20 pounds; in the next fourteen minutes the decrease was again 20 pounds. In the five minutes, commencing one hour and thirty-two minutes after the "time test," the decrease was 10 pounds, showing an increase of the rate of decrease. Another observation was twenty-two minutes, when the rate was found to have largely increased, the decrease of resistance in these twenty-two minutes being 82 pounds. In three minutes after taking the last reading, when it balanced at 911 pounds, the bar suddenly broke without warning. The deflection was unchanged during this entire "time test." The elastic limit was reached at about 900 pounds.

287. **The Effect of Repeated Strain** is greater with the non-ferrous metals, and usually with the alloys, than with iron and steel. The investigations of Wöhler and Spangenberg were made principally upon the latter class of materials, but were also made to cover the action of a few other metals.

Wöhler's law, that the rupture of a piece may be produced by the repeated action of a load less than that which, once applied, would cause fracture, is true, probably, of all the non-ferrous metals, and this effect is with them much more serious than with the ferrous metals. Spangenberg found that gun bronze in tension would endure a stress of 22,000 pounds per square inch (1,547 kgs. per sq. cm.) laid on and at once removed 4,200 times before rupture; a stress of 16,500 pounds (1,160 kgs.) 6,300 times, and 11,000 pounds per square inch (773 kgs. per sq. cm.), 5,547,600 times. It may be considered safe under indefinitely repeated loads falling well under one-half its tenacity as determined by ordinary test. Phosphor bronze, forged, bore 53,900 repetitions of the smallest of the above loads, and 2,600,000 of the next load, but broke under 1,621,000 repetitions of a load of 13,750 pounds per square inch (967 kgs. per sq. cm.). The cast metal sustained 408,350, 2,731,161 and 2,340,000 repetitions of the same loads. This peculiar behavior is not explained by the experimenter.

Further experiment in this direction is desirable. Meantime, the engineer will probably find it advisable to allow, for intermittent loads, but one-half the stresses which would be permitted for single applications of load, and one-quarter where suddenly applied, while the factor of safety should be probably not less than one-half greater for non-ferrous material than with iron. The limits of stress sometimes proposed are not far from the following, which may be compared with the values already given for factors of safety and ultimate strength.

TABLE XCVI.

PERMISSIBLE REPEATED STRESSES FOR NON-FERROUS METALS.

	Factor of Safety.		Maximum Stress.			
			Dead Load.		Live Load.	
	Dead Load.	Live Load.	Lbs. per sq. in.	Kgs. per sq. cm.	Lbs. per sq. in.	Kgs. per sq. cm.
Copper, cast	4	8	5,000	352	2,500	176
" forged	4	8	15,000	1,055	7,500	528
" wire	4	8	16,000	1,125	8,000	563
Gun-bronze, cast	4	8	10,000	703	5,000	352
Brass, yellow, cast	4	8	5,000	352	2,500	176
" " rolled	4	8	10,000	703	5,000	352
" " wire	4	8	12,000	845	6,000	423
Lead; rolled	4	8	1,000	70	500	35

When the stresses are reversed, as in connecting rods, the factor of safety should be doubled and the maximum stresses reduced at least one-half. [See Appendix for Table of Properties of Metals and Alloys.]

CHAPTER XIV.

MECHANICAL TREATMENT OF THE METALS.*

288. Qualities Affected by Mechanical Treatment.— The metals used by the engineer in construction, as they are found in the market, and often when they have been given the form and dimensions desired in the finished piece, are known to be liable to exhibit certain defects and to possess certain peculiar characteristics. Some of these defects are removable by proper mechanical treatment, and some of the characteristic qualities may be modified in a marked manner by special methods of manipulation. All known and actually practised methods of so altering the character of the metals used by the engineer, involve, directly or indirectly, the elevation of the original elastic limit of the material; and they usually produce a change, more or less marked, in the ultimate strength, the elasticity, the resilience—in fact, in all the physical properties of the metal.

The subject of the mechanical treatment of metals has already been considered, incidentally, and to a very limited extent, in Part II. of this work.† It is intended, in the present chapter, to describe successful and established methods at some length, when they have not already been so described. The effect of mechanical treatment is due to that change of volume, density, and condition of molecular aggregation which is produced by any action causing flow while under stress, and, especially, while under compression.‡ This action is sometimes, as in wire drawing, incidental to the process of

* Principally from an article contributed to the *Metallurgical Review*, 1877.

† Part II., §§ 48, 165, 178, 191, pp. 71, 196, 262, 328

‡ Part II., Chapter X.

manufacture, and sometimes, as in the Whitworth or Jones systems of compressing ingot metal, and as in the cold-rolling process, an independent operation.

Mechanical treatment does not directly modify the chemical composition of the metal, and is, therefore, incapable of changing, either for better or worse, the nature of the material, so far as it is determined by the chemical constitution. So important, however, are the modifications which can be effected by mechanical treatment, and so extensively are they likely to be applied in the arts, that a more extended and a more precise analysis than can be here given would be required to do full justice to the subject.

All defects removable by mechanical treatment may be properly classed as defects involving want of homogeneousness. Metals may be homogeneous in two ways: (1.) They may be homogeneous in structure—*i.e.*, they may be free from such defects as blow-holes, which are generally numerous in cast metals, and from the cinder streaks which produce the fibre in rolled and forged iron; the molecules of the several constituents of which they are composed are then uniformly distributed; (2.) The metal may be homogeneous as to strain—*i.e.*, it may be free from such stresses as are known often to exist in badly designed castings of brittle materials like hard cast iron, speculum metal, and in glass.

Defective homogeneousness of structure may be removed, more or less completely, at any temperature below that of fusion, by methods specially adapted to use at the given temperature.

Blow-holes are probably due to the presence of air and of other gases, either absorbed from the atmosphere, as illustrated in the "spitting" of silver, or developed by chemical actions occurring within the mass of metal while in a state of fusion. This gas can be condensed, excluded or expelled, either by the mechanical act of compression, or by the use of some material in the form of a flux, which shall either prevent the development or the absorption of the gas, or which shall unite with it, forming a compound which can be separated by the usual process of skimming the molten metal in the melting pot, or which shall, if retained in the mass, be less injurious than the free gas.

The latter process is illustrated in the use of silicon and of manganese to confer soundness upon the cast ingots in the Bessemer and other processes of steel making, and by the use of phosphorus in insuring soundness in the better class of copper-tin and of copper-zinc alloys, which metals are very liable to be made seriously defective by the absorption of oxygen and the formation of oxide. The bronzes especially, when rich in copper, are exceedingly liable to this kind of defect, and the immense increase in the tenacity, ductility, and other valuable qualities of such alloys, which may be obtained by securing perfect soundness by such removal of the cause of their unsoundness, has only recently been made generally known.

The conception of the compression of fluid metals was probably first introduced by James Wood, a well-known engineer and mill-wright of Lancashire, England. He used this process in making printers' rolls of copper, 1856–9, at the Broughton Works, Manchester, and at the works of J. Wilkes & Sons, Birmingham. He is said to have shown his method to Sir Joseph Whitworth.

289. **The Whitworth Process.**—The mechanical treatment of metal at the point of fusion, for the purpose of securing homogeneity of structure, is illustrated by the Whitworth process of making compressed steel.

In all the usually practised methods of making steel, the metal is cast in ingots, which are subsequently hammered or rolled into any desired shape. The steel is sometimes poured into moulds and given working shapes like cast iron; the resulting shapes are known in the market as "steel castings."

These ingots or castings are very liable to contain blowholes or air cells, which are produced by the retention, while solidifying, of occluded air and bubbles of disengaged carbon monoxide originating in the oxidation of a portion of the carbon previously united with the metal. The lower the percentage of carbon present, the greater the injury produced in this manner. The use of manganese is resorted to for the purpose of preventing this "piping;" but as it is used in the form of a carbide, it is usually found difficult to use a sufficient quantity of manganese in the "milder" steels without, at the same time, introducing too much carbon. Silicon, also, has been found to possess the same property in an even higher degree than manganese. One or two one-hundredths of one per cent. has been said to reduce liability to such porosity very greatly. At Terrenoire, France, the double silicide of iron and manganese, instead of spiegeleisen, is added to the molten metal as a carburizer.

In large castings and ingots, also, the internal strains, induced by the contraction of the inner portions after the external part of the mass has solidified, produce serious weakness, and often crack the whole body of metal to such an extent as to entirely destroy its value. This is peculiarly liable to occur in hard steels. Such steels are entirely unfitted for the use of the engineer in construction; and such metal is only used for tools. The "low" steels, on the contrary, possessing great strength, combined with great ductility, are the best known metals for constructive purposes. The cast metal, for the reasons already stated, is usually worthless for immediate application; but could it be produced free from porosity, and as dense as the forged steel, it would have equal strength and ductility, and would be equally applicable for use in structures; it would also have the important advantages of cheapness and of facile production in any desired shape. This result is said to have been very perfectly secured at Terrenoire by the method of fluxing above alluded to.

Whitworth secures this condition by subjecting the fluid steel to very heavy pressure while contracting and until completely solidified, by the use of the hydraulic press. A pressure of 20 tons to the square inch produces all of the compactness, density, strength and ductility of a forging. By this method, Whitworth has, in place of worthless metal—as castings—produced steel of tenacities varying in the several grades from 80,000 pounds per square inch to 150,000 pounds, and of ductility varying from 35 per cent. in the softer metal to 14 per cent. in the strongest grade. Guns made of the softest grade, when burst, do not fly in pieces as cast guns, invariably, and even wrought-iron guns very generally, do, but simply open along the line of minimum strength, and thus explode with comparative safety to the gun's crew.

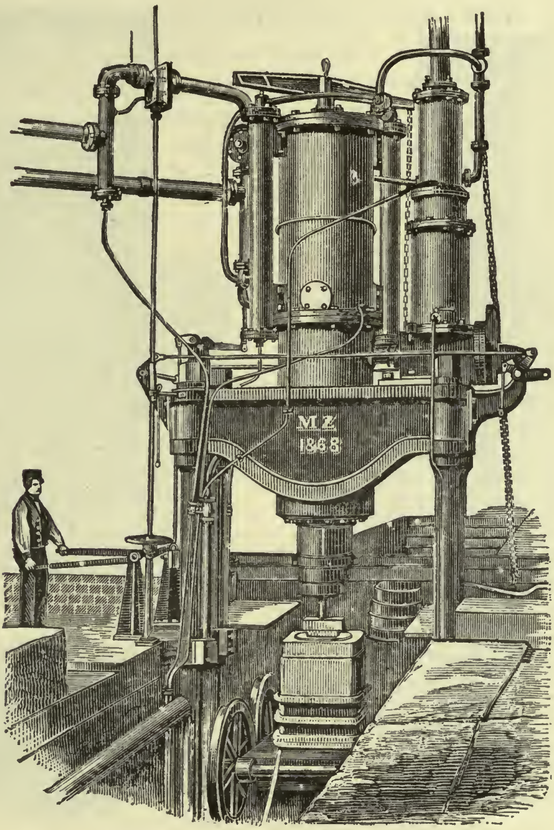
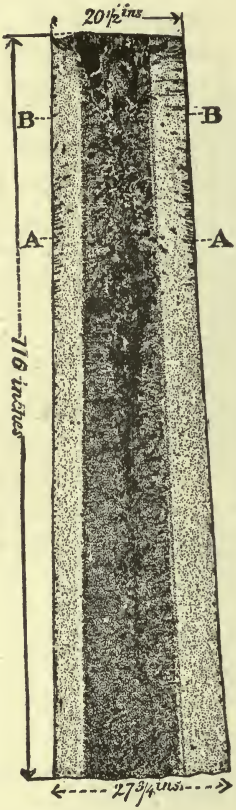


FIG. 34.—WHITWORTH'S PRESS FOR INGOT METAL.

Metal shown to the Author by Sir Joseph Whitworth, in 1870, at Manchester, England, as a product of this process, was very remarkable for its strength, ductility and homogeneousness, and worked under the tool with most admirable freedom and uniformity.

Whitworth states that the column of fluid steel, while solidifying under pressure, shortens an inch and a half to each foot of its length. The fact is a good index of the value of the process, and gives some idea of the degree of unsoundness of the best of ordinary castings. The change



Vertical Section.

Enlarged Section through A, A.

Horizontal Section through B, B.

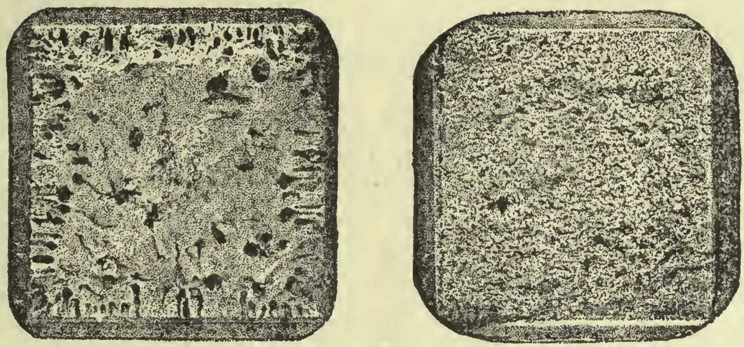
FIG. 35.—INGOT CAST WITHOUT PRESSURE.

of texture due to compression is very marked, as shown in the accompanying engravings,* and is readily observed by the most inexperienced eye. The only special precaution demanded in the use of this method is to so arrange the plant that the molten steel may be put under pressure before

* From Whitworth on Guns and Steel.

solidification has commenced; the requisite strength of moulds must also be secured.*

290. **The Lavroff Process.**—Bronze and brass may be treated by the same methods which are seen to have been so successfully adopted in working steel, and with no less important gain in excellence of quality. These compositions are peculiarly liable to defects arising from the occlusion of gas and by the formation of oxide within the mass. Copper has a very great affinity for oxygen at high temperatures, and the very best of copper-tin and of copper-zinc alloys, if made



Transverse Section of Steel Ingot Cast in the Ordinary Way.

Transverse Section of Steel Ingot Compressed while in a Fluid State.

FIG. 36.—INGOT.

without special provision against such injury, are seriously defective from these causes. The strongest piece of such composition which the author has ever made, and which far exceeded in tenacity any gun metal or any other metal approximating to the same composition, was visibly and keenly defective. Treatment with phosphorus, or other oxygen-absorbing element, has been found to do much toward correcting this fault. Could a perfect absorption of oxygen be effected, the almost invariable unsoundness of bronze and

* See Report on Machinery and Manufactures at the Vienna International Exhibition, 1873, by the Author. Washington, 1875. Page 439.

brass castings would probably be prevented, and what would now be thought a remarkable combination of strength and ductility would be secured. Muschenbroeck gives the tenacity of fine copper wire at about 90,000 pounds to the square inch (6,327 kgs. per sq. cm.). Cast copper rarely reaches a tenacity of 20,000 (1,406 kgs). Yet, with maximum density and perfect purity, the one should be as strong as the other.

Compression with proper fluxing will do all that can be done toward giving castings of these metals a maximum of strength, ductility and resilience. Colonel Lavroff, of the Russian army, has applied the Whitworth method to the making of cast bronze guns. To make the process thoroughly complete, it is only necessary that the metal compressed should have been previously purified by effective fluxing before pouring.

Col. Lavroff, as stated by Col. Laidley in his ordnance notes (No. xl., printed by the Ordnance Bureau of the United States War Department), places the flask, in which the gun is to be cast, in a pit directly beneath the cylinder of a hydraulic press. The upper end of the flask is closely capped by a strong plate of iron, having a cylindrical hole in its centre. Through this opening a plug of sand is forced down upon the molten metal by the hydraulic press, and enters the mass of fluid bronze two inches or more, producing the required degree of condensation. With such pressures as are employed for steel, the improvement in the quality of bronze would be expected to be quite as marked as in that metal.

291. Rolling and Forging.—Compression and "working" metal in the solid state, but at high temperature, is the most usual method of not only giving the materials of construction their shape, but also of improving their valuable qualities. As is well known to every engineer, all the metals are found to gain strength with hammering and rolling. The strength of a grade of iron which has a tenacity of 50,000 pounds per square inch of section, when made into bars two inches in diameter, becomes gradually increased as the size of the bar is reduced by rolling, until a one-inch bar of the same iron is found to have a tenacity of nearly or quite 60,000 pounds to the square inch. Copper and some of the alloys may be similarly improved by heating to a moderately high temperature and drawing out under the hammer, or in the rolling mill. Cast copper, of a tenacity of 20,000 pounds per square inch, acquires in this way a strength of 40,000 pounds and upward.

292. **Hydraulic Forging and Drop Forging.**—This process is not always effective, however, as large masses, both welded and cast, are very liable to contain cavities, even after having been subjected to the most skilful manipulation in the forge or the rolling mill. The most effective system of hammering is likely to prove inefficient, where applied to large pieces, in consequence of the fact that the inertia of the mass attacked will often cause the effect of the blow to be felt only near the exterior, the internal portions remaining after treatment nearly as spongy and as irregular in structure as before. The comparatively moderate, but pervading—there is no better word—effect of the heaviest hammer, is best adapted to do such work. The best of all methods of securing thorough condensation, in the process of forging small pieces which can be so treated, is that in which the hydraulic press with its slow action, producing an effect which is felt throughout the entire volume of the piece, is employed. This process has been well developed by Mr. R. L. Haswell, at Vienna, and is fully described by Prof. W. P. Blake in his report on iron and steel at the Vienna Exhibition of 1873.*

The process of making forging, with the "drop press," which has attained greatest perfection in this country, and in which the piece is shaped in a die by a single heavy blow, is also thoroughly satisfactory as applied to small pieces. The system of hydraulic forging is most economical of power, as it has been shown by Prof. Kick that the loss of power, wherever shock is employed in such work, is serious. It is wasted by dispersion in all directions in the form of heat, due to compression and to directly produced tremor of molecules,

* Reports of the U. S. Commissioners to Vienna International Exhibition, 1873. Washington, 1876. 4 vols. 8vo, pp. 3,500.

and in the jar and shake which affects all neighboring masses. The quiet, steady action of the hydraulic press accomplishes the desired change of form without the latter kind of loss of energy, and with a minimum loss of power from the production of heat by molecular motion.

293. **Thermo-Tension and Annealing.**—Defects of homogeneousness of structure may thus be removed, partially or wholly, by several known processes of treatment of heated metal. Defect of homogeneousness as to strain is removable from iron, and perhaps from other metals, by annealing and by a method called in 1836, by its discoverer, Prof. Walter Johnson, "thermo-tension." The metal is heated to a full red heat, but with great care to avoid a temperature so high as to give rise to danger of serious reduction of strength by approaching the welding heat. At this elevated temperature it is subjected to a tensile stress of as great intensity as is safe. The metal is then allowed to cool, retaining the stress applied, and when cold it is released. Prof. Johnson found this process to confer upon the iron experimented with a maximum resistance to change of form exceeding, by about 16 per cent., that which it had originally possessed. He offered no explanation of the molecular change to which the effect noted was due; but it has been attributed by the Author to a release of internal strains which had previously been introduced by the irregularly produced flow of the metal occurring during the processes of manufacture.

Cast metals, glass, and other materials which have been given form by fusion, casting in moulds and solidification which so occurs as to produce irregular contraction and a consequent unsymmetrical distribution of metal, and which are, therefore, found to be weakened by the presence of internal strains, are relieved of such internal strain by the familiar process of annealing. The more brittle the material, the more carefully and slowly must the process of annealing be conducted. The more ductile the metal and the greater the freedom with which it is found to "flow" under the action of applied forces, the less serious are these strains, and the less important is the process of annealing.

294. Cold Working.—Metals are worked perfectly cold in some cases, and the several methods of treatment at the ordinary temperature may be divided into two classes:

(1.) Those which are practised for the purpose, simply, of conferring greater density, and of thus securing homogeneousness of structure.

(2.) Those which are adopted for the purpose of modifying the character of the metal in respect to internal strains, and thus of altering the normal elastic limit of the material by the intermittent application of external forces.

Cold working is illustrated in the processes of wire drawing, cold hammering and cold rolling, simple compression, and simple extension of metal without heating. The effect of either of the processes involving compression will assign the process to the one or the other of the two classes, according to the nature of the material. It may be that the same remark will be found applicable to all methods of cold working.

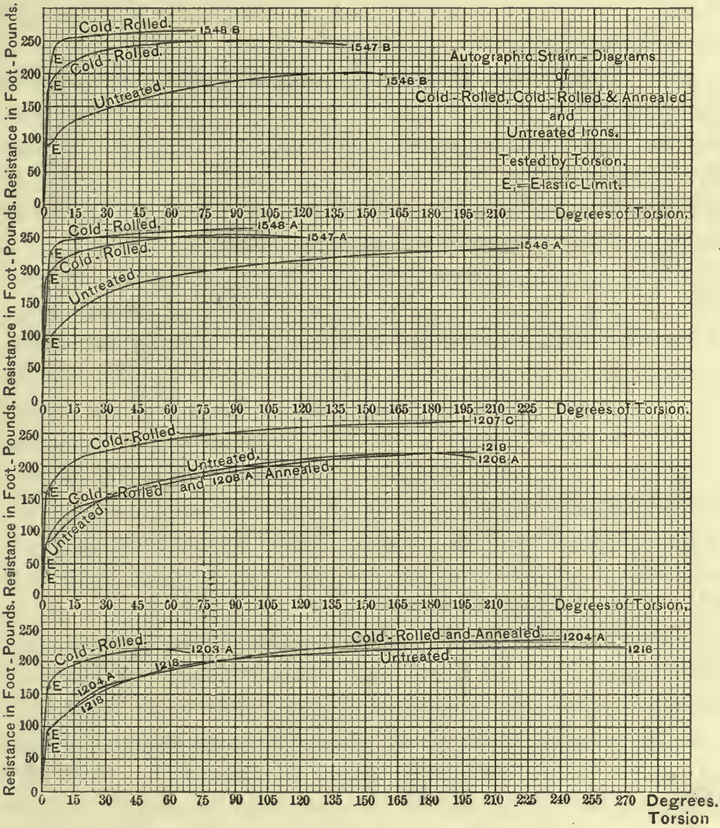
295. Wire Drawing.—The process of wire drawing is the oldest and most generally familiar of these methods of treatment of the useful metals. In the manufacture of wire, the metal is rolled down into rods a quarter of an inch or less in diameter, which rods are called "wire rods." These rods are then, in the wire mill, drawn through holes in steel plates, each of which holes is slightly smaller in diameter than the wire to be passed through it. As the wire is reduced in size, it gradually becomes hardened, and, at intervals, the process is interrupted, and the metal is subjected to the process of annealing to soften it, and thus to enable the decrease in size to be carried on without the serious loss of power and risk of breaking which would otherwise be met. As the decrease of diameter progresses, the wire is found to exhibit a gradual increase in tenacity, which increase becomes very great when the wire is drawn very fine.

Brass, and probably all other metals and alloys which have the requisite qualities to permit them to be worked by this process, are similarly increased in tenacity by the action of the draw plate. The precise combination of qualities which best fits metal for making fine wire, has never been exactly determined. It is not sufficient that the metal have simple tenacity, or tenacity and malleability, or even ductility, in the unlimited sense in which that term is often applied. The observations and experiments of the writer have led him to suppose that perfect homogeneousness of composition, freedom from foreign substances, such as cinder in iron and oxide in copper and its alloys, and a high ratio of tenacity to resistance at the limit of elasticity are requisite. Some metals which have exhibited great strength and also very great ductility, when tried in the testing machine, have failed to work well when it has been attempted to draw them into fine wire. Those irons which have been drawn as fine as No. 36, or even to No. 40, have usually been marked by a limit of elasticity much lower than other very fine metals of equal tenacity and equal ductility as indicated by their behavior in the testing machine. No. 40 wire has a diameter of 0.003 inch = 1-13, or 0.078 millimetre. (See Part II., Iron and Steel.)

296. Cold Rolling—The Lauth Process.—As has been above stated, it is occasionally necessary to anneal wire during the process of drawing, as it is rendered too hard to work without this treatment. This increase in the hardness of the metal is also accompanied by an increase, equally marked, in the elasticity of the wire; and this change in the character of the material is quite independent of the simple strengthening which is seen in even the annealed wire. Any process of compression at low temperature, properly conducted, will exhibit the latter effect. Hammering metal at the ordinary temperature is sometimes resorted to to give it an increased hardness and elasticity. The same process is also practised to confer upon forgings a smooth and hard surface. If not intelligently executed, this process is liable to weaken the mass by extending the exterior portions, and thus straining the inner parts. Where practicable, it is probably better to use the hydraulic press in doing this work.

A process technically called "cold rolling" has been adopted to give increased stiffness and elasticity to iron, steel and other metals intended for certain special purposes, as for shafting, for the finger bars of reaping machines, and for other parts of machinery intended to have great stiffness and very perfect elasticity.

FIG. 37.—EFFECT OF COLD ROLLING.



The precise temperature at which this effect can be produced has not been determined. It is within a range which extends nearly, if not quite, up to a full red heat.* Prof. Johnson and Mr. Fairbairn found that the cohesion of wrought iron was practically unaffected at a temperature of

* See Metallurgical Review, Oct. 17, pp. 159–162.

six hundred degrees Fahrenheit, and this may be taken as evidence that the effect of cold rolling is attainable at temperatures exceeding the black heat.

This process and its effects upon iron have been described in Part II. The accompanying strain-diagrams, Figure 37, exhibit this effect, and may be taken as illustrative of the effect of the process on all metals, and especially the bronzes to be referred to.

297. **The Dean Process—Cold Working Bronze** has been practised in the United States by Mr. S. B. Dean, and in Europe, on a more extended scale, by General Uchatius, of Vienna. These experimenters endeavored to apply the process to the manufacture of bronze ordnance, and used the same general method of adapting it to the work.

This method, as described by the inventor, Mr. Dean, in 1869, is the following: The gun is "placed in a frame, or upon a bed somewhat like a boring mill for guns, but instead of using a bar provided with cutters, there is fixed in the end of the bar a smooth cylindrical plug of hardened steel about 5-100 of an inch larger than the diameter of the reamed hole in the gun. The plug should be made of two frustra of cones with their bases connected by a short cylinder.

"For condensing the bores of rifled guns, the plugs used should have ribs to correspond with the grooves previously made by the rifling machine.

"The bore being well lubricated, the steel plug is made to traverse the bore by a screw or other suitable means till it reaches the bottom of the bore, proper provision being made to allow air and excess of the lubricant to escape through a vent in the plug or at the bottom of the bore. Instead of forcing a plug or plugs from the muzzle to the bottom of the bore, the condensation may be performed by commencing at the bottom of the bore and drawing the plug outward; in which case the plugs should be so made as to be expansible. After the first plug has been removed from the bore, two or more similar plugs are successively forced through, enlarging the bore to the desired size.

"Care should be taken that each succeeding plug shall have a diameter slightly larger than the one preceding it, and each plug should perform a slightly smaller amount of compression than the preceding plug, on account of the increasing hardness and density of the bore, which increases the resistance to be overcome by each successive plug."

Dean found the effect of this treatment to be very marked in increasing the hardness, strength and density of bronze.

A cylinder of metal taken from the sinking head of a bronze gun having originally a specific gravity of 8.321, a tenacity of 27,238 pounds per square inch (19 kilograms per square millimetre), and a hardness, by the scale used by General Rodman, of 1, was given a tenacity of 41,471 pounds per square inch (29 kilograms per square millimetre). Its hardness was increased to 2.97. Its density, in a ring one-quarter inch thick, next the bore, was made 8.780. In the innermost thickness of one-eighth inch it was 8.875; and the density of a circular piece one-quarter inch, taken across the bore, was 8.595. The increase here noted of 50 per cent. in tenacity by compression has been exceeded by other experimenters.

General Uchatius, the director of the arsenal at Vienna, has reduced this process to practice in the manufacture of guns for the Austrian army; and, as he informed the Author by a note dated June, 1875, the official action of the Committee on Artillery resulted in the promulgation of the order that "steel bronze"—the name given by General Uchatius to the new product—"is to be accepted as gun-metal in the Austrian army." The process of investigation and its results are given to the Author by Uchatius substantially as follows: *

298. Uchatius' Methods of Treating Bronzes.—Ordinary bronze for guns is an alloy, consisting of about 90 parts, by weight, of copper, and 10 parts of tin. Since the atomic

* See the report by the Author to the President of the United States "On Machinery and Manufactures, with an Account of European Manufacturing Districts;" contained in the reports of Scientific Commissioners of the United States to the Vienna International Exhibition, 1873. According to Volmaer and others, Künzel was the originator of the "steel-bronzes" and deserves more credit than has been given him.

weight of copper is 63.4, and that of tin 118, the above proportions of the alloy correspond to a combination of 1 equivalent of tin with 17 equivalents of copper. Experiment shows us that it is questionable whether these two metals form a chemical compound in these atomic proportions. When large molten masses of this alloy solidify, an alloy which is poorer in tin begins to crystallize first where it touches the mould, its composition being about 92 parts, by weight, of copper, and 8 parts of tin, or 1 equivalent of tin to 21 equivalents of copper; while an alloy richer in tin is pressed from the former, and solidifies last. This latter alloy, then, forms in the inside of the casting, and also enters the cracks which sometimes form in the outer walls.

This behavior in the fusion of alloys rich in tin was also noticed in the researches on alloys of copper and tin made by Alfred Riche.* M. Riche noticed that all alloys of copper and tin, except those whose compositions correspond to the formulas $SnCu_3$ and $SnCu_5$, undergo refusion at the moment of solidification. An alloy richer in tin is separated, so that different compounds are to be found at different points in the casting. When the alloy consists of tin and copper in the proportion of 1 to 5, this refusion occurs to but a slight extent, but when the composition is different it becomes very serious.

As a proof of the occurrence of these conditions in alloys, it may be stated that rich bronze of a very homogeneous character is always found in the smaller parts of bronze castings; for example, in the cascabel, or in the trunnions of a gun. This bronze contains about 8 per cent. of tin, while the body of the gun is permeated by thin sheets of tin. An 8-inch tube was made at the Royal Imperial Arsenal, for which 28,000 kilograms (61,600 pounds) of metal were employed. The greatest diameter of this casting was about 0.84 m. (33 in.), and the proportion of tin at this part was 8 per cent. on the outside and 12 per cent. on the inside.

Bronze with 8 per cent. of tin has not yet been employed for guns, because its wear is greater than that of 10 per cent. bronze. "Gun-metal" has long been employed because of

* "*Annales de Chimie et de Physique,*" tome 30.

its great tenacity and consequent safety, and because it has the advantage of cheapness and ease in working. Its strength has satisfied the demand nearly up to the present time, and it has, therefore, been retained in the manufacture of field-pieces, in spite of its tendency to " bulge " and to burn out. Modern practice, however, will no longer permit its application as formerly.

From an accompanying table of properties of types of gun-bronze, we find those of ordinary gun-bronze, as compared with Krupp's steel for guns, to be—

	BRONZE.	STEEL.
Tenacity	2,260 kilograms per square centimetre (32,092 pounds per square inch).	4,800 kilograms (68,160 lbs.).
Elastic resistance	400 kilograms per square centimetre (5,680 pounds per square inch).	900 kilograms (12,780 lbs.).
Extension when broken	15 per cent.	21.4 per cent.
Hardness (depth of indenture)	12.5 millimetres (½ inch).	10.5 millimetres (.42 inch).

We see that the tenacity as well as the limit of elasticity of cast steel is almost twice as great as that of ordinary bronze, which has even less ductility than steel. If the properties of bronze could not be further improved—wrought iron being unreliable as gun-metal—we would necessarily be compelled to accept steel. But, fortunately, new wants are generally supplied in time by the progress of science and art.

A new modification of gun-bronze, which is much superior to ordinary gun-bronze, according to Uchatius' table of gun-metals, is now made, for which General Von Uchatius has proposed the name "steel-bronze," on account of the resemblance of its properties to those of cast-steel.

If, instead of employing sand, we use iron chills of a corresponding thickness of material, the process of solidification takes place with such rapidity that the alloy rich in tin cannot separate, and the bronze becomes perfectly homogeneous.

The strength rose to 3,050 kilograms (43,210 pounds per square inch), the elastic limit remained at 400 kilograms, the hardness (depth of indenture) at 12.5 millimetres, .5 inch), while the amount of stretch before breaking, or the ductility of the material, rose to 40 per cent. These improvements in the quality of bronze are a step forward in bronze-casting, but it is, nevertheless, not sufficient to satisfy modern requirements. A gun-barrel cast in this manner would not burst, as the ductility of the material (40 per cent.) is enormous; but it would not be capable of resisting the pressure of the gas; and, since the elasticity is not greater than with ordinary bronze, the gun-barrel would "bulge." The hardness also remained unchanged, and it is therefore not great enough to cut the grooves in the sabots of the shot.

General Von Uchatius next tried to roll a piece of the chilled bronze cold. This could be done, although considerable power was necessary. Not the slightest crack was produced, even when stretched to the amount of 100 per cent. of its original length. When the bronze had stretched 20 per cent., it attained the strength, hardness, and elasticity of steel. The figures are as follows:

The tenacity, 5,066 kilograms per square centimetre, (71,937 pounds per square inch).

The elastic resistance, 1,700 kilograms per square centimetre (24,140 pounds per square inch).

The hardness (depth of indenture), 10.2 millimetres (.41 inch).

It is evident that if this characteristic of chilled bronze, of assuming the properties of steel, when rolled, could be employed on the inner surface of gun-barrels, the process would be of great value. On examining the table of gun-metals, he remarks the peculiarity that all tough metals assume a much higher elasticity when they are stretched beyond the elastic limit, which fact had already been noted by Dean.

In this fact we may find the explanation of a well known phenomenon, often observed. A bronze barrel which was not strong enough to resist the charge, and which, therefore, "bulged," still approximately retained its form after long-continued use. It could even be reduced, by turning off the outside, without losing its resisting power. The natural chilled bronze has its limit of elasticity at 400 kilograms, (5,680 pounds per square inch), and permits a stretch of 0.0004 of its length; while if a permant set of 0.00441 of its length is produced, its elastic limit becomes 1,600 kilograms (22,720 pounds per square inch), and its stretch within the elastic limit, 0.00192. The rolled chilled bronze attains its limit of elasticity at 1,700 kilograms (24,140 pounds per square inch), and has an elastic extension of 0.0017 of its length, while a permanent stretch of 0.00018 of its length raises the limit of elasticity to 2,400 kilograms (34,080 pounds per square inch) and its elastic extension to 0.00252.

This advantage is as great with steel, wrought iron, and in general all extensible metals, but it has never been taken advantage of in the manufacture of guns, until Dean and Uchatius made the application.

The following principle was enunciated by General Von Uchatius as a theory of working a gun-barrel from a homogeneous, very ductile, and tough metal. It is based upon results obtained by precise measurements of the properties of the metals:

I. The work performed by the pressure of the gases of the exploded powder, and destroying the fit of the shot by enlarging the bore, should be performed originally by mechanical means, and to a far greater extent than will be produced by the heaviest charge. By this means the elastic limit of the metal of the barrel is increased to such an extent that the smaller pressures of gas produced in discharging the gun have no effect.

II. The surface of the bore must be submitted to a proccss resembling rolling to such an extent as to give it the necessary hardness.

By this process of mechanical working of the casting the material is not overstrained. Its quality is not injured; on the contrary, as this extension goes on in the cold state, the molecules take new and stable positions, refining the metal. Its properties are, therefore, improved.

Before proceeding to the method of working on the casting, it was necessary to solve two very important problems, namely:

Which alloy of copper and tin is best suited for chilled casting?

How can the quality of the metal at the inside, or nearest the bore, be made to correspond to that of the alloy at the outside, so that the metal can be subjected to the process of rolling?

In order to determine the best alloy, a small cast-iron chill was made, of 25 millimetres (1 inch) and 50 millimetres (2 inches) width in the clear, and 25 millimetres (1 inch) thickness of sides, into which the following alloys were cast:

12 per cent. bronze.
10 per cent. bronze.
8 per cent. bronze.
6 per cent. bronze.
10 per cent. bronze, with 2 per cent. addition of zinc.
10 per cent. bronze, with 1 per cent. addition of zinc.
8.5 per cent. bronze, with ½ per cent. addition of zinc.

The last of these alloys is that which Lavissière exhibited at the Vienna Universal Exposition of 1873, and which attracted attention by its uniform and homogeneous appearance and by its peculiarly excellent quality.

Two rods were cut from each of the castings, and these were rolled out until they acquired the hardness of "mild" steel. It became evident, during this process, that the 12 per cent. bronze could not bear rolling, and the tests were limited to the remaining alloys.

It was found necessary to continue the rolling of the rods in order to reach the hardness of steel; with the

10 per cent. bronze, to an elongation of 20 per cent.;
8 per cent. bronze, to an elongation of 30 per cent.;
6 per cent. bronze, to an elongation of 50 per cent.;

with the—

10 per cent. bronze and 2 per cent. zinc, to an elongation of 10 per cent.

10 per cent. bronze and 1 per cent. zinc, to an elongation of 15 per cent.

8.5 per cent. bronze and ½ per cent. zinc, to an elongation of 20 per cent.

The results of tests made can be seen in the following table:

ALLOYS.	TENSILE STRENGTH.		ELASTIC LIMIT.		ELONGATION WITHIN THE ELASTIC LIMIT IN 0.00001.	SET IN PER CENT. OF LENGTH.
	Pounds per square inch.	Kilograms per square centimetre.	Pounds per square inch.	Kilograms per square centimetre.		
10 per cent. bronze	71,937	5,066	24,140	1,700	174	1.5
8 per cent. bronze	73,840	5,200	19,880	1,400	140	2.5
6 per cent. bronze	77,532	5,460	18,460	1,300	128	3.5
10 per cent. bronze and 2 per cent. zinc	42,884	3,020	8,520	600	89	0.5
10 per cent. bronze and 1 per cent. zinc	59,214	4,170	14,200	1,000	120	0.7
8.5 per cent. bronze and ½ per cent. zinc.	53,960	3,800	21,300	1,500	157	1.7

These tests showed that, in general, the 10 per cent., as well as the 8 per cent. and 6 per cent. bronzes, may be employed in the new method of making gun-barrels, while the addition of zinc is of no use whatever, but, on the contrary, decreases its value in no inconsiderable degree.

The 8 per cent. bronze was judged to be the best for large castings, and this has, therefore, been taken as the proper alloy for "steel-bronze."

A number of trials were made to determine what method of casting and cooling would make the inner layers of the casting homogeneous, and give the necessary toughness for standing the treatment to which they were to be subjected.

Simultaneously with these trials, those castings whose quality was shown to be good, by the appearance of the fracture, were subjected to the mechanical treatment. A hydraulic press was employed for this purpose, of a capacity of 100,000 kilograms (220,000 pounds).

The following is a short sketch of the main features of the method which was employed for making gun-barrels subsequently to September, 1873:

The castings were 260 millimetres (10.4 inches) thick, 300 millimetres (12 inches) long, having a bore of 80 millimetres (3.2 inches) diameter. They were conical and turned down at one end to 180 millimetres (7.2 inches) diameter. They were then placed vertically under the die of a hydraulic press, which was then driven through them, in accordance with the Dean system, a system the earlier existence of which General

Uchatius seems ignorant. The surface of the die was of well-hardened steel, and was a slightly-tapering cone, thus increasing the diameter gradually. But, since the resistance increased with the enlargement of the barrel, the difference between the diameter of the plunger and that of the last formed barrel must decrease gradually. Six plungers were employed in succession, of which the first increased the bore by 2 millimetres (.08 inch) and the last by ½ millimetre (.02 inch).

The original diameter of the bore, 80 millimetres (3.2 inches), was thus increased to its normal size of 87 millimetres (3.88 inches); that is the increase amounted to 7 millimetres (.28 inch), or 8.75 per cent., while the exterior diameter of the casting was increased by 2 per cent. The surface of the bore which was thus produced had a hardness, when measured by indentation, of 10.5 millimetres (.42 inch), or equal to that of gun-steel; it was as smooth as a mirror, and only needed rifling. It was further remarked that the same result as to hardness was produced at the end which was weakened by turning down, which would seem to indicate that the outer layers of guns do not come into play at all when firing.

299. Experiments on Compressed Bronze.—The material of the first two experimental barrels of steel-bronze had the following properties:

PROPERTIES OF STEEL-BRONZE.	TEST-BARREL NO. 1, NEAR THE—		TEST-BARREL NO. 2, NEAR THE—	
	Bore.	Exterior surface.	Bore.	Exterior surface.
Tensile strength per 1 square centimetre, in kilograms	4,250	3,320	4,250	3,320
Tensile strength per 1 square inch, in pounds	60,350	47,144	60,350	47,144
Limit of elasticity per 1 square centimetre, in kilograms	1,100	500	1,100	700
Limit of elasticity per 1 square inch, in pounds	15,620	7,100	15,620	9,940
Stretch, ultimate, in per cent. of length	16.5	50	16.5	50
Stretch, elastic, in per cent. of length	0.306	0.060	0.306	0.060
Section at the point of rupture, which was originally taken = 1.00	0.56	0.50	0.56	0.50
Hardness, depth of indenture, in millimetres	10.6	12	10.6	12
Hardness, depth of indenture, in inches	.42	.48	.42	.48

Both barrels were subjected to tests by firing.

These tests were made on the "Simminger Haide," from 40 to 50 shots being fired daily, two shots with the diminished charge of 1 kilogramme (2.2 pounds), and 238 shots with the normal charge of 1.5 kilogrammes (3.3 pounds). The projectiles were 2½ diameters in length, and the powder used for the charge was large-grained powder, the size of the grains being from 6 millimetres to 10 millimetres (0.24 inch to 0.4 inch), the density was 1.605.

The barrel showed no signs of either a widening of the bore or any other flaw after these tests.

The test-barrel No. 2 was tried on the "Steinfelder Haide" to determine the decrease in precision of firing consequent upon the firing a great number of shots with the charge of 1.5 kilogrammes (3.3 pounds), and with projectiles 2½ diameters in length, weighing 6⅓ kilogrammes (14 pounds). The velocity attained with this charge was 1,480 feet. In all, 2,130 solid shot were fired and twenty shells were thrown.

The examination of the barrel showed the chamber to be quite unaltered. The enlargement, which was perceptible—about 0.1 millimetre (0.004 inch)—was due to burning out and to mechanical wear. The lands and grooves of the barrel were worn considerably, after this great number of discharges, by mechanical wear and by burning out, but from the muzzle to the vicinity of the trunnions the lands were left quite sharp, and consequently were capable of seizing the projectile with perfect accuracy, giving the necessary stability in the barrel.

After 2,100 discharges, a projectile was purposely made to burst in the gun, in order to determine the amount of damage thus produced and its effect upon the accuracy of fit of the shot. The following series of 25 shots did not show loss of accuracy, although the grooves and lands were badly damaged, for the latter were crushed and the metal squeezed into the grooves.

This method of working castings applies advantageously to the production of steel gun-barrels. Steel, having an elastic limit of 2,000 kilogrammes per square centimetre (28,400 pounds per square inch) and a ductility of 20 per cent., cannot be produced by any hardening process or method of manufacture, except by stretching in the cold state.

300. **Uchatius' Deductions.**—The steel-bronze barrels will, according to General Uchatius, prove to be better than those of steel, for the following reasons:

On account of the quadruple price of the steel, and because old steel-bronze barrels can always be remelted.

On account of the time required in manufacturing, which with steel is six or seven times as long as that needed with steel-bronze. In order to produce a cast-steel barrel fitted with rings, the inner tube is first cast. It is then heated and worked under the steam-hammer; it is then bored, and finally the rings are shrunk upon it. For this purpose are needed, not only very costly plant, but also skilful, experienced, and very reliable workmen. The steel-bronze barrels are simply cast, then bored and pressed, and finally drawn; all of which manipulations are very simple.

On account of the greater rapidity of destruction of the steel by atmospheric influences. The destructive effect of oxidation rapidly penetrates to the interior with steel, while steel-bronze merely receives a superficial layer of verdigris, which does not penetrate.

Because steel barrels are not as safe for the gun's crew as steel-bronze barrels, of which the exterior layers are so tough that they must be stretched 50 per cent. before fracture.

The cost of a steel-bronze barrel thus made and of the size here described is given as $175, and that of a gun made of steel at $750.

301. **Frigo-Tension.**—There is, finally, another process—which is applicable, however, only to ductile iron and steel, and to such other metals as exhibit an elevation of any normal elastic limit by the intermittence of strain—which may be usefully applied at ordinary temperatures with the result of increasing the elastic resistance, and, usually, the ultimate strength of the material. This process has been long used by bell-hangers when wishing to give wire greater stiffness

and uniformity of stretch; but it has not become generally known or extensively applied in the arts.

When a bar of copper, zinc, tin, lead, or other metal than iron or steel, is subjected to gradually increasing distortion, it offers gradually increasing resistance up to the point of rupture, and this resistance follows a regular law in most cases, whether the distorting force is applied steadily or intermittently. This gradual increase of resistance is due to the fact that the normal elastic limit for all metals becomes higher as distortion progresses, until it finally coincides with the ultimate strength of the piece, and fracture then occurs.

When, during the process of extension, the stress is intermitted, the effect of such intermission, as has been seen, Art. 285, is often to produce a marked change in the position of the normal elastic limit due to the degree of stretch attained, and it is found that on renewing the effort to distort the piece, the limit of elasticity, when distortion again begins, is not precisely where it was at the interruption of the process of distortion. In some cases the change is hardly, if at all, observable; in other cases the elastic limit is found to have been elevated; and in still other cases, where the load has not been removed, it is lowered. This difference has led to the division, by the Author, of the metals used in construction into two classes. One comprehends iron and steel, and, possibly, other metals not yet determined. The other class comprehends the inelastic metals, including copper, tin, zinc, and their alloys.

302. **Comparison of Methods.**—The effects of the several methods of working which have been described can be well explained and illustrated by a comparison of the strain-diagrams of the product of each.

The effect of the processes which are adopted to improve metals by treatment before, or during, solidification after fusion, is to give greater strength, ductility, elasticity, and resilience. The strain-diagram is, therefore, given higher ordinates, a greater maximum abscissa and an enlarged area; that is, the diagram of the untreated metal is given increased altitude, an increased extension, and a much greater area.

The general character of the diagram remains unchanged, except as to dimensions, unless modified by peculiarities of subsequent treatment. The effect is the same in kind, to whichever class the metal may belong. It is the same with the Whitworth as with the Lavroff process. The treatment of the molten metal by fluxing before subjecting it to any mechanical manipulation, produces the same modification of the strain-diagram. A combination of the two processes, as the addition of phosphorus to bronze, with compression of the metal by the Lavroff method, would evidently give a still more important improvement and would be represented by a still more marked change in the strain-diagram.

The process of working the metals at a red heat, as in the rolling mill and in the forge, effects changes which are in general exhibited on the strain-diagram by those modifications which indicate increased strength, ductility, resilience, and homogeneousness in the character of metals. The effect is not precisely the same on the two classes. All cast and unworked metals give a strain-diagram of approximately parabolic form and free from any sudden change of curvature. Their elastic limits are, therefore, modified by the slightest distortion, and an elastic limit is found at the zero of load and of strain. This was first explicitly stated by Hodgkinson, when reporting on his experiments on cast-iron. The strain-diagrams published by the Author in the cases already referred to * show that this is true of the other cast metals. The slightest force in all such cases produces a set.

After having been subjected to the action of the rolls or of the hammer at a red heat, the inelastic metals of Class 2 give the same smoothly curved diagram as before, the change being observable in the dimensions and not in the form of the curve. The metals in Class 1, however, give strain-diagrams which are of a somewhat different form. Instead of the form O E A, Fig. 38, a sharp change of direction is seen at some point, and the diagram is more like O E C. The normal elastic limit of the piece when tested is found to be at first rapidly elevated as distortion progresses, until at some

* Part II., Fig. 98

point, E, a sharp change of the ratio of the distorting force to the amount of coincident distortion takes place, and the sets become approximately equal to the total distortions. This point is the "apparent" elastic limit, which is the elastic limit as commonly understood. Rolled or forged metals of the first class, therefore, have an apparent elastic limit which is much more clearly marked than in any cast metal, or in any metals of the second class.

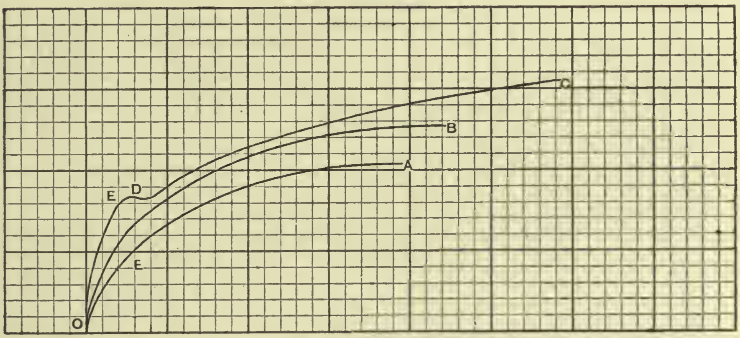


FIG. 38.—STRAIN-DIAGRAMS.

Thus, in Figure 38, let the curves A, B, and C represent the strain-diagrams, (1) of any cast metals, (2) of a rolled metal of the second class, and (3) of a part of the diagram of rolled iron, respectively. The characteristic differences between the two rolled metals and between them and the cast metal are well indicated. These curves are copied from actual diagrams produced automatically, and are real graphic representations of those characteristics.

The depression seen at D is an indication of the presence of fibre in the metal.

303. **The Effect of the Processes of Rolling and of Hammering** the metal cold are graphically represented in Figure 39. The strain-diagram A is a copy of the beginning of that given in the Mechanical Laboratory of the Stevens Institute of Technology by a piece of merchant bar iron of excellent quality. That marked B is a copy of the initial

portion of a diagram produced automatically by a sample of cold-rolled shafting made by treatment of a piece of iron of similarly good quality.*

It is seen at a glance that the effect of cold-rolling is, in this case, to bring the apparent elastic limit nearly up to the maximum of resistance, which is only attained in the untreated metal after very great distortion. As has already been stated, the piece also exhibits a much greater ultimate

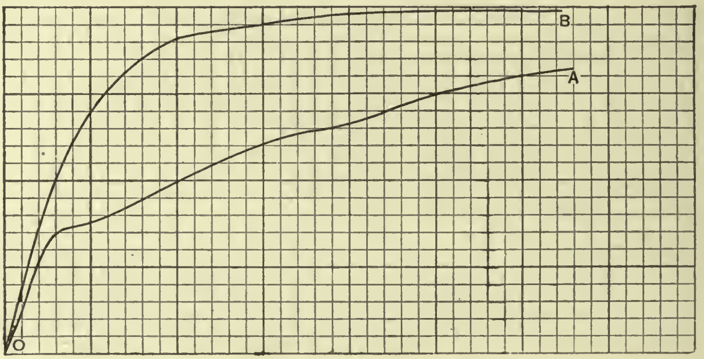


FIG. 39.—STRAIN-DIAGRAMS OF IRON.

resistance than the same metal prepared in the usual way. The resilience, taken at the elastic limit, is immensely increased, and the elasticity of the metal was found to be the same, wherever measured, while distortion was progressing. The metal is probably compacted to some extent, but to so slight a degree that the resulting change of density has not been measured.† Examining the piece after fracture, it is found that concentric layers differ from each other in the degree in which they exhibit the effect of cold-rolling, but that in each layer the metal is rendered exceedingly homogeneous. As in all ordinary work the metal is never intended to be perma-

* See plate, above referred to, Part II., strain-diagram No. 85; see also Report by the Author on an extensive series of tests of cold-rolled metal for the American Iron Works, 1877.

† Major Wade found no increase of density, but apparently a slight *decrease* after cold-rolling iron.

nently distorted—is never expected to be subjected to strains which can produce permanent set—the increased value for constructive purposes which is conferred by this treatment is measured by the increase noted in its strength, elasticity, ductility and resilience within the elastic limit. It is seen to be immensely great. The effect observed is, in this case, due probably to the elevation both of the apparent and the normal elastic limit, by both the simple condensation and increase of homogeneousness which occurs with metals of the

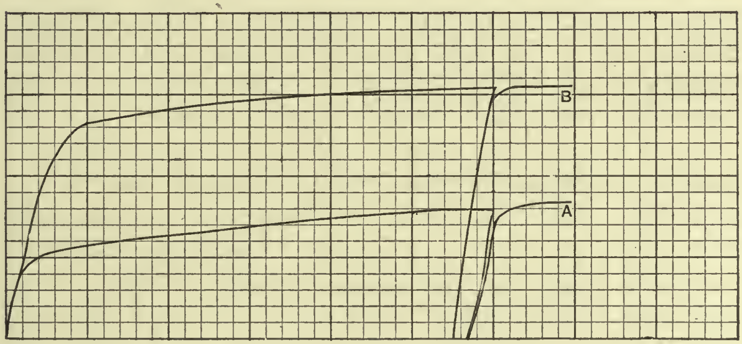


FIG. 40.—STRAIN-DIAGRAMS OF BRONZES.

second class, and by that peculiar exaltation of tenacity, by some as yet not fully determined change in molecular relations, which is only known to take place with metals of the first class.

The effect of the cold-rolling process is, however, the same in kind, so far as it affects the form of the strain-diagram, where the second class of metals is treated, and the curves seen in Figure 40 are copies of diagrams produced automatically, during the tests of two pieces of bronze from an old gun. The diagram A was given by a test piece taken from the exterior of the gun, where it had been little, if at all, affected by the compression; and that marked B was given by a specimen taken from the inside of the bore, where the effect of compression was most marked.

On comparison, it is seen that the effect of the process of compression, at the ordinary temperature, of both classes of metal is the same in kind. So far as it affects simply the relation of the distorting force to the distortion produced by it in each, the result of the operation is the elevation of the limit of cohesion by condensation of the metal and by the production of greater homogeneity. In the case of iron and steel, the effect of this treatment is heightened by the peculiar property of those metals which has been already fully described. With both, the result of cold working is highly advantageous for many purposes. In some cases—as, for example, when the metal is to be subjected to extremely violent shocks, and is therefore likely to be permanently deformed, and where it should be capable of offering a maximum resilience up to the point of actual rupture, *e.g.*, the armor-bolts of an iron-clad—the metal should not be subjected to this process, or should be treated very cautiously. Where great strains are liable to be met, but without impact, as in the more usual applications of such metals in machinery, and as in ordnance, where the tremendous pressures exerted are due only to the elasticity of a confined gas, it is as evident that cold-worked metals are well fitted to give a maximum resistance without counterbalancing disadvantages.

304. Historical—Discovery of Facts and Determination of Laws.—It is impossible to say just when all the facts and laws above given were first known. The first intelligent statements of the simpler facts were made, probably, by Galileo, who, in 1656, published a work—"*Opere di Galileo*"—at Bologna. Robert Hooke, in 1676 and 1678, was the first to announce the important principle which forms the basis of our theory of elasticity of bodies within the elastic limit, in the now celebrated Latin phrase, *ut tensio sic vis*—the extension is proportional to the force. Marriotte, Leibnitz, Parent, Bernouilli, and other mathematicians, discussed the theories of flexure and of rupture of beams with equal mathematical skill and practical ignorance. Coulomb, about a century ago, gave the best mathematical treatment published up to that time, and made some experiments which were of real value. Dr. Thomas Young, the ablest writer who has ever devoted a mind rich alike in scientific knowledge and in power of useful application, to practically valuable study, defined the modulus, or coefficient, of elasticity, and reduced to practical shape the laws enunciated by Hooke and other earlier writers. Dr. Young also defined the quality which Professor Lewis Gordon afterward called, "resilience," and showed that it measured the amount of "work" done in distorting a body.*

The first connected and special treatise on strength of materials, and on construction, was the work of the distinguished Navier, the lecturer at the *École des Ponts et Chaussées*, in 1824; but Tredgold had already prepared his excellent treatise on iron. Since then, Fairbairn and Hodgkinson, Morin, and many others, have written valuable treatises on the subject, or upon special divisions.

Probably the most reliable and extended of early researches in this field were the experimental investigations of Muschenbroek, of which an account is given in his Introduction to Natural Philosophy, published in 1762. Banks, in 1803, and Rondelet, in his "*Art de Batir*," 1814, published the results of experiments on iron. The best work which has since been done has been published within a few years by Fairbairn and Hodgkinson, Kirkaldy, Styffe, Bauschinger, Wohler, and by our own countrymen, Rodman, Wade, Shock and some other experimenters in special directions.

The fact of the existence of an elastic limit was very early discovered. Duleau, in his "*Essai Théorique et Experimental sur la Resistance du Fer Forgé*," printed in 1820, gives the elastic limit of that metal as at 8,540 pounds per square inch, and at an extension of about 1-3333 of the original length of the piece in tension. Tredgold, writing in 1823, says: "I find that while the elastic force, or power of restoration, remains perfect, the extension is always directly proportional to the extending force, and that the deflection does not increase after the load has been on for a second or two; but when the strain exceeds the elastic force, the extension or deflection becomes irregular and increases with

* Thomson and Tait; Nat. Philos, vol. i., part ii., p. 228.

time." Coulomb had already, many years before, noticed that many materials take a permanent set long before the breaking point is reached, and Emerson had, as early as 1758, asserted that the materials of construction should not be subjected to a force exceeding from one-third to one-half their ultimate resistance, and thus proposed the now invariable practice among intelligent engineers of taking a certain "factor of safety." In Tredgold's time, also, the work of Telford, Brown, Rennie, Barlow, and Rondelet, was well known. The fact that the elastic limit of a piece of metal exceeds its primitive value more and more as the piece is more and more distorted, was exhibited by some of the very earliest of these experiments. Dr. Young, in 1807, made the fact the basis of his remark: "A permanent alteration of form limits the strength of materials with regard to practical purposes, almost as much as fracture; since, in general, the force which is capable of producing this effect is sufficient, with a small addition, to increase it till fracture takes place." (Nat. Phil., vol. i., p. 141.) He also pointed out the importance of the determination of the resilience of a piece as a measure of its power of resisting impact. Tredgold gives, 1823, simple rules for the application of this principle, and both indicate the necessity of noting the variation of the resistance as distortion progresses in order to obtain a measure of that resilience.

305. **Experiments** published in 1840, in the Phil. Transactions, by Hodgkinson, were the first to supply data for an exact determination of the method of variation, and of the values of the normal elastic limit from the instant of its departure from its primitive value. His work is still quoted as standard authority, and as the most extended as well as thoroughly precise series of experiments yet made. His later work, extending over several years, is no less valuable. His tabulated results of test showed that sets occur with very light, if not under all, loads; that the sudden change which marks what is here termed the apparent elastic limit, is followed by a gradual elevation of the limit as distortion proceeds, and that the normal elastic limit has a value, for

each stage of distortion, which may be expressed by formulas of the kind already given. The fact was shown that the increase of resistance, as change of form occurred, became less and less marked up to the maximum.

Clark, in his account of the Britannia and Conway bridges, in 1850, makes the statement, based on results obtained by Hodgkinson and himself: "We have seen that as we increase the permanent set of wrought iron we diminish the subsequent extension and compression from any load, and we have alluded to the fact that the tubes would have deflected less from any given load if the top and bottom had been previously compressed and extended by any artificial strain. It follows from this consideration that if the compressed and extended portion of a wrought iron bar could be, by any artificial means, permanently strained previously to its employment as a beam, such a beam would deflect less than a new bar, and would be practically a stronger beam, since the strength is regulated solely by the bending of the bar." This is probably the first time that such a statement was made of this now well-known and very important principle. Long after, few engineers were aware of the fact that it was then so distinctly enunciated and that the discoverer determined, by direct experiment, the effect of this method of treatment.

Clark gives the tabulated results of test of bars thus treated, beside those derived from the test of other bars left in their original state. The former deflected but 1.765 inches under a load of 46.5 hundredweight; while the latter deflected 5.145 inches under a load of 41.9. The bars were 1½ inches square and the supports were 3 feet apart.

Werder, at Munich, in 1854, used tie-rods which, by a single effort of tension, had been similarly stiffened. Neither Clark nor Werder seems to have understood the peculiar phenomenon of the exaltation of the normal elastic limit by intermitted strain, or to have availed himself of it by repeating the efforts of distortion.

Later experiments made at the Woolwich dockyard exhibited another interesting and important phenomenon due to the same characteristic. A rod was broken several times in succession, and exhibited continually increasing ultimate resistance. Other rods similarly treated gave the same result. The mean of 10 gave a tenacity at the first fracture of 24.04 tons per square inch; the means of succeeding breaks were at 25.94, 27.06, 29.20, while the extension varied too irregularly to indicate any law. Similar experiments have since been made in 1873, by Bauschinger and other experimenters. It was at first generally supposed that the last noted behavior of iron was due to the obvious fact that the bar must have broken at the weakest point first, at the next weakest place next, and so on, until the last fracture occurred at very nearly the section of maximum strength of the bar. It is now, however, evident that it is, or may be, due partly to the action noted by Clark, and also that it may take place in metals of *both* the classes which have been above defined by the writer. In the iron class, however, the effect is undoubtedly more marked than in metals of the tin class, since there the exaltation of the normal elastic limit also comes in to increase the resisting power.

306. **The Exaltation of the Normal Series of Elastic Limits** by intermittence of strain and by lapse of time at a constant distortion, was observed by the Author in 1873. Commander L. A. Beardslee, U. S. N., independently noted the same phenomenon, later in the same year. The latter has since determined the magnitude of this change in iron during periods varying from one second to one year. (See Part II., Art. 298.) The Author, at about the same time, observed the depression of the normal series of elastic limits in the inelastic metals.

As early as 1858, Prof. James Thomson, who had seen the importance of the property which produced the variation of resistance of materials between their primitive elastic limits and their ultimate fracture, and had called it "viscosity," had shown its effect in modifying the mathematical expressions deduced for the torsional resisting power of metals. He pointed out the marked difference in the forms of these formulas where applicable to brittle and to ductile, or viscous metals, and, in the latter case, to the resistance within and beyond the primitive elastic limit. Almost nothing has, however, been since done in the further modification of working formulas with reference to the position and variation of the normal elastic limit, or to the determination of actual resistance, except that the Author has applied the same process to the modification of formulas for transverse resistance of tough metals, and independently of Prof. Thomson, but many years later, to the general case of torsion and to the intermediate condition in which a part only of the section is strained beyond the primitive elastic limit.

M. Tresca and Captain Beardslee have shown, as has the Author (1873–83), all working independently, that, with iron, the variation of the normal elastic limits may extend nearly or quite up to the point of actual rupture, and that the modulus of elasticity remains almost unchanged. The Author, experimenting with all the common materials of construction and with the whole range of alloys of copper-tin and copper-zinc and with the copper-tin-zinc alloys, has found the same to be true.

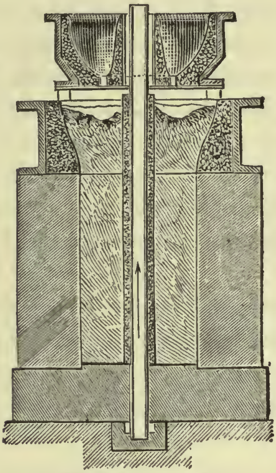
Fairbairn, who was thoroughly familiar with the behavior of iron under strain, supposed the increase of resistance with distortion to be a consequence of the gradual bringing into action of particles in bodies which are not homogeneous as to strain, as the fibres of a rope are brought gradually into tension as the rope is more and more stretched. The Author has proposed a very similar explanation of the exaltation of the normal elastic limit by intermitted strain, and has shown how such a condition may be produced by the process of manufacture of those metals which exhibit that phenomenon most strikingly, but does not regard it as a satisfactory explanation of the kind of variation of the elastic limit which is observed in both classes of metals alike, to explain which it was offered by Fairbairn.

Kick has (1870–80) shown the increased resistance of soft bodies attacked by shock, and confirms the deductions of the Author in that respect.

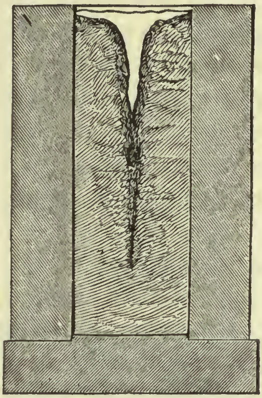
307. Strain-Diagrams.—Gen. Morin was probably the first, about 1850, to represent the relation of the distorting force to the amount of distortion by the graphical method, and, in his "*Resistance des Materiaux*," plotted beautifully the results of Hodgkinson's experiments. His curves exhibit perfectly the characteristics of the metals, the tests of which they represent, and exhibit plainly and accurately the variation of the elastic limit by continued strain. They do not, of course, indicate the exaltation of the normal limit by intermitted strain. Mallet, in 1856, uses the same curves to illustrate his application of the principle of the equivalence of the work done in producing fracture of the materials used in the construction of ordnance with the resilience of the metal, and the *vis viva* of the shot or other mass attacking by impact. Gen. Rodman, Major Wade, Kirkaldy, Styffe, and other later experimenters, have used the graphical method during the last quarter of a century in illustrating nearly all their work. In all such strain-diagrams, the variation of the elastic limit is exhibited, and the law of its variation with gradual change of form is expressed. Rodman was the first investigator to adopt the method as a system, using it in his report on his experiments on metals for cannon made in 1856 and 1857.

Finally, the Author, in 1873, observed the exaltation of the normal series of elastic limits as recorded on automatically produced strain-diagrams, and gave an account of that, and of other interesting phenomena exhibited by the autographic strain-diagram.

308. History of Processes of Working Metals.—Reverting to the several processes of working metals which have been described, it will be seen that the methods of securing improvement by an increase of homogeneousness by treatment of the metal while fused, have no relation to any other modification of the elastic limit than that which distinguishes a structurally weak and defective material from a more perfect specimen of the same metal. The processes of cold-rolling and of other methods of compression of cold metal involve, whether the metal be iron, steel, bronze or brass, that form of variation of the elastic limit which has been known since the time of Tredgold, and possibly of Muschenbroek, in addition to the change produced by the condensation of solidifying metal, and in a marked degree. The ordinary processes of working metal hot are intermediate in character between the other two. It is seen that the iron class, whether worked hot or cold, experiences, besides, a change which the writer has proposed to denominate the "exaltation of the normal elastic limit by intermitted strain." It is seen that the latter action is not involved in the cold-working of bronze.



Internally Cooled Ingot.



Cast Ingot.

FIG. 41.—INGOTS.

In securing homogeneousness of structure by treatment of the molten metal, various methods of fluxing have been practised from an unknown and very early period. The most successful methods have involved the use of phosphorus as a flux in casting bronze and of the silicide of iron and manganese for iron and steel. The method of compression of molten metal at the point of solidification was first brought into use by Sir Joseph Whitworth, of Manchester, England, about 1860. It was subsequently adopted on the Continent of Europe, and is now becoming well recognized as one of the most efficient known methods of producing metal of the highest possible grade. This method was first applied to the production of bronze guns by Colonel Lavroff, in the Russian arsenals, about 1867. By him the process was perfected in 1870.

Chill-cast bronze was probably first proposed by Mallet in 1856, and he at the same time proposed the use of a hollow core to be cooled by currents of air, as in Figure 41. This method was adopted with great success by makers of bronze a few years later. It was adopted by General Uchatius in 1873, after having seen the remarkable success of M. Lavissière, who exhibited a bronze gun made in this way at the Vienna Exhibition of that year. Colonel Rosset, of the Italian artillery, had also adopted the same method, and it is referred to in his work, "*Esperienze Meccaniche sulla Resistenza dei Principali Metalli da Bocche da Fuoco. Torino*, 1874," in which he also recommends the adoption of the Dean method of making bronze guns.

The form of chill used for ordnance is shown on a subsequent page.

The ordinary methods of forging and working metals at a red heat were introduced hundreds of years ago, and their early history is quite unknown. Rolling mills for working iron were introduced about 1784 by Cort, the inventor of the process of puddling.

Wire was made by hammering by the ancients and at a date which is not known. Wire drawing was invented 500 years ago, in Nuremberg, Bavaria, by a "wire-smith" named Ludolf. By the middle of the seventeenth century the business of wire drawing had been imported into Great Britain, and was employing thousands of people in England and in Germany. In 1813 Dr. Wollaston introduced his method of enclosing one metal within a bar of another metal and drawing down the two together. When finished the outer coating was dissolved off by an acid, and the inner and extremely fine wire was left perfect. Platinum wire has been thus made, by enclosing it in silver, of but 1-30,000th inch diameter. Mr. Brockedon, as early as 1819, using the precious stones as draw-plates, produced wire 0.0033 inch in diameter.

309. **Cold-working Iron,** as a system, has been practised but a comparatively short time. It had long been known that such treatment imparted stiffness and elasticity to metals, but it was not known at what stage of the process of condensation, if any, the action ceased to produce benefit and became liable to injure the metal by weakening it by the introduction of internal strains. It was well known to experienced engineers and metal workers that cold-hammered iron, and iron rolled cold, was often seriously injured by being worked too cold; and the Author was accustomed, many years ago, to give special instructions to the smith who was about to make the forgings of a steam engine which were to be left without tool finish, not to attempt to give them the fine finish under the hammer which may be given by hammering at a "black heat," lest they should be weakened by the treatment. It was not then generally known that cold-working might be so conducted, and safely, as to secure an increase of strength.

The process of cold-rolling was introduced in the United States by its inventor, Bernard Lauth. His experiments were first made in 1854, and in 1857 he fitted up a set of rolls for systematic experiment; and in January, 1858, he brought out cold-rolled iron as an article of manufacture. Two other inventors, Messrs. Cuddy and Savory, invented very similar processes almost simultaneously with their successful rival Lauth. Mr. Lauth was assisted pecuniarily, and by the practical knowledge of, Mr. B. F. Jones, and the work was done at the mills of the American Iron Works, Pittsburgh. The process was introduced into Great Britain by Lauth in 1858. He introduced it into France and Belgium in the following year. The process has now become one of the well-established methods of iron-working, and is gradually becoming recognized as a valuable method of modifying the properties of steel, bronze, and other metals.

As applied to iron and steel, it evidently results in the strengthening of the metal by condensation and by the production of greater homogeneousness of structure, and also gives stiffness and elasticity by the long-known form of elevation of the primitive elastic limit, as well as by the exaltation of the normal limit by the action ascribed by the Author to intermitted strain. As applied to gun-bronze and other metals of the tin class, it produces its useful effect only by the first two methods of change.

310. **Cold-working Bronze** and that class of metals by Mr. Samuel Buel Dean, of Boston, Mass., was applied by him to the improvement of gun-bronze at some time previous to 1859, at which date he laid his plan before the ordnance officers of the United States War Department, and illustrated its effects by treating samples of gun metal, as has already been described. The Ordnance Bureau ordered guns to be made by the Dean method in July, 1870, and the work was subsequently interrupted in consequence of the neglect of Congress to vote the necessary funds. In Great Britain, the Committee on Field Artillery for India, in 1870, reported in favor of the adoption of this method.

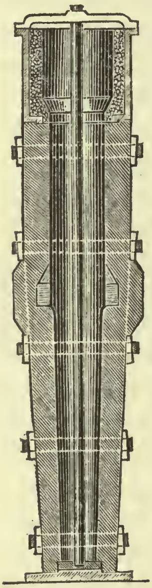


FIG. 42.—CHILL FOR ORDNANCE.

General Uchatius, of the Austrian artillery, adopted the process in 1873, using the method of condensation described in the patent of the inventor, Dean, which had been filed in Vienna July 16, 1869, in Register sub-vol. xix., fol. 378. The British and French patents were dated May 10 and May 12, respectively, of the same year. The United States patent was dated May 18.

Uchatius adopted the method of chill-casting suggested by Mallet in his work "On the Construction of Artillery," as has already been stated. The first information given abroad relating to the Dean process was probably the statement made by Mr. Clemens Herschel to Mr. Isidor Kanitz, of Vienna, May 18, 1869.

The following figure represents Dean's apparatus. The metal cylinder to be strengthened, A, is supported by a casting, B, while the rod, C, carrying the mandrel, is driven through it.

The adoption of the process invented by Dean, by the

Italian military authorities, was advised by Colonel Rosset also, and is referred to in his work on gun metals, published almost simultaneously with the description, by General Uchatius, of the details of the method of application of the Dean process in the Austrian arsenal.

311. **Conclusions.**—The processes which have been described at such length in the preceding pages are regarded as the most important known processes of modification of the primary qualities of the useful metals.

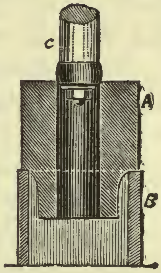


FIG. 43.—COLD-WORKING BRONZE.

It may be concluded, from what has preceded, that the proper method of preparation of metal to secure a maximum value is the following:

(1.) Reduce the metal, when possible, to the molten condition, flux thoroughly with such a flux as will remove, first, all deleterious substances with which the metal may be contaminated; secondly, every particle of gaseous oxygen and of oxide; and, thirdly, all other occluded gas liable to produce "blow-holes."

(2.) Cast the metal under heavy pressure, in order to secure maximum density and to close up every pore as perfectly as possible. If the metal is an alloy which is liable to liquation, it should be cast in a chill of sound iron and of considerable thickness.

(3.) If the metal is either iron or steel, produce any considerable change of shape which may be desired by rolling, by the drop-press, or by hydraulic forging at a full red heat, and permit it to remain unused as long as is possible, in order that the internal strain, unavoidable to some extent with any method of treatment, may be given time to become reduced by that process of flow which will ultimately relieve it. If stiffness and a more perfect elasticity are demanded, finish by the process of cold-working, taking great care not to carry it so far as to seriously injure the continuity of the metal.

(4.) The bronzes, and other metals of the inelastic and viscous class, may be given very considerable modification of form by the processes of working cold. The same precaution must be taken to avoid destruction of continuity, and thus, by the production of incipient fracture, permanently and seriously injuring it.

By observing these precautions, the maximum value of the metal for constructive purposes may be attained. Whitworth has made "homogeneous iron" castings having a tenacity of 35 tons per square inch by his process, and the Author has made brass without any special treatment, either by fluxing, compression, or other modifying processes, having a strength of 70,000 pounds per square inch (4,921 kgs. per sq. cm.) It is not unlikely that the theoretical maximum for any material —the maximum due to the effort of the force of cohesion, and that which is perhaps approached, in special cases, in fine wire—may be nearly attained, even in large masses, by the skilful and intelligent combination of the processes which have been here described in the treatment of such cast metals, and in their adaptation to purposes of construction.

APPENDIX.

§ 51, p. 90.—Aluminium and zinc in the proportions 67 and 33 give an alloy of much value for special purposes.

From a series of tests made in the Mechanical Laboratory of Sibley College, on the strength of alloys of aluminium and zinc in varying proportions, the best results were found for mixtures of not far from the above proportion. The principal properties of the metal were found to be as follows:

Tensile strength deduced from small bars............	22,000
Maximum "fiber stress" deduced from transverse tests.	44,000
Modulus of elasticity	8,000,000
Specific gravity....................................	3.3

Apart from the above, comparative experiments have been made more recently between small bars of this metal and like bars of cast iron, showing the same general indications, and apparently warranting the conclusion that this alloy is the equal of good cast iron in strength, and its superior in location of elastic limit. The other general physical properties of chief interest are as follows:

The color is white and it takes a fine, smooth finish and does not readily oxidize. It melts at a dull red heat or slightly below, probably about 800–900 F. It can, therefore, be readily melted in an iron ladle, over an ordinary blacksmith's forge or other open fire. It is very fluid and runs freely to the extremities of the mould, filling perfectly small or thin parts. In this particular it is much superior to brass. It does not burn the sand into the casting, and hence comes out clean and in good condition to work. It is rather softer and more easily worked than ordinary brass, and yet is not as liable to clog a file. It is brittle like cast iron, and hence is not suited to pieces which require the toughness possessed by brass. For equal volumes and with aluminium at 50 cents per pound, it is about equal in expense to brass bought at 15 cents per pound. It becomes ductile at 212° F.

This alloy would seem to be admirably adapted to many small parts of machines, models, etc., where it is desired to obtain castings without waiting for a regular foundry heat, and where lightness combined with good finish, strength, stiffness, and non-corrosiveness, are among the desiderata. It has been employed with great success in the construction of small screw propellers for experimental work.*

According to Hunt, zinc is used as a cheap and very efficient hardener of aluminium castings for such purposes as bicycle frames, sewing machines, etc. Proportions up to 30 per cent. of zinc with aluminium are being successfully used; an alloy of about 15 per cent. zinc, 3 per cent. tin, and 82 per cent. aluminium having especial advantages.

Copper in proportions of from 2 to 15 per cent. has been advantageously used to harden the metal in cases where a more rigid metal is required than pure aluminium. Copper is the most common metal used at present to harden aluminium. A few per cent. of copper decreases the shrinkage of volume, and gives alloys that are especially adapted for art-castings. The remainder of the range, from 20 per cent. copper up to 85 per cent., give crystalline and brittle alloys of no use in the arts, which are of grayish-white color, up to 80 per cent. copper, where the distinctly red color of the copper begins to show itself.

Aluminium brass has an elastic limit of about 30,000 lbs. per square inch; an ultimate strength of from 40,000 to 50,000 lbs. per square inch, and an elongation of 3 to 10 per cent. in 8 inches.

An alloy of 70 per cent. copper, 23 per cent. nickel, and 7 per cent. aluminium has a fine yellow color and takes a high polish, a small percentage of phosphorus in phosphor-tin hardening the alloy considerably.

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* *Science*, vol. v., No. 114.

Tin has been alloyed with aluminium in proportions from 1 up to 15 per cent. of Sn., giving added strength and rigidity to heavy castings, as well as sharpness of outline, decreasing the shrinkage of the metal. The alloy Al. 50, Sn. 25, Zn. 25 has a tenacity of 20,000 pounds and 8 per cent. elongation.

§ 54, p. 95.—" Magnesium as a Constructive Material " * is as yet little known, but its properties indicate large possibilities. Weighing but two-thirds as much as aluminium, and between one-fourth and one-fifth as much as iron or steel, it seems likely to find uses in the arts, and, like aluminium, particularly in the alloys.

The following are its physical constants:

PROPERTIES OF MAGNESIUM.

Specific gravity	1.743 (109 lbs. per cu. ft.).
Specific heat	0.2499.
Atomic weight	2394.
Melting point	433° C., 811° F.
Boiling point	800° C., 1472° F.
Electric conductivity	41.2.
Tenacity per sq. in	22,000 to 32,000 lbs.
Compression resistance	37,000 lbs.
Bending modulus	23,750 lbs.
Length sustainable	28,000 to 42,000 ft.

Its flame has a temperature of about 1,340° C. (2,444° F.), but the light is similar to that of an ordinary flame at three times this temperature. Its radiant light energy is 13.5 per cent.—a higher figure than that of any other known flame, constituting three-fourths its total energy of combustion and four times that of illuminating gas. Its total light-giving efficiency is 10 per cent., as against one-fourth of 1 per cent. for gas; and taking into account the greater luminosity of its light rays, it has fifty or sixty times the value of gas. Its spectrum is nearer that of sunlight than that of any other as yet discovered artificial illuminant.†

Magnesium is usually obtained by reduction from fluor-

* Mainly from paper, by the author, of similar title; *Machinery*, May, 1896.

† See papers of Professor Nichols and of Mr. Merritt: Trans. Am. Inst. Electrical Engineers, 1890–91.

spar with sodium, but it may also be reduced by the electric arc, like aluminium, and it is very possible that, once its valuable properties and possible applications have attracted attention, it may be produced in quantity very cheaply.

It is quite easily distilled and may be thus purified successfully. The spectrum indicates a close relation between magnesium and aluminium; both giving bands in the yellow and green, of which those of the former are noticeably duller than those of the latter.*

The following are the results of test of the commercially pure metal in form of wire.† The strength here obtained is but about two-thirds that given by authorities generally, as quoted above:

PROPERTIES OF MAGNESIUM.

Specific Gravity, 1.74; *Melting Point*, 446° *F.*, 230° *C.*

NO. OF SAMPLE.	DIAMETER, INCHES.	ELASTIC LIMIT, LBS. PER SQ. IN.	BREAKING LOAD.	DUCTILITY, PER CENT.	MODULUS OF ELASTICITY.
1	0.433	8,800	23,800	4.2	2,040,000
2	0.433	10,780	22,050	...	1,880,000
3	0.442	8,400	20,900	1.8	2,060,000
4	0.435	7,090	19,500	2.5	1,830,000
5	0.424	.....	24,800	3.1	1,930,000
6	0.432	.....	22,500	2.3	....
Average	.....	8,770	22,250	2.8	1,945,000
Best figures	.....	10,780	23,800	4.2	2,060,000

Tests of *cast* magnesium have given results averaging about one-half the above, and ranging from 9,640 to 13,685 pounds on the square inch. The figures given in the table as the best may, perhaps, be taken as those most closely representing the qualities of a pure metal of maximum den-

* See a paper on "Materials of Aëronautic Engineering," by the writer, in Transactions of the Aëronautic Congress, 1893; also *Aëronautics* for March, 1894. In these studies all materials were compared by deducing from the data obtained the length of their own substance which each metal could sustain. Steel, for example, when of 75,000 pounds tenacity, would carry about five miles of straight, suspended bar.

† Published in the Sibley *Journal of Engineering*, January, 1894.

sity and purity, and better than can usually be expected in commercial work. They constitute a standard to which specifications may perhaps gradually approximate. The pure metal thus greatly excels pure aluminium in tenacity.

Copper and magnesium have not been found to alloy, although much time and labor have been expended in the endeavor to secure such compositions.

Brass will take up a minute proportion of magnesium, but with no sensible useful result. The presence of the lighter metal produced neither accession of strength nor increased tenacity. In fact, in every instance the alloy was unsound and weaker than the brass itself.

Iron refuses to alloy with magnesium in any sensible amount, and so far as our experiments indicate anything, the magnesium would seem to have no value either as flux or as a strengthening element. Magnesium and aluminium alloy with increase of strength of the resulting composition up to 10 per cent. magnesium, when the alloy becomes brittle and valueless for constructive purposes. The following are figures obtained:

MAGNESIUM-ALUMINIUM ALLOYS.

NO. OF SAMPLE.	PER CENT. MAGNESIUM.	LIMIT OF ELASTICITY.	TENACITY.	MODULUS OF ELASTICITY.
13	0	4,900	13,685	1,690,000
14	2	8,700	15,440	2,650,000
15	5	13,090	17,850	2,917,000
16	10	14,600	19,680	2,650,000
17	30	......	5,000	....

The addition of magnesium to cast aluminium increases its tenacity by a percentage which exceeds five times that of the per cent. of admixture. The best of these alloys are ductile, and can probably be increased in tenacity 50, possibly 100 per cent. by cold-working pure, well-fluxed, and sound samples, and the sustaining power thus carried up to lengths far exceeding those of "mild" steel.

The only recorded figures for alloys of copper with small doses of magnesium which have come to the knowledge of the Author, previously to those obtained in Sibley College work, are reported by M. Mouchel, but the composition is not given. The tenacities of these bronzes are substantially the same, it is said, as those found for silicium bronzes in similar form,—that of fine wire. They range from 50 to nearly 100 kilograms per sq. mm., of from about 70,000 to 140,000 pounds per square inch; where made for electrical transmissions—and with conductivities of from 95 to 50 per cent.; but they have been given 10 per cent. higher tenacities when it has been found practicable or desirable to employ alloys of conductivities as low as 20 per cent.* The densities of these alloys are not stated; but if Mouchel's compositions change by single tenths of one per cent., the effect of magnesium on copper is obviously very considerable, both in reduction of density and increase of tenacity. The same authority elsewhere gives the conductivity of copper containing one-tenth per cent. magnesium as 94.29.† The following is the table:

COPPER-MAGNESIUM ALLOYS.

CONDUCTIVITY. COPPER = 1.	TENACITY.		PROPORTION OF MG.
	LBS. ON SQ. INCH.	KGS. PER SQ. MM.	
95.16	73,659	51.80	0.001
81.60	86,869	61.09	2
63.89	106,892	75.17	3
58.01	115,718	81.37	4
51.43	135,767	95.49	5
50.61	108,740	76.47	6
21...	29,862	21.00	?

Comparing magnesium with other substances, on the basis of combined strength and lightness, the length of a prism of uniform cross-section which the metal can carry suspended vertically is probably the best standard; it was this which was adopted in the paper above referred to in the endeavor

* "Reports on the Paris Exhibition of 1889," vol. iv, p. 233.

† Ibid., vol. iv, p. 232.

to ascertain the relative value of metals and other substances for aëronautical construction. Taking the tenacities of magnesium as from 22,000 to 32,000 pounds per square inch, it would sustain from 30,000 to 40,000 lineal feet of its own substance, or the equivalent of steel of 100,000 to 150,000 pounds tenacity. The latter is a tool steel and only exceeded by the wire-drawn and rolled steels of exceptional fineness and thinness, which sometimes attain tenacities of 300,000 and even 400,000 pounds per square inch, and are capable of sustaining from 20 to 25 miles of their own material. Machinery now built of open-hearth or Bessemer steel of common tenacities, if constructed of these materials of exceptional lightness and strength, would be correspondingly reduced in weight. Thus, the lighter marine engines seldom fall below 200 pounds per horse power; although torpedo-boat machinery and the engines of fast steam yachts sometimes fall to one-half, or even, in rare instances, to one-fourth these figures. Were it practicable to construct such machines of aluminium, their weights would be but little reduced. Could they be made of magnesium, the weights would be reduced about 50 per cent. But, on the other hand, could the ultimate tenacity of absolutely pure steel in the form of fine wire or watch-spring be used, the weights would become from 50 to 15 pounds per horse power. The maximum molecular tenacity of the finer steels is probably not less than 400,000 pounds per square inch, and when we shall be able to so purify and compact our metals as to attain this maximum, steam engines may be constructed of standard design, similar to those to-day employed, and not exceeding 10 or 12 pounds weight per horse power; and exceptional designs, such, for example, as those adopted by Maxim and by Langley—who have actually introduced the finer steels in strongest forms, and who have already thus brought down the weight of engines alone to 10 and 6 pounds per horse power—would probably give us weights as low as 3 or 5 pounds per horse power. Magnesium has thus no promise of competition with steel, in general construction ; but its place may nevertheless be very probably found in bearings and cast parts, even where the running parts are steel.

It curiously happens, also, that some of the woods may, for such parts as they may be adapted to, compete not only with magnesium and its possible alloys, but also with these fine steels. Professor J. B. Johnson finds tenacities of 20,000 to 30,000 pounds for woods weighing one-twelfth as much as steels, or where strengths and lightness combined are compared, having values equivalent to steels at tenacities of a quarter of a million pounds and upward.

It is thus evident that until we know more than at present of the gain to be secured by alloying other metals with magnesium, it can only be said that it seems a possible rival of aluminium.

The fact that we find aluminium alloyed with small percentages of titanium and of other metals, gaining enormously in strength, without serious loss of its peculiar lightness—sometimes doubling its value on the above scale of comparison, and becoming the equivalent of steel of 150,000 pounds tenacity—renders it extremely possible that the same or greater effect may be found to obtain with magnesium, and that one of our most promising fields of investigation is now among its alloys. Both aluminium and magnesium alloys may have important applications in the construction of electro-dynamic machinery. It is known that the conductivity of the former alloyed with copper, titanium, and silver, is very high.

Magnesium-aluminium alloys containing 10 per cent. magnesium resemble zinc, with 15 per cent., brass, and with 20 per cent., bronze. They give good castings and are resistant to the atmosphere, are fairly hard and work as well as brass. The alloys are lighter than aluminium, and while possessing no great strength, are of value for many purposes where a light metal like aluminium would be used, if it could be cast and worked successfully.

Partinium is a new alloy of aluminium now being tried for the bodies of motor-vehicles. The aluminium is alloyed with tungsten, and the resultant metal is said to have a specific gravity of 2.89 cast, and 3.09 rolled; the elongation varies from 6 to 8 per cent.; its tensile strength is given as from 45,500 to 52,600 pounds per square inch. It is said to be cheaper than aluminium, nearly as light, and to possess greater strength. (See Wright's studies of ternary alloys of these metals; Proc. Roy. Soc. of London, 1891-4.)

PRODUCTION OF ALUMINIUM.

By R. H. Thurston.

* * * * * * * * * *

A remarkable and most simple and beautiful device, however, after a time revolutionized the manufacture of aluminium and through the utilization of this unpromising compound in electrolytic work. This was the discovery or invention, perhaps both discovery and invention, of Mr. Charles M. Hall, at the time a student or alumnus of Oberlin University.

This process consists in the *solution* of alumina in, as he expresses it, " a bath composed of the fluoride of aluminium and the fluoride of another metal more electro-positive than aluminium"—*i. e.*, some metal, as sodium, having higher affinities and less easy of reduction than the aluminium itself. It was found that the oxide is freely soluble in cryolite, for example, the natural double fluoride of sodium and aluminium, and still more so when a slight excess of the sodium fluoride is added. In a molten " bath " of this double salt, alumina dissolves "as freely as sugar or salt in water." A molten mass of cryolite is maintained fluid at its comparatively low melting point and by a voltage which is not far from, in this case, 4.5 volts, and a current of a dozen amperes. Adding ten to twenty per cent. its weight of alumina, a substance which only fuses at a white heat, the bath, at its low red heat, instantly dissolves it, in spite of the cooling effect of adding so much material at the temperature of the atmosphere, and it is seen that the pointer of the volt-meter drops as if freely falling, while the ammeter as promptly shows a rising amperage. The solution is evidently effected instantly. Thus the alumina is dissolved—not melted or fused, in the ordinary sense—and, becoming a conductor through this solution, which we may perhaps correctly call the equivalent of a low-temperature fusion, it becomes also an electrolyte and can now be decomposed by any current exceeding 2.8 volts intensity.

Allowing the decomposition thus to proceed, the dose of alumina is, after a time, exhausted and the voltage rises, as sharply, very nearly, as it originally fell on introduction of the salt, and the amperage coincidently falls off, showing a wonderful sensitiveness in the bath. By continuously supplying alumina, the process becomes a continuous one of indefinite period. No impurities being introduced with alumina or solvent, the restoration to the bath of the equivalent alumina, as aluminium is removed, maintains the conditions of its operation constant, and for as long a period as it may be desired to work, or until the introduction of impurities with either the solvent or the dissolved salt compels its purification.

Every requirement of successful electrolysis is here provided. The solvent fuses at a low temperature—perhaps about 900 or 1000° F.—dissolving the electrolyte freely, notwithstanding its high temperature of fusion—between 3000° and 4000° F.—and offers such an adjustment of voltages of decomposition of the respective intermingled salts as insures the electrolysis of the alumina first. It is a freely conducting bath, when the alumina is in solution, and a distinctly more resisting fluid when the solution is broken up by the removal of the alumina. Its density is such as to permit the reduced metal to fall to the bottom of the bath, instead of, as would be the fact with many other molten salts, floating it to the surface where it would be oxidized, perhaps, as rapidly as formed.

The alumina employed in this operation is the native ore "bauxite" which may be found in many parts of the world and in large quantities. It is readily freed from its impurities and thus it serves its admirable purpose in this process. Cryolite is less generally distributed and is comparatively costly; but as it is not broken up in this process and only small wastes need be made up, the tax upon the business through the cost of cryolite is small. The low voltage needed in electrolysis of alumina, once it is dissolved and thus rendered electrolytic, makes the cost of current and of power in this application of energy comparatively small, also; and the total cost of reduction of the metal on a commercial scale is so moderate that the introduction of this method has thrown out of use all others; it now makes the aluminium of the world. Even the cost of fusion of the bath and of maintaining it in a fluid state, when the operation is conducted on the large scale of commercial production, is extinguished. The heat incidental to the traversing of the bath by the current, and the combustion by the oxygen separated from the alumina, of the carbon anodes of the cells, when the cells are two or three feet wide and four or five feet long, and where there are twenty to forty carbon anodes of 2½ inches diameter and several inches length below the surface of the bath, is quite sufficient to maintain the bath in fusion and to keep the system in steady operation.

By this invention and process, the costs of the metal have been very rapidly reduced. Its price in the market, as one of the rare metals, a few years ago, was several dollars an ounce; as late as 1885, it cost about $5 a pound and then only in alloy with other metals; in 1889 it had come down to $1.50 to $2.00, and then, as this new method came into use and developed in magnitude of production, the price rapidly fell, the world over, until, in 1898, it sold in tons at 25 to 30 cents a pound and thus became, volume for volume, a cheaper metal than copper, tin, brass or bronze. The product as rapidly increased in quantity, all finally being made by the alumina process, thus :—

PRODUCTION OF ALUMINIUM.

Date.	Product: Tons per Year.	Price per Ton.
1890	40	$5,500
1891	200	2,500
1892	300	1,500
1893	530	1,400
1894	1,200	900
1895	1,800	800
1896	2,000	750
1897	2,500	700
1898	4,000	600
1900	7,500	600

The increasing magnitude of the apparatus of electrolysis has had an important influence upon cost, by reducing wastes of heat and current, and the magnitude of the scale of manufacture, at the same time, gives economy of production, thus :—A 50-h.p. plant is producing 1 pound per horse-power, per 24 hours' work. A 1000-h.p. plant produces 1.4 pounds per h.p., and a 3000- to 6000-h.p. plant produces 1.5, or more. The reduction of conduction and other wastes of current, at such low voltages as are required in this process, tell very powerfully upon economy of operation. Thus, a gain of a single volt now unnecessarily lost, where a total of six volts is employed at each pot, means a gain of 16 per cent. in cost of power, which is the principal item of cost. In many cases these losses are enormous.

Purity of product is a peculiarity of these electrolytic processes. Thus the market pays considerably more for electrolytic copper than for any other, with the single exception of the native copper of the Lake Superior mines, which is very possibly itself a product of nature's electrolysis. This purity comes of the fact that no two metals have the same affinities for their electro-negative associated elements. For this reason the current may, in any given case, be adjusted, as to voltage at the terminals of the electrodes, so as to give an intensity intermediate between that voltage required for the separation of the desired metal and that needed for the reduction of the companion elements whenever it is practicable to find an electrolyte in which the desired element stands at the foot of the list in equivalent reduction-voltage. Thus: with a cryolite bath and alumina in solution; the latter is the lowest in required voltage for electrolytic decomposition, and it is only necessary to so adjust the current as to give more than 2.8 and less than 4 volts within the bath to insure the deposition of aluminium; and, if the bath be itself pure or preliminary purified from undesired elements, absolutely nothing else can be precipitated by the current. The product should thus be a chemically pure metal, in this case. In fact it is possible, by careful purification of the materials of the bath, to secure a metal 99 per cent. fine, and better. The commercial article is usually less pure as the raw material is not pure ; but it is preferred with some alloy, as being, for most uses, better ; the alloy conferring upon it increased strength and hardness.

The production of aluminium by the electrolytic way is one of the most interesting of all recent innovations in the art of metallurgy, the process being one illustrating a most singularly remarkable method and the product being practically a new material of construction. The industry thus created has rapidly come to be an important division of modern metallurgical production. The arts are by its introduction promoted in many new and unanticipated ways ; a new industry is given the world to add to that diversification which is one of the vital elements of advancing civilization and the discovery of a new application of the electric energies opens the way into a new field of promise for further exploitation by the chemist, the electrician, the metallurgist, the engineer and the constructor, in many departments of the modern industrial arts.*

§ 185, p. 305.—*Aluminium* is displacing copper as a conductor, the product of weight into conductivity and price having fallen sufficiently to give some advantage in its use. Added to steel also, as now practised extensively, the following advantages are said to result :—

(1) The increase of sound ingots and consequent decrease of scrap and other loss.

(2) It increases the fluidity of steel and allows successful pouring of cold heats.

(3) Increases homogeneity

a. by preventing oxidation ;

b. by alloying rapidly with steel, and thereby increasing the ease with which other metals alloyed with it will alloy homogeneously with steel ;

c. by allowing the steel to remain molten longer and, when solidifying, doing so more evenly.

(4) It increases tensile strength without decreasing ductility.

* Sibley Journal of Engineering : Proceedings of the Electrical Society of Cornell University, June, 1899.

(5) It takes out oxygen or oxides; aluminium acting in the same way as manganese. Good steel has been made for electrical purposes, using aluminium in place of manganese.

(6) It renders steel less liable to oxidation.

(7) It furnishes smooth castings.

Aluminium is usually added in proportions of from one-fourth to three-fourths of a pound to the ton of steel; being added either in the ladle or as the metal is being poured.

Aluminium combines with iron in all proportions.

None of the alloys, however, have yet proved of value, except those of small percentages of aluminium with steel, cast iron and wrought iron. So far as experiments have yet gone, other elements can better be employed to harden aluminium than iron, and its presence in aluminium is regarded as entirely a deleterious impurity, to be avoided if possible.

TENSILE STRENGTH OF ALUMINIUM BRASS ALLOYS.

Aluminium.	Copper.	Zinc.	Tensile Strength per Square Inch.
			Pounds.
1.00	57.00	42.00	68.600
1.15	55.80	43.00	70.200
1.25	70.00	28.00	36.900
1.50	78.00	27.50	42.300
1.50	77.50	21.00	33.417
2.00	70.00	28.00	52 800
2.00	70.00	28.00	52.000
2.50	68.00	30.00	65.400
3.00	67.00	30.00	68.600
3.30	63.00	33.30	86.700
3.30	63.30	33.30	77.400
3.30	63.30	33.30	92.500
3.30	63.30	33.30	90 000
5 80	67.40	26.80	96.900

Aluminium heated in presence of many oxides reduces the metal from the oxide, and so energetically that Goldschmidt has employed this method in obtaining chromium, magnesium, and other rare metals. The oxide of the metal required is packed, in excess, with finely divided aluminium and, sometimes, with sand, and the mass ignited. The combustion which results develops intense heat, and complete reduction of the oxide follows, with as complete oxidation of the aluminium, and a pure product can be thus obtained.*

"The burning of aluminium as fuel gives us sapphires and rubies in the place of ashes, and metallic fuel is burnt, not by the air above but by the oxygen derived from the earth beneath, as it occurs in the red and yellow oxides to which our rocks and cliffs owe their color and their beauty." †

HEAT EVOLVED BY BURNING ONE GRAMME.†

Element.	Product of Combustion.	Calories.
Aluminium	Al_2O_3	7,250
Magnesium	MgO	6,000
Nickel	NiO	2,200
Manganese	MnO_2	2,110
Iron	Fe_2O_3	1,790
"	Fe_3O_4	1,580
"	FeO	1,190
Cobalt	CoO	1,090
Copper	CuO	600
Lead	PbO	240
Barium	BaO	90
Chromium	Cr_2O_3	60
Silver	Ag_2O	30
Carbon	CO_2	8,080
"	CO	2,417
Silicon	SiO_2	7,830

§ 269, p 477.—At a recent meeting of the Royal Society of New South Wales a paper by Professor Warren and Mr. S. H. Barraclough (M.E., Cornell University, 1895), was read on the effect of temperature on the tensile and compressive properties of copper. The investigation was carried out on some fifty copper test pieces. The temperature range attained was from 25° Fahr. to 535° Fahr., the temperatures being measured by certified mercurial thermometers. The chief conclusions arrived at were: (*a*) The relation between the ultimate tensile

* Zeits. für Electrochemie, 1898, iv., 21, p. 494; Sci. Am. Supp., May 20, 1899, p. 19553.

† Royal Institution Proceedings, vol. xvi., part iii.—Roberts-Austin.

strength and the temperature may be very closely represented by the equation $f - 32{,}000 - 21t$, where f is the tensile strength expressed in pounds per square inch, and t is the temperature expressed in degrees Fahr. (*b*) Temperature does not affect the elongation or contraction of area in any regular manner; and at any one temperature the variation in these two quantities is so variable for different specimens that no particular percentage could be included in a specification for the supply of copper. (*c*) The elastic limit in tension occurs at about 5,400 lbs. per square inch; this limit probably decreases rapidly with increase of temperature, but the differences in the behavior of individual specimens are so great as to prevent the determination of the relationship between the two quantities. (*d*) The elastic limit in compression occurs at about 3,200 lbs. per square inch; it decreases with increase of temperature, the relationship between the two being more regular than in the tensile tests. (*e*) The rate of permanent extension and compression increases rapidly with increase of temperature.

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