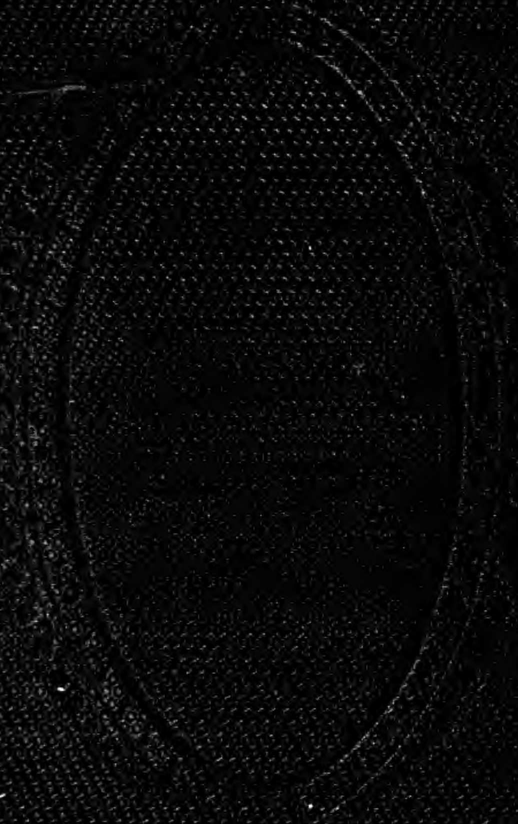

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THE PRACTICAL
METAL-WORKER'S ASSISTANT:

COMPRISING

METALLURGIC CHEMISTRY, THE ARTS OF WORKING ALL METALS AND ALLOYS, FORGING OF IRON AND STEEL, HARDENING AND TEMPERING, MELTING AND MIXING, CASTING AND FOUNDING, WORKS IN SHEET METAL, THE PROCESSES DEPENDENT ON THE DUCTILITY OF THE METALS, SOLDERING, AND THE MOST IMPROVED PROCESSES, AND TOOLS EMPLOYED BY METAL-WORKERS.

WITH THE

APPLICATION OF THE ART OF ELECTRO-METALLURGY

TO

MANUFACTURING PROCESSES:

COLLECTED FROM

ORIGINAL SOURCES, AND FROM THE WORKS OF HOLTZAPFFEL, BERGERON, LEUPOLD, PLUMIER, NAPIER, AND OTHERS.

BY

OLIVER BYRNE.

A NEW, REVISED, AND IMPROVED EDITION, WITH ADDITIONS BY
JOHN SCOFFERN, M. B., WILLIAM CLAY, WILLIAM FAIRBAIRN, F. R. S.,
AND JAMES NAPIER.

With Five Hundred and Ninety-two Engravings, illustrating every Branch of the Subject.

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PREFACE.

"THE PRACTICAL METAL-WORKER'S ASSISTANT," as now presented to the public, is a new, revised, and very much enlarged, and, it is believed, greatly improved edition of a work issued from the press of the present publisher several years since. The volume, as then published, was received at that time with great favor by practical men, and, although the edition has been entirely exhausted for many months, the demand for it has continued unabated. This demand, and the consciousness of the great value of the book, with the knowledge that it will fill a want much felt at this day, have combined in influencing the present publication.

Besides the revisal of the text generally, entire and valuable new chapters have been added to the book, among which may be named the following: "On Metallurgic Chemistry" and "Special Metallurgic Operations," by John Scoffern, M. B.; "Recently Patented Refining Processes;" "Wrought-Iron in Large Masses," by William Clay; "Application of Iron to Ship-Building," by William Fairbairn, and several on the various branches of Electro-Metallurgy. It is believed that that on Recently Patented Refining Processes will be found especially interesting and important, on account of the extended statement therein given of the details of Mr. Bessemer's Process of Refining Iron.

PHILADELPHIA. MARCH 1 1864.

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CHAPTER I.

ON METALLURGIC CHEMISTRY.

THE USEFUL METALS AND METALLIC ORES DEFINED.—Of sixty-four simple or elementary material bodies, no less than fifty or fifty-one are metallic. We shall not enter upon the characteristics which serve to define a metal—that more especially belongs to the functions of a chemical treatise; but taking it for granted that the attributes of a metal are sufficiently well agreed upon for popular use, we shall proceed to offer a few general remarks on their useful properties, of which rigidity, cohesion, tenacity, and durability are the most remarkable, although many more are conjoined in variable degrees.

The ancients were only acquainted with seven metals, whereas we know of fifty or fifty-one; nevertheless those now in most general requisition, and to which the appellation "useful metals" most peculiarly belongs, were all known to the ancients. Methods of working them, however, and new sources from which to obtain them, have multiplied so much in modern times as almost to rank in importance with the discovery of the existence of a new metal.

Metals are either found native—that is to say, in the condition of obvious metallic existence—or they are combined with other substances, so as to lose all obvious evidence of their metallic constitution. The latter condition is by far the more frequent; and to this fact more than any other the consecutive history of special metallic discovery is attributable. This circumstance leads us to an important chemical consideration, having reference to the comparative tendencies of different metals to combine with the non-metallic elements, and to lose by such combination their obvious metallic form. The term "noble metals," though applied to gold and silver in ages when the principles of chemical science were unknown, has nevertheless a positive chemical significance. Modern discovery has added platinum to the list; and they all agree in the property of being very slow to combine with any foreign material save other metals. Hence it is that they are so frequently found (gold and platinum almost universally) in the native or metallic state, united frequently with other metals, it is true, but still exhibiting the metallic aspect. If the noble metals existed in larger quantity, offered equal facility for working them, and equal hardness after being worked, their slowness to unite with oxygen would render them, more than all others, deserving of the appellation of "useful metals;" but, being deficient in these qualities, notwithstanding their nobility, they must yield the palm to iron, tin, copper, zinc, and lead, in the first instance, and perhaps to mercury or quicksilver, and bismuth also; considering the various applications of these metals to the useful arts of life.

The progress of metallurgy and of smelting operations demonstrates how great may be the advance of arts based upon scientific principles, without these principles being understood. The production and utilization of metals are intimately allied with chemistry; and deriving such immense advantages from the application of chemical principles at this time, it is extraordinary to reflect on the comparative excellence to which the art of working several useful metals had arrived, before the aggregation of chemical facts and principles to which the denomination "science" is alone justly due, had dawned. Chemical science may be indeed said to rest on an historical basis of metallurgic aspirations, and metallurgic empiricism.

Coeval with the earliest historical records, some metals were worked, and the operations of working involved the influence of chemical laws; yet the simplest principles of chemistry had not then dawned. At later periods it was alchemy—the vague hallucination of making gold—which prompted men to undertake investigations fruitful of chemical deductions, to be marshalled into a science hereafter. Metallurgy, then, may justly lay claim to be considered the fountain source of chemistry; and the subsequent development of the science to the art, might supply the theme of argument in favor of empiricism over intellectualism, if, at various periods within the last two hundred years, the miner and the metallurgist, by their devotion to chemistry, and the chemist by his successful labors in the practical fields of mining and smelting, had not demonstrated how mutual is the relation between theory and practice, how inseparable for good, how redundant of advantages the one to the other. Metallurgy (accepting the word in its most extensive signification) derives its best processes, and not unfrequently its best practical aids, from a due appreciation of chemical principles. And, on the other hand, the mere theoretical chemist derives a useful lesson of the necessity of checking his theoretical deductions by facts, as they are found to be, by attending to some of the teachings of metallurgy. Several metallic operations there are, the success of which is at variance with all the theoretical indications of chemistry. "*Corpora non* *agunt nisi fluida*" was a chemical dictum of received universality; nevertheless, the practice of annealing, or the conversion of iron into steel by combination with carbon, is a practical refutation of the universality. This process consists in the heating together iron bars and wood-charcoal in a suitable furnace. Both iron and carbon are here brought together in the solid state; both may be said to be devoid of volatility, and almost of liquidity; nevertheless, in violation of the formerly received canon, combination ensues, and steel is made. A similar disaccordance between the indications of theory, and the teachings of practice, is illustrated by the hot-blast operation, introduced some years ago in the practice of iron smelting. On the other hand, chemistry illuminates many dark recesses in the field of metallic empiricism, and points to facts, the existence of which would not have been suspected.

It is unnecessary, however, further to expatiate on the advantages which the metal-worker derives from the knowledge and application of chemical theory, the connection being now admitted by none more readily than by the practical metallurgist.

HISTORY OF METALLURGY.—In illustration of the mutual dependences of a branch of practical metallurgy and chemical science, it may be here not unadvisable to anticipate the contents of the monographs which especially deal with special metals, and to trace cursorily the various phases which the production of the metal iron has undergone. From one of several metalliferous sources this useful body has been produced from perhaps the earliest historical periods. True though it be that the ancient Greeks, at the very earliest period of their history, do not seem to have been acquainted with the existence of, far less the method of working, iron—yet we read of both in Scripture; and there is good reason to believe that anterior to the earliest historical record of the Greeks, iron, and the processes of manufacturing it, were known in China and Hindostan. We know, too, that immutability is impressed on all the processes of the East; whence it is not unreasonable to infer that the processes of rude iron manufacture now followed in Asia, are types of, if not identical with the processes followed there in times long passed. What are these processes? What is their general characteristic? What are the principles involved? What is the result? One general scheme of appliances pervades them all. The object is to begin with an ore of iron capable of reduction by charcoal fuel, and of yielding a semi-fluid result, which the subsequent process of welding fashions into shape. Even in this simple form of iron-smelting, a good deal of latent chemistry is involved; but the fullest acquaintance with chemistry could not improve the practice of iron-smelting, as followed by the Persians and Hindoos, if limited to the means at their command, and the ends proposed to be gained. The iron manufacture of England, as prosecuted in bloomaries by the aid of charcoal fuel was only a modification of the Persian method, and conducted almost as empirically. No sooner was the practice of iron-smelting by charcoal fuel abolished, and pit-coal, or its immediate derivative coke, introduced, then an application of chemical principles became necessary. How far these applications resulted in empirical tentative experiments, or in the suggestions of chemical teaching, it would not be possible at this time to decide; but the historian of the iron manufacture has not to pursue his labors much further before the reaction of chemical knowledge on mere empiricism is made evident. Practice demonstrated the fact that coal-smelted iron was inferior to charcoal-smelted iron; but practice could not say wherefore, until science came to the iron-smelter's aid, making known to him the composition of pit-coal, proving that it contained many foreign substances, which found their way into the smelted iron, and injured its quality. Analysis of coal-smelted iron demonstrated the existence of both sulphur and phosphorus incorporated with it, demonstrated moreover that, *cæteris paribus*, the amount of deterioration of the iron was in direct proportion to the quantity of these elements which it contained.

Chemistry next began to shed a light on the nature and property of fluxes, in showing how a mixture of several iron ores might conduce to yield a more fluid mass in the furnace than any one ore by itself. The next chemical glimmering fell on the apprehension of Cort, that Nestor of the British iron trade, and led to his improvements in the processes of refining and puddling, the results of which, combined with the rolling aid devised by his mechanical genius, eventuated in Britain, supplying iron in large quantities to other countries, from which she had heretofore obtained that metal.

It was our proposition, that as the operations of metallurgy (accepting the word in its largest sense) came down to our own times, the reaction of theoretical chemistry upon its practical development has continued to increase. Whilst the supply of British wood-charcoal lasted, and before the demand for iron became so enormous, as it has from the beginning of the last century, charcoal answered its purpose tolerably well. The iron manufactured by it resulted in small quantity; but, by comparison with coal, or coke-smelted iron, it was pure. England, however, in course of time became deforested in the neighborhood of the existing iron-works, the source of wood-charcoal thus failed, and pit-coal of necessity was obliged to be employed henceforth for the production of iron. Simultaneously with its adoption, the clay iron-stone began to supply the place, to a variable extent, with iron ore. The result was attended with both advantages and defects.

Iron admitted of being obtained in enormous quantities from these sources; but it had no longer the purity of the charcoal-iron of heretofore. Not only was the quality of the result deteriorated by the presence of impurities originally contained in the ore, but other impurities, especially sulphur, derived their existence from the coal or coke employed as fuel. Against the presence of these impurities, iron manufacturers have continued, in one sense, to struggle up to the present time. The difficulty of getting rid of these impurities, however, has not been entirely disadvantageous. The fact is known even to general popularity, that the only difference between wrought-iron and cast-iron consists in the relation between the extraneous bodies—chemically speaking, impurities—in each, and the results of mechanical action upon the former. Iron absolutely or chemically pure, is far more rare, and more difficult to obtain than absolutely pure gold. It is, indeed, only met with in chemical laboratories, and very seldom there. Wrought-iron, however, may be practically considered as pure iron; and cast-iron as the latter combined with some four or five per cent. of impurities. That such impurities are not prejudicial to the nature of iron for all purposes and all uses, will be rendered sufficiently evident by a consideration of the products made of wrought and cast-iron respectively. Wrought-iron (that is to say, commercially pure iron) is almost infusible. By virtue of its malleability and power of adhesion under the operation of welding, it may be fashioned into a multiplicity of useful forms; but if any person casts his eye over the comparative number and variety of the products of cast and wrought-iron respectively, and reflects on the fusible quality which the presence of certain impurities confers, he will rise from the survey with the conviction that the existence of these impurities in iron, and the difficulties of evolving them, are not without their advantages. To these circumstances we owe the enormous development which the production and working into shape of cast-iron has attained; so that whilst we have been necessarily dependent upon the purer charcoal iron of Sweden, Norway, and Russia, as the basis of our steel and wrought-iron for exclusive purposes, cast-iron girders and bridge-beams made in this country have been largely exported.

Nevertheless, it was desirable that we should not be restricted to the operation of casting, but that we should be able to abstract the four or five per cent. of impurities from the cast material, and thus change it into wrought-iron. All the consecutive improvements in refining and puddling have had reference to this end; but, notwithstanding the comparative perfection to which these processes have been brought by Cort, and others—notwithstanding the mechanical aids of hammering and rolling, by which it was hoped that such impurities as could not be rendered capable of entering by combustion into volatile products would be mechanically forced away—the problem has never been solved of abstracting the impurities from cast-iron, and rendering the result equal in quality to the charcoal wrought-irons imported from Russia, Norway, and Sweden. All the chemical processes of iron purification hitherto employed on the large scale had been based on the operation of bringing highly-heated external surfaces of molten, or pasty iron in contact with atmospheric air, and renewing the surface as often as the impurities which studded it had been burned away. The operations of refining and puddling were designed with this object in view; and the operations of mechanical extrusion effected by hammering, or cylindrical pressure, were designed with the object, and successfully carried out up to a certain point, of accomplishing by mechanical means that which chemistry alone was unable to effect.

REFINING PROCESSES.—Every person who takes a passing glance at the operations of metallurgy in the aggregate, cannot fail to be struck with a certain functional similarity between the process of cupellation as applied to separate ignoble from noble metals, and the process of puddling, by virtue of which the impurities held by cast-iron are removed from the latter. In both cases the general result is obtained by passing a current of air over a highly-heated metallic surface. The puddling process (for perfecting which the world was indebted to the ill-requited Richard Cort) consists in placing partly-purified iron in a reverberatory furnace, and vigorously stirring it about so as to expose it to the action of the air: by which operation oxygen is rapidly absorbed, while carbonic acid gas escapes, giving the metal a bubbling and boiling appearance. As carbon escapes, the metal passes from a fluid to a spongy half-fluid mass; and in this state it is ready for the puddler. The metal is collected at the end of an iron bar, in a ball or bloom of sufficient size, which is swung through the air, and placed under the forge-hammer, to the crushing blows of which it is subjected, being turned and twisted in every possible direction, while sparks of fire dart from the surface, and liquid drops exude from the interior of the metal.

This is continued until the ball rings under the hammer, and the liquid drops give place to scaly masses. In this state it is passed through the rollers, in the grooves of which it is drawn out and compressed, then doubled up and rolled; again heated, doubled up and rolled, until the process is complete. The new process, by which the reader will be at no loss to understand that we advert to the scheme devised by Mr. Bessemer, advances by one step further, as it is stated, and may be considered to be a nearer approach to the complete purification. By it a current of atmospheric air is forcibly projected not *over* but *through* a molten mass of impure iron; and it is assumed that by the chemical operation of this atmospheric blast, such impurities as are at once combustible, and the volatile results of combustion, will be expelled.

Now the combustible extraneous matters are for the most part carbon, sulphur, and phosphorus. The results of combustion of the first, will evidently be carbonic acid and carbonic oxide, both volatile; of the second, sulphurous acid, also volatile; of the third, phosphoric acid, not volatile. The theory of the process is based upon the idea of removing the impurities by the heat developed from their own combustion, instead of employing other combustibles, themselves holding impurities.

A more beautiful and more immediate application of chemical knowledge to improvement of the iron manufacture it is impossible to conceive; although from its recent occurrence, and the probationary stage to which it has only yet arrived, we are precluded from treating of it without a certain feeling of constraint inseparable from the dawn of all new inventions.

Our remarks have already conveyed sufficient intimation of our cognizance that the indications of theory and the deductions of practice are not always accordant to satisfy the reader of our freedom from any mere theoretical bias. At this early period, however, Mr. Bessemer, in common with every inventor who lays before the world a proposition which he believes in, and which a large section of the public is prepared to receive as an improvement on pre-existing modes, is probably experiencing some of the crosses and disagreeables inseparable from the office of pioneer in the regions of science or the arts. It is only a matter of common justice, then, that those who have to speak or write of processes in his domain, should give them, so far as in them lies, a helping word of congratulation. Without, therefore, committing ourselves to a premature expression as to how much or how little the processes may accomplish, we are justified in stating that which is much more satisfactory to him and to us. The communications we have opened in relation to the matters in hand, have necessarily thrown us into correspondence with various iron-smelters. On the premises of one of these—one of the largest, if not the very largest in Great Britain—Mr. Bessemer's process is about to be placed on trial, and under the most favorable auspices for a searching and impartial one; the result of which will be communicated to our readers in the present volume.

But it becomes a question of very grave import, and one requiring the test of wear and tear of time as well as experiment, to set at rest, whether there are not mechanical requirements in preparing malleable iron not comprised in Mr. Bessemer's process. Iron, like all other metals, has a strong tendency to crystallize at a given temperature; and an ingenious friend, theorizing on the subject, suggests an hypothesis which we have not met with before, that the puddling process supplies a mechanical as well as a chemical bond of union in the metal. The crystals, he suggests, are disturbed at the moment of formation, driven into each other by the stirring operation; and that the jagged edges of the particles thus become knitted or laced into each other in a fibrous mass.

This would seem to explain the tenacious and fibrous character of wrought-iron; and if so, it may be doubted if the new process will altogether supersede that of puddling, though it may greatly facilitate the operation.

Nor does it appear that Mr. Bessemer will be suffered to monopolize the attention of those interested in iron. Mr. Plant, of

Holly Hall Colliery, Dudley, had patented, as early as July, 1849 a refining process by which a current of air and steam is directed upon the iron while it is in the puddling furnace. Another process, patented in 1855, by Mr. Martien, of New Jersey, consists in passing currents of air and steam *through* the heated cast-iron as it runs from the blast furnace. A third invention is by Captain Uchatius, Engineer-in-Chief of the Imperial Arsenal, Vienna, who has devised a method of producing every description of cast-steel from crude pig-iron in the short space of three hours; and the process was exhibited in London before a number of scientific and practical men, to their entire satisfaction, as it is stated; although these experiments were conducted in furnaces not well suited to the operation. This process consists of running melted pig-iron from a crucible into a vessel filled with water, when the iron is converted into small granulated shot-like particles. A weight of twenty-four pounds of these granulated iron drops was mixed with crushed ore and filled into a crucible, which was placed on the furnace prepared for it. After the lapse of a period of two hours and three-quarters, the crucible was taken from the furnace and the contents poured into an iron mould. . When this was opened, an ingot of steel weighing twenty-five pounds was exhibited to the company, and pronounced by competent judges to bear every external evidence of being perfect in quality. While this metal was being melted, an ingot of steel prepared by this process at the steel works of Messrs. Turton, of Sheffield, was subjected to the steam hammer, and a bar of steel produced from the ingot which was pronounced to be of excellent quality by the practical men present. It is impossible to over-estimate the importance of these discoveries should they bear the test of experiment on a suitable scale.

Between theoretical indication and practical confirmation, however, there is a bridge to be passed, which frequently breaks down and engulfs the inventor, through the interposition of some collateral obstacle. It may be that the processes of Mr. Bessemer and the other ingenious men named are in this category. Davy suggested the protection of the copper bottoms of ships by the attachment of zinc galvanic preservers. He caused the suggestion to be practically carried out, and *quoad* protection it succeeded. But Davy was foiled, and his process was rendered inoperative through the interposition of a collateral circumstance which had not entered into his calculations. The copper was no sooner prevented from undergoing solution, than its surface became harmless; seaweeds and sea-mollusks stuck to it, and the ship's course was impeded thereby. It may be somewhat thus with the inventions to which we have adverted,—some collateral issue may interfere with the practical realization of the inventor's hopes in respect of the invention. It is always well to bear in mind these probabilities, seeing that they are the reflex of the history of most inventions. But nevertheless the theory on which Mr. Bessemer's operation is based is so simply beautiful, that now, at this early stage of it, before the ultimate practical issues of it are known, it is fitting that Mr. Bessemer should be cheered with the provisional recognition which a clear apprehension of principles, and a seemingly practical way of giving them effect, bespeak as justly his due. In the puny microcosm of a chemical laboratory, where thousands of little appliances can be invoked to gain the end proposed by chemical analysis—it is possible, nay, it is probable, that a chemist may not justly interpret the data which small operations evolve, into the less numerous, though individually larger, conditions of the practical man.

ADVANTAGES OF CAST-IRON.—We have already intimated that the presence of impurities in iron as rendered by our smelting works, and the difficulties of removing them, are not barren of all good results; and we have adverted to the capabilities of cast-iron. Let us now contemplate the subject of iron from the opposite point of view; let us assume that instead of the facility wherewith the *genius* of our smelting operations enables us to turn out enormous quantities of iron, cast into the form required, the genius of the process had been in the direction of depriving us of this impure material, but rendering us iron commercially pure—that is to say, in the state of wrought iron. What difficulties would have beset us then! The operation of casting no longer possible, but every piece of manufactured iron being necessarily manufactured by the laborious operations of forging, hammering, and welding,—not merely would the price of iron for many purposes have been enhanced, but for numerous purposes to which iron is now applied it could not have been used at all. Contemplate the prices of cast-iron which constitute the blocks of which Southwark Bridge is built, and imagine the circumference of blocks having the same form, weight, and dimensions, made of wrought instead of cast-iron, and *hammered* into shape. The thing would have been utterly impossible. It would be impossible even now, notwithstanding the aid of the ponderous steam-hammer. The ease with which a blacksmith heats, and welds, and fashions into shape the half-molten paste of glowing wrought-iron on his anvil, would convey but feeble indications of the difficulties which beset these operations when conducted on a large scale. It is difficult to pronounce, and it would be invidious to make the attempt of fixing, the extreme limits or size of which a piece of wrought-iron admits of being forged. Practical effect is given to that operation to the extent of forging anchors, shafts and beams, for the largest marine engines. These are achievements sufficiently difficult, and until lately critics were found—nay, indeed, they are to be found still—who confidently assert that much beyond these achievements of wrought-iron manufacture the operation could not go. Whether wrought-iron ordnance of large size could or could not be manufactured, having the strength necessary to ordnance practice, was a moot-point. Some years ago the experiment was tried in the United States, and failed,—as a terrible accident from the bursting of a wrought-iron piece of ordnance painfully testified. Since then Mr. Nasmyth repeated the experiment, with so bad a result that it was considered by himself to be a failure, and he expressed himself very hopelessly respecting wrought-iron heavy ordnance. Nevertheless, a large piece has been made by an enterprising Liverpool firm, and presented to the British government. It is now, whilst these remarks are written, under process of trial; and hitherto it has stood all the tests deemed necessary with complete satisfaction.

The result of the manufacture of this interesting piece of ordnance, and the trials to which it has been subjected, demonstrate that those who *ex cathedra* predicted so confidently that wrought-iron heavy ordnance could not be made (due regard being had to their strength), may have reason to alter their opinions. Confessedly, however, as between the casting of iron into a specific shape, and the welding and hammering of iron into a similar shape, the difference is enormous.

In addition to the mechanical difficulties attendant on the manipulation of wrought-iron—in addition to the difficulties of removing huge masses of it from the forge to the anvil—the difficulty, moreover, of welding two or more large pieces together in such a manner as to give solidity to the welded joint—a chemical or molecular tendency of wrought-iron when retained at a glowing heat in large masses for long periods together, threatened to impose an insuperable barrier to the manipulation of wrought-iron in pieces much larger than anchors, or marine steam-engine axes.

CRYSTALLIZING TENDENCY OF WROUGHT-IRON IN LARGE MASSES.—It was found by Mr. Nasmyth, in turning out his monster gun, that the iron had ceased to be fibrous, and had assumed a crystalline texture at its centre, thus losing the strength and tenacity which the fibrous condition would have given. It had been fully known that wrought-iron under some peculiar circumstances is prone to assume this condition. The axles of revolving carriage-wheels have been known to assume this crystalline state from vibration, after the lapse of time and long usage, although they were originally fabricated of the best wrought-iron. Iron wire too, which, as all connected with metallurgy know, is necessarily made of the purest iron, occasionally assumes this crystalline state if long exposed to the agency of chemical forces; as, for instance, in a laboratory. Various hypotheses have been propounded to afford a rational explanation of this molecular change from fibrous to crystalline condition. As regards the case of railway axles, the supposition appears rational that constant percussion has given rise to the crystallized state; but the change experienced by iron wire is not so plausibly explicable. The crystallization of large masses of wrought-iron under the heating and cooling process involved in the operation of welding, seems to admit of easier explanation. The result appears to be only a special illustration of a general resultant of the undisturbed play of cohesive affinity, tending as it does, if sufficient time and freedom of molecular motion be given, to assume the most perfect cohesive state of which matter is capable—that is to say, the state of crystals. Had the result of crystallization been inseparable from the practice of welding large bars of iron, there would have been an end to wrought-iron ordnance of large calibre; there would have been an end also to the production of any pieces of wrought-iron considerably larger in dimensions than the forms hitherto produced. We shall look forward therefore with some interest to the monograph on the working of wrought-iron in large masses promised us by Mr. Clay.

Impressed with specialities as the metals are, each one conducing to certain purposes better than any other—nevertheless, with the exception of iron, these capabilities are numerous, and one generally admits of being substituted for another. But no civilized race could exist as such without the co-operation of the metal iron. For the greater number of purposes to which it is applied there is no efficient substitute. True, the ancients did manage at one time to manufacture cutting instruments out of bronze; true, that Sir Francis Chantrey in our own times, in his reverence for classic metallurgy, caused a bronze razor to be made, wherewith he shaved; nevertheless, we doubt whether any one less ardent in the love of ancient metallurgy than himself would have borne contentedly the daily infliction.

Classification of Metals.—Before indicating the chemical principles upon which each special process of metallurgy is based, it will be desirable to arrange the metals in classes, according to the several characteristics which they present. Great specific gravity is so prominent a characteristic of metallic bodies, viewed in the aggregate, that anterior to the discovery of potassium, sodium, and the other alkaline and terrigenous metals, the quality was thought to be inseparable from the metallic condition. So far, however, is this from the truth, that lithium—the metal of the alkali or alkaline earth lithia: it may be said to be intermediate between the two—is the lightest known solid, metallic or non-metallic, in all nature. Based on a consideration of the quality of specific gravity, then, we arrive at a division of metallic bodies into the light and the heavy. In a purely chemical sense, such a division has no value. But it is otherwise to the metallurgist. Inasmuch as the metals of the alkalies and alkaline earths—that is to say, the light metals—are only produced by complex and refined chemical processes, they may be considered as lying without the domains of metallurgy. It is only with the remaining class (the heavy metals), therefore, that the metallurgist has to concern himself, and to which the reader's attention throughout this introduction and the succeeding pages will be exclusively directed. Contemplating the heavy metallic bodies, in a practical or metallurgic sense, with reference to their subdivision, their various demeanor with regard to oxygen, and their general relations to that extensively diffused non-metallic element, we have a natural as well as a ready means of classification. It has been calculated that almost two-thirds by weight of our globe's constituents—solid, liquid, and gaseous; its vegetables, and its animals and minerals—consist of oxygen. The chemist need not to be reminded of the powerful tendency to combustion which oxygen manifests, especially with metals. Unquestionably the most considerable and the most important metallic ores are oxides, or combinations with oxygen. It is natural, therefore, that the metallurgist should seek, in an examination of the relations of metals to oxygen, the basis of their practical subdivision. Five well-marked subdivisions, founded on these peculiarities, admit of being established. They are as follow:

1. Metals having a strong tendency to combine with oxygen, and to generate bases. These metals admit of arrangement in three sections.

§ (*a*). Metals whose oxygen-compounds are basic, or have the property of bases. They are zinc, cadmium, lead, and uranium.

§ (*b*). This section has only one representative, *i. e.* arsenic, or arsenicum; a metal the peculiarity of which is, that its combinations with oxygen are acid, not basic.

§ (*c*). Metals which form both acids and bases by combination with oxygen. They comprehend copper, nickel, cobalt, bismuth, tin, copper, manganese, iron, antimony.

2. Metals the tendency of which to combine with oxygen is but slight: comprehending gold, silver, platinum, and mercury. The three former are sometimes called "noble metals."

The relative fusibility of metals also affords a good means of practical classification. Having reference to this difference, five well-marked subdivisions admit of being established.

1. Fusible, and remaining liquid at the lowest heat of temperate climes. There is only one metal which answers to these conditions: it is mercury.

2. Fusible between 392° and 788° F., and passing off into vapor when the heat is still further raised. The metals represented by this subdivision are zinc, cadmium, lead, bismuth, antimony, and arsenic or arsenicum.

3. Fusible at temperatures above 1830° F.: copper, silver, gold.

4. Not completely fusible by the strongest furnace-heat: manganese, iron, nickel, cobalt, platinum.

5. Fusible in the hydro-oxygen jet: chromium.

ALLOYS.—Having taken a cursory survey of the classes and subdivisions of which metals, practically considered, are susceptible, we shall now proceed to describe the principal compound forms of which metals are susceptible. The first of these which presents itself is the class of alloys.

The term alloy in its most general acceptation means the mutual combination of two or more metals. When one of the metals, however, entering into combination is mercury, the result is not usually termed an alloy, but an amalgam. Alloys are practically interesting to the metallurgist in two ways; either the metals to which a metallurgic process of extraction is applied are found in the condition of native alloy—*i. e.* one naturally existing—or an alloy results as the consequence of an intermediate metallurgic process. The native state of gold with silver, and of platinum with rhodium, iridium, palladium, and its other associated metals, present familiar instances of native alloys. The intermediate combination of lead and silver resulting from the metallurgic process of reducing galena, furnishes a good instance of the second. At the present time the belief prevails—we may even say it is universal—that alloys are not always mere mechanical mixtures of different metals, but are constituted in accordance with the laws of definite chemical combination; being no less atomic (to adopt the language of the atomic theory) than oxides and salts are atomic. It would lead us too far from the subject of metallurgy to adduce the various arguments which exist in favor of the belief; and indeed a superficial glance at the bearing of the hypothesis would perhaps induce the practical metallurgist to pass it by as devoid of utilitarian interest. Few subjects, however, are more intimately related to the utilization of metals than those involved in the seemingly abstract question of chemical composition, or of mere admixture, in relation to alloys. An illustration very much to the point is afforded by the manufacture of the alloy called "silver-steel."

In the course of some experiments performed by Professor Faraday and Mr. Stodart, they discovered that silver when fused with steel in certain given proportions, entered into mutual combination, and formed a valuable alloy. If, however, the quantity of silver was increased above a certain proportion not yet quite ascertained, the excess of silver was extruded from the metallic mass during the process of cooling. This result at once affords testimony as to the chemical constitution of the alloy, and points to the practical advantages likely to be derived from a solution of the question, "What are the exact or atomic proportions in which steel and silver can combine?" Granting, for the sake of argument, that the silver-steel be so far superior to ordinary steel as to warrant its manufacture, the conclusion follows that it is a point of the utmost importance to determine the exact maximum amount of silver which steel can take up. Not merely would the addition of every grain of silver beyond the indicated proportion be an unnecessary expense, but such of the uncombined silver as might be locked up mechanically in the alloy during the cooling process would lessen its strength, and, indeed, impart a general deterioration of quality.

As a general rule, it may be stated that all metals which form alkalies have a particular tendency to unite with those which form acids. When two metals are alike in their affinities for oxygen, they do not readily combine, and may often be separated by crys tallization only, when both metals absorb nearly the same quantity of oxygen in forming their oxydes. Nearly all chemical combinations liberate heat. Zinc and copper, when melted together, produce a high temperature. Where a mere mechanical mixture of metals occurs in an alloy, it is characterized by distinct crystals being formed with one metal, between which the other is visible. When an alloy is formed with proper equivalents, no such disconnected crystals are observed. In cooling a melted alloy, that composition which is most refractory crystallizes first, and that which is most easily reduced to fluidity is compelled to occupy the spaces between the crystals. Thus copper and tin are fusible; but in cooling, copper-tin crystallizes first, and tin-copper last. Iron and arsenic are very fusible; but in cooling, iron-arsenic crystallizes first; in consequence, the surface, when cool, exhibits a perfect net-work of bright lines in regular forms. In all of these compounds, however, portions of each alloy are contained. When a bar of cold lead is dipped in mercury, the pores of the lead become filled with mercury, but the mercury also absorbs lead. When iron is strongly heated while imbedded in carbon, as is the case when blistered steel is produced, the carbon penetrates to the very centre of the iron rods; but no iron is imparted to the carbon, because its atoms are not movable.

Alloys are more fusible than the individual metals, and will melt at a lower temperature than the mean would indicate. Though tin melts at 500°, and pure copper at 2,500°, equal parts of copper and tin do not melt at the mean 1,500°, but at a lower heat. Pure iron is extremely refractory; but when combined with arsenic and phosphorus, it may be melted in a cast-iron pot without adhering to it. Again, a composition of three metals is still more fusible than their various degrees of melting would indicate; and if their component parts are according to the laws of chemical affinity, the melting point is lower still. Need we repeat, after this, how important is the study of forming alloys in the smelting-furnaces? It is the degree of fusibility of the slags and metals, which determines the cost of the process.

Iron is rendered fusible by the presence of carbon; but when that substance is removed it becomes refractory, and can hardly be melted. Tin is refined by oxidizing or evaporating sulphur, arsenic, and other matters; a process which renders tin less fusible and more tenacious. Zinc melted in an iron pot, and exposed to the air, exhibits dross on the surface; its fluidity is diminished, but its malleability is increased. A layer of carbon, or common salt above ashes, prevents these phenomena.

Alloys are generally harder than might be expected from their constituents; although there are exceptions to the rule. Silver and arsenic render iron hard, although both metals are soft in themselves; copper and tin, both soft metals, become hard when melted together in certain proportions; and zinc and copper makes brass soft. Antimony causes all metals to become hard, but very brittle. Iron mixed with a little antimony will cut glass.

The ductility of alloys is sometimes greater than might be expected; in others, it is more brittle than the original metals. Alloys of zinc and lead, are very tenacious; lead and antimony, very brittle. Any alloy which is slowly heated and gradually cooled—annealed, that is—is softer than when the compound is suddenly chilled; hence the hardness of chill-cast iron.

The above-mentioned examples are types of many others, demonstrating that though metallic alloys occupy a less prominent position than metallic oxides, sulphurets, chlorides, etc., nevertheless the conditions which regulate their existence must not be neglected by the metallurgist.

The separation of the constituents of metallic alloys is accomplished by several methods. Of these the one most obviously suggested by theory consists in a gradual application of heat up to the point of melting the more fusible metal, and leaving the other unfused. In this way lead is separated from an alloy of that metal with copper. Scarcely less obviously suggested by theory is the application of heat to effect the volatilization of one of the metals entering into an alloy. In this way is mercury separated in practice from alloys (amalgams) of mercury with gold, and mercury with silver. In this way also is silver obtained from argentiferous zinc.

The metallic constituents of some alloys admit of separation by subjecting them to fusion and gradual cooling. During the cooling process the metals of an alloy will in some cases separate in layers according to their specific gravity. In other cases the separation ensues from one of the constituents shooting into crystals and becoming solid, thus furnishing a means of its removal. The celebrated process of effecting the separation of silver from lead, known as Pattinson's crystallization process, is of this kind; but the most extraordinary circumstance in relation to it is, that the lead or the metal of lesser fusibility is that which first crystallizes out. The rationale of this curious phenomenon has never been explained. Occasionally separation of two or more metals constituting an alloy is effected by means of acid-solution. The process of quartation by which silver is dissolved out from an alloy of that metal and gold, will serve as a familiar illustration.

Metallic Oxides.—We have already said that these are the most numerous and the most important of metallic ores. The smelting of them depends on an application of the best practical means of removing oxygen. The relations of metals to oxygen, and the relative facility wherewith they evolve oxygen wholly or partially, have all been accurately determined by the chemist. On the large scale, the exact agents employed in the laboratory for effecting deoxidation cannot always be applied; nevertheless, chemical principles have to be followed as closely as circumstances will permit: therefore it will now be proper to explain the relations of different metals to oxygen in respect of the comparative difficulty of removing that element from them.

The reduction of metallic oxides may be effected by the dry and the moist processes. It is the former, however, which immediately concerns the metallurgist, and to which we purpose to direct the attention of the reader. The noble metals gold, silver, and platinum are characterized, as is well known, by the difficulty wherewith their respective combination with oxygen admits of being effected. Conversely, the respective oxides of these metals are characterized by facility of decomposition. The application of heat alone, without the contact of any extraneous body, suffices to liberate oxygen from the oxide of the noble metals, and of course to evolve the metal.

All other metallic oxides require the agency of a second body to effect their reduction, mere application of heat being insufficient; and a consideration of the deoxidizing materials at the disposal of the metallurgist, and employed by him, opens a field of great utility and interest. The deoxidizing agent of greatest importance to the metallurgist is coal in its several varieties, and the derivative materials yielded by its combustion. When coal is burned in a furnace, the first product of combustion may be considered to be carbonic acid gas; but inasmuch as the latter is readily decomposed by permeating ignited pieces of solid carbon (coke), losing a portion of its oxygen, and becoming carbonic acid gas,—we may say that the products of the combustion of coal are firstly carbonic acid; secondly, carbonic oxide and carbonic acid; and lastly, carbonic oxide alone. The latter in combination with heat is a most powerful deoxidizing agent. Were it not for the production in furnaces of carbonic oxide gas—were it necessary that the solid carbon of the coke should be alone the deoxidizing body, then it follows that every particle of the ore to be reduced must be brought into intimate contact with the reducing body; a process involving more care and trouble than are compatible with large metallurgic operations. The reducing agent being a gas, there is no longer a necessity for that intimate mixture of fuel and ore which would otherwise be necessary. Provided that the gaseous results of combustion are placed under circumstances of readily permeating the ore, the necessities of practice are amply subserved. In many cases of reduction of the oxides of lead, silver, tin, and copper, the fuel is actually contained in a furnace by itself, the ore to be reduced being in another. There is great difference as to the amount of heat at which the reduction of different metallic oxides can be effected. The oxides of lead, bismuth, antimony, nickel, cobalt, copper, and iron, require a strong red heat; whilst the oxides of manganese, chromium, tin and zinc, do not lose their oxygen until heated to whiteness.

Combinations of the metallic ores with oxygen take place in certain definite proportions, and, so far as relates to most metals, in definite quantities. There are three oxides of iron which interest us here, namely—the protoxide of iron, which is a strong base; the magnetic oxide, a feeble base; and the peroxide, which is more of an acid than a base. Peroxide and protoxide of iron, both infusible by themselves, form a fusible slag. Arsenic forms, in all states of oxidation, an acid which never melts with any other acid, or with highly oxidized metals; it being a requisite condition of fusibility, that one of the constituents in which the other is merely suspended must be fusible. This chemical relation admits of a wide range, nor is the same substance in all its relations of the same character.

The oxides of iron are always basic as to silic acid, but they are acid in relation to oxide of lead. The study of the metallurgist must be directed to these chemical relations, as well as to the degree of fusibility of the compounds and the relation they bear to the metal to be produced under their influence.

As a rule, it may be stated that the compounds of single equivalents of metal and oxygen constitute a base of alkali, and that the addition of more oxygen destroys that property. Thus the protoxide of manganese is a strong base, and precipitates the protoxide of iron from a slag; but the peroxide of manganese is driven out by the protoxide of iron. When carbon is present, one atom of oxygen is absorbed by it from the peroxide of manganese, and the iron is again driven from its union. This affinity of oxygen for metal is most difficult to be overcome at a state of oxidation half-way between the extremes. Protoxide of tin is easily converted into metal, so is peroxide; but the sesquioxide, intermediate between the two, presents much greater difficulties. Practically it is usual to smelt with the highest oxides, and convert the ores into that state, in order, not only to remove the oxygen from the metal, but also to produce so high a heat as to fuse the metal at the precise moment when the oxygen is removed.

Hydrogen and carburetted hydrogen gases must not be omitted in our enumeration of the deoxidizing agents employed by the metallurgist. The latter agent, carburetted hydrogen, is evolved during the combustion of coal; the former, when employed, as it is, though sparingly, as a metallurgic agent, is developed by transmitting aqueous vapor over red-hot coke. When this gas is produced by dissolving iron or zinc in a diluted acid, it is always moist, and invaluable for the performance of any delicate experiment; for the reduction of metallic oxides it should be dry, and free from any foreign substance. Carburetted hydrogen or coal-gas is used to reduce oxides under a low heat, the carbon which is precipitated in the formation of the metal being removed by smelting. Hydrogen or carburetted hydrogen is applied in the assaying process, by leading it into a glass tube which contains the ore specimen in a proper form already heated. A gentle current of gas is passed over the ore until no more is burned by it, which is manifested by the escape of the gas in a pure form.

Next to metallic oxides, metallic sulphides are of the deepest importance to the metallurgist. Their reduction generally involves the operation of roasting, a process to be treated of hereafter.

SULPHIDES.—All metals combine more or less with sulphur, and form sulphides when sulphur is brought into contact with the metal, in the absence of oxygen or chlorine. When oxides are treated with sulphur in sufficient quantities to absorb all the oxygen in forming sulphuric acid, the sulphur remaining combines with the metal. When sulphates are treated in the presence of carbon or hydrogen, the oxygen of the sulphuric acid is abstracted, and sulphides remain. The chemical relation of sulphur to metal is similar to that of oxygen—that is, the number and equivalents of the sulphides correspond with the number and equivalents of the oxides of the respective metals—causing them to be more fluid and brittle when cold, and impairing their ductility when hot. Large quantities of sulphur cause a low degree of fusibility, which is shown in the sulphurets of antimony, lead, copper, and iron, the fusibility in each decreasing more rapidly than the evaporation of sulphur. Iron pyrites melts at a low red heat; but when reduced to half its original quantity, by evaporating the sulphur, it requires a strong white heat to melt the sulphides. The presence of free oxygen is required for the removal of sulphur; nor can it be removed entirely when carbon, hydrogen, or any other reducing agent is present, an oxidizing influence and thorough exposure of the metal to oxygen being necessary.

Nevertheless, the partial decomposition which certain metallic sulphides undergo, when heated without the access of atmospheric air, is to the metallurgist a consideration of importance. Galena treated in this way suffers partial decomposition; so, in like manner, does the monosulphuret, or monosulphide of copper,—a sufficient amount of sulphur being evolved from it to yield disulphide of copper as the permanent fixed result. The higher sulphur combinations of iron, or chemically speaking, the sulphur salts of that metal, generated by the combination of two sulphurets or sulphides, also give a portion of their sulphur when exposed to high heat in close vessels. Monosulphide of iron, however, does not yield up any of its oxygen by the mere process of heating in close vessels. The sulphide of zinc (zinc blende) is unchanged by the highest temperature; so, in like manner, is the sulphide of silver. The sulphides of gold and of platinum are decomposed when heated into sulphur and their respective metals. The sulphide of mercury can be distilled without change. Sulphide of antimony melts at a high red heat, afterwards distils over unchanged. The mono and the ter-sulphide of arsenic (orpiment and realgar) both fuse, and distil without undergoing any decomposition.

By far the more important and usual method, however, of effecting the reduction of metallic sulphides, consists in exposing them to the combined agency of heat and atmospheric air—constituting, in point of fact, the operation of roasting. Usually, the change which ensues during the operation of roasting, is the conversion of sulphur of the sulphide into sulphurous acid gas, which escapes: the original sulphide, either losing a part of its sulphur, and being thus reduced to the lower stage of sulphurization, or else, losing the whole of its sulphur, oxygen is absorbed in place of the latter. Occasionally the sulphurous acid first generated absorbs the necessary amount of oxygen, to change it into sulphuric acid, which combining with the metallic oxide simultaneously generated, gives rise to the sulphate of an oxide. This latter is the case when galena (sulphide of lead) is roasted, the final result of the operation being oxide of lead, and sulphate of oxide of lead. This change is eminently favorable to subsequent metallurgic operations of which galena is the subject. If the galena be argentiferous, the following reactions ensue: The mixture of oxide of lead and sulphate of the same oxide being heated to whiteness in contact with silver (of the argentiferous galena), oxidizes the silver by decomposition of the sulphuric acid, of the sulphate and oxide of lead; hence there results a mixture of oxide of silver and of lead—a mixture easily dealt with, and deoxidized by a subsequent operation. The sulphide and disulphide of copper are changed by roasting, into dioxide of copper and sulphurous acid, and sulphate of the oxide of copper, which latter, when the temperature is raised to the highest pitch, evolves the whole of its sulphuric acid and oxygen; leaving metallic copper. Monosulphide of iron by roasting undergoes many progressive changes; beginning with the formation of protoxide of iron and sulphurous acid, and ending in the development of sesquioxide of iron. Sulphide of zinc (zinc blende) slowly changes under the influence of roasting, first into oxide of zinc, and sulphate of the oxide; then into subsulphate of the oxide; and, lastly, into oxide exclusively. Sublimate of bismuth changes, under the influence of roasting, into oxysulphuret: sulphide of silver is decomposed, and yields metallic silver. Tersulphide of antimony changes under roasting into antimonious and antimonic acid. The sulphide and the sesquisulphide of arsenic are changed into arsenious and arsenic acids.

By a modification of the same process, sulphide of nickel admits of decomposition into a mixture of oxides and sesquioxides of that metal. Sulphide of cobalt is also decomposed into a mixture of oxide of that metal and sulphate of the oxide. Finally, the sulphides of gold, platinum, and mercury are also reduced to the metallic state, sulphurous acid gas being evolved.

Another element equal in importance to oxygen, requires the attention of the metallurgist. Chlorine has a tendency to induce metals to crystallize, and causes consequently fluidity and brittleness. Chlorine removes all other matter from metals when the latter are in a state of fusion. Carbon, sulphur, and phosphorus are drawn off by it, and, if the heat is continued, the chlorine itself escapes with a portion of the metals, but only when a minute proportion is present; it is thus a powerful element in the purification of metals. Lead smelted from chlorides is purer than from oxides and sulphurets, and its proper application to smelting and refining purposes has a most beneficial influence. Zinc does not readily combine with iron unless chlorine be present; it removes oxygen from the protoxides, thus purifying the surface and preparing it for closer union with an alloy. All metals smelted under the influence of chlorine, are inclined to oxidize, unless it is removed entirely. It is harmless to the metals, powerful as a means of fluxing slags and ores, and producing fluidity; its use, therefore, ought to be much more extended than it has been.

Calcination, and Roasting.—These processes are more frequently made use of than any other operation had recourse to by the practical metallurgist for effecting the elimination of sulphur and other volatile substances from the ores which are sulphides or sulphurets. No agency is so commonly employed as this, although the mention of a few others should not be omitted. Amongst these may be enumerated the combined application of heat and aqueous vapor; of heat, and the decomposing agent of a metallic oxide; finally, of heat, and the decomposing agency of alkalies, alkaline earth, and their combinations. As a general rule, however, we may regard all other metallurgic processes having reference to the decomposition of sulphurets, rather as preliminary *assay* operations than the final processes capable of adoption by the manufacturer.

The process of calcination is generally adopted to remove volatile substances. Iron and zinc ores are heated to expel water from them, and iron, lead and zinc, are calcined to expel carbonic acid. Water will escape by the application of a gentle heat; but if much clay be present with the ore, it adheres tenaciously to the mineral. Calcination is most conveniently performed in a crucible, because no stirring of the mass is required. The heat of an air furnace is generally sufficient for the performance of this operation.

The operation of roasting is performed by various processes, depending on the nature of the ore, the quantity of the fuel, and the object in view. Roasting in heaps in the open air is the method most generally adopted with iron ore, pyrites, and ores which can bear a strong fire. The operation consists in spreading over a plane surface of ground billets of wood, or lumps of mineral coal, from six to eight inches thick, the interstices between the coarse fuel being filled up with chips of wood, charcoal, coke, or coal. Over the fuel thus prepared, according to the kind of ore, is spread a layer of from twelve to twenty-four inches in thickness. Coarse ore, which will bear a great heat, may be piled pretty high; but fine crushed ore from the stamps, and ores which smelt easily—such as sulphurets or arseniurets—should not have too much coal in a body, nor the ore piled over high.

Alternate beds of fuel and ore are thus formed, and roasting heaps accumulated, which are in many cases extremely large, retaining the fire for a long time.

Roasting means heating a substance to such a point that the mineral does not melt, but at which the volatile substances are expelled, and as much oxygen combined with the ore as it can absorb. In some cases, chlorine, carbonic acid, or steam, is required along with the air. In other instances, the object is to oxidize the ore to a higher degree, to drive off volatile matter, or to reduce the ore to metal, and evaporate it, as in the case of arsenic, zinc, and antimony.

The tendency of carbon to unite with metals is slight and circumscribed. Only two metals, considered in a metallurgic sense, are amenable to this kind of combination,—copper and iron. Nevertheless, they are the most important of all metals; and without the carburets of iron (cast-iron and steel), the most useful purposes to which iron is now applied could never have been subserved. The union of carbon with copper is only productive of inconvenience, and the care of the metallurgist is devoted to effect the removal of the former; but in the case of iron, though on one hand the removal of carbon is a metallurgic process highly desirable in order that soft wrought-iron may result, nevertheless, on the other hand, the problem of causing the union of soft iron with carbon is one of importance equally great; for on its successful issue depends the conversion of iron into steel.

As regards the theory of the metallurgic processes had recourse to for effecting the removal of carbon, they are such as naturally suggest themselves from a chemical consideration of the properties of that non-metallic element. Carbon is the most ordinary material of combustion known to man,—it is the very type of combustible bodies. To deprive a carburet of its carbon, therefore, nothing seems more natural than to burn it away. This is indeed the process usually followed. It lies at the basis of iron-refining and puddling; still more obvious is the application of the combustive energy in the new operation of Mr. Bessemer. Combustion. nevertheless, is not the only agency taken advantage of for effecting the removal of carbon from iron. A very elegant process for converting steel or cast-iron into soft or decarbonized iron, consists in exposing an article fabricated of either of these materials to heat in contact with iron oxide. The chemical agencies thus involved are sufficiently obvious. The oxygen by its affinity for carbon at an elevated temperature unites with it, forms carbonic acid, and is evolved, leaving the iron, to the extent of the removal of carbon thus effected, pure. The process in question unfortunately has but an application restricted to a limited number of articles of inconsiderable dimensions.

The union of soft iron with carbon, or, in other words, the formation of steel, is usually effected by the process known as cementation. It consists in stratifying bars of iron with charcoal in an iron case, and subjecting the whole to furnace heat until the desired union of the carbon with the iron has been effected. The chemistry of this union is very peculiar: furnishing an almost unique example of combination ensuing between bodies neither fluid nor gaseous, and contravening the long-accepted chemical axiom, *Corpora non agunt nisi fluida.* Perhaps however, after all, the exception is more apparent than real. Laurént was of opinion that the carbon thus entering into combination with iron, and forming steel, became actually vaporized by the heat employed. Stammer advances another hypothesis. He believes that the play of affinities resulting in the union of carbon with iron, is more complex than had up to his experiments been imagined. He infers that a mixture of iron and oxide of that metal, when brought to an elevated temperature, as in the process of cementation, in contact with carbonic acid gas, robs the latter of its oxygen, thus liberating carbon; which, whilst still in this condition, unites with the metal to form a carburet.

Though the great magazine of phosphorus in creation is the bones, and some of the fluids of animals, nevertheless, phosphoric acid, combined with oxides of metals and constituting phosphates of these oxides, give rise to a small though important group. Perhaps no element wherewith metals are naturally found in combination is more difficult to separate effectually, or exerts a more deteriorative influence when present, even in minute quantities, than phosphorus. The processes usually had recourse to by the metallurgist for effecting the separation of phosphorus, are based upon the employment of some body which manifests a strong affinity for phosphorus at elevated temperatures. Of this kind is chalk, which is sometimes employed for the purpose of separating phosphorus from iron.

Occasionally, though not very often, the metallurgist has to deal with the extraction of metals from their salts, both oxygenous and haloid. This kind of extraction, too, involves not merely the dry process, but also the use of chlorine and of acids. Platinum is a metal which has to be dealt with exclusively by the process of moist solution. Limiting our observations for the present to the case of dry operations, we find that certain metallic salts are decomposable by heat alone, whilst others require the agency of some collateral reducing body. Most of the salts of the metals, gold, platinum, and silver, are characterized by their facility of complete decomposition by the mere application of heat. Of this change, the chlorides of gold, of platinum, and the sulphate of the oxide of silver, present familiar examples. Many other metallic salts when subjected to the agency of heat, instead of being reduced to the metallic form, yield their several oxides. The sulphate of iron and the sulphate of copper are of this class,—yielding, when sufficiently heated, oxides of the respective metals.

To the practical metallurgist, the most interesting series of saline decomposition by fire, and deoxidizing materials, are those in which the sulphates of different metals are concerned. Sulphates differ merely from sulphides (viewed as to their composition) in the mere circumstance that the former contain oxygen, whilst the latter do not. Hence, when sulphates are heated in contact with coal, coke, or other deoxidizing matter, oxygen is frequently removed and a sulphide remains. The relative facility of this kind of decomposition varies for different sulphates, but it furnishes a type of most of the decompositions which ensue when sulphates are exposed to the combined agency of deoxidizing materials and heat. Of all the salts which come under metallurgic cognizance, the chlorides next to the sulphates are most important. The reduction of the chloride of silver forms the basis of the mode of silver extraction followed in America, Hungary, and various parts of Europe,—the reducing agent being iron. Various other methods of reducing chlorides to the metallic state are followed in the processes of metallic assaying; and, although not much involved in the practise of metallurgy on the large scale, are still of great importance to the metallurgist. The reduction of chloride of silver by heating with alkalies; of the chlorides of certain metals by the contact of another metal; and of the chlorides of gold and platinum by sulphurous, oxalic, arsenious, and formic acids, sulphate of iron, and a few other reagents,—are familiar examples.

CHAPTER II.

SPECIAL METALLURGIC OPERATIONS.

WE now come to the principles on which metallurgic processes are based, and the practical application of these principles. Mechanical and chemical sciences are here involved,—the former to effect a due comminution of the extracted ore from foreign impurities; the latter to complete this separation and evolve the metal in a condition as near that of absolute purity as may be possible or desirable. The mechanical part of metallurgy can only be discussed advantageously hereafter; in this introduction, therefore, we shall limit ourselves to an exposition of the chemical principles of metallurgic operations.

Between abstract chemistry, if the term be allowable, and technical chemistry, there seems a wide difference at a first glance. The only real distinction between them, however, will be found to be one of degree. The principles are the same, and both are amenable to the same laws: the laboratory chemist, however, having more agents at his command—being little amenable to considerations of profit—more readily carries these indications out to their several finalities.

The chemical part of metallurgy has for its object the separation of various substances, and the isolation of a few, by the operation of chemical affinities; being amenable thus to ordinary rules of chemical guidance, the first of which is based upon the law that chemical action takes place (with few exceptions, and those doubtful) between portions of matter the cohesion of which is slight. Reversing the proposition, we may also say that chemical decomposition is effected by loosening the state of cohesive affinity.

Of the three forms in which matter is found, namely, the solid, the fluid, and the gaseous state, respectively, it is evident that the two former are most under the control of cohesion;—gases, indeed, are often said to be absolutely devoid of cohesion as between their particles; a proposition which, though chemically unsound, may be considered to be practically correct.

The metallurgist, then, in effecting his numerous decompositions, proceeds to diminish the cohesive force by which the particles of his material are held together. He begins by mechanical processes—by hammering, grinding, stamping, etc. When these can go no further, he has recourse to chemical means. The problem now is to liquefy, or to gasify—usually the former, though many important mineralogical operations involve the production of gas, or at least of vapor; for gases and vapors may be generally regarded as identical. Supposing liquefaction to be the object in view, the metallurgist has the choice, theoretically, of dissolving his substance in chemical menstrua or of fusing it by heat. The former alternative is superior in the correctness of its results, and for that reason is usually adopted by the laboratory chemist; but it is so expensive, and slow, and inapplicable where large masses are concerned, that it is never adopted by the metallurgist, otherwise than by necessity. With the exception of platinum and its associates, all worked exclusively by the process of solution in chemical menstrua—by the moist process, in point of fact—gold occasionally, and a few of the common metals under certain peculiar conditions, the moist process of effecting solution of cohesiveness may be regarded as beyond the pale of applied metallurgy.

We have thus limited the metallurgist to the agency of fire; and we have assumed, as is most usual, that the object of furnace-heat shall be to reduce the material to the condition of fluidity. We might, therefore, at once, pursuing the thread of demonstration, enter upon the theory and operation of fluxes, were it not that a case of effecting chemical decomposition by the formation of gas or vapor sometimes precedes and therefore claims precedence in our remarks. Many ores either contain substances naturally volatile or which generate, under the combined influence of heat and air, volatile combinations. Sulphur and arsenic are prominent examples of this kind, and serve well to illustrate that application of a chemical law which is involved in the metallurgic process of roasting or calcination; respecting which sufficient par-

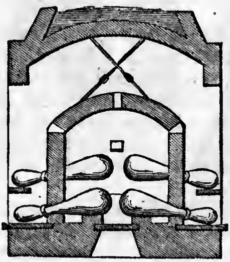


Fig. 1.

ticulars in an earlier part of this introduction have been already given.

The process of roasting is variously modified to accord with the peculiarities of certain metals, or to gain the precise end desired. In some cases it is no more than the process known to chemists as dry distillation; in other cases, its success depends on the combined agency of an atmospheric current as applied, for instance, to the evolution of antimony.

Though the metallurgic operation of roasting involves a well-marked case of gasefaction applied to a definite end, yet similar results are obtained under different forms of apparatus. The operations involved in the production of mercury and zinc are familiar examples. Both these metals are remarkable for their extreme volatility, the first especially so: hence the process of metallurgy adopted in their production is not one of smelting, properly so called, or of roasting as popularly understood, but as one of veritable distillation. Mercury is frequently produced by simple sublimation, without the addition of flux or coal, so also is arsenic; but in most instances carbon, and such substances as decompose the ore, are added. In the mercury distillation-furnace here annexed (Fig. 1) the similarity to ordinary distillation vessels and receivers is sufficiently obvious; not very remote, either, is the similarity to the ordinary distillation apparatus shown by the Belgian furnace for zinc extraction (Fig. 2). There is no difficulty in smelting zinc under cover of carbonate of soda and potash with carbon, but this is an expensive flux, and, when not closely watched when fluid, the loss may exceed the value of the metal obtained. It is for these reasons found good economy to mix the zinc blende with iron; although the heat required by this process is much greater than for smelting, it is asserted that distillation is the cheaper process. The apparatus here figured is a vertical section of a furnace with its retorts, of which there are as

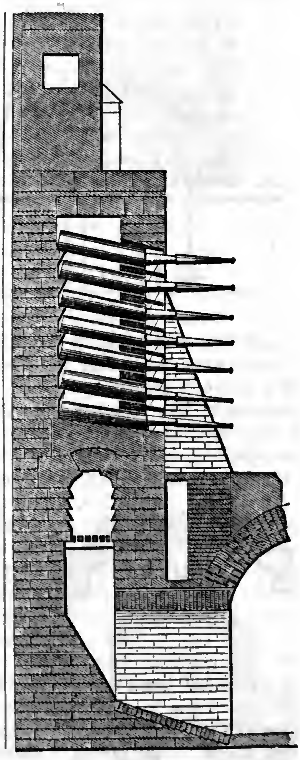


Fig. 2.

many as twenty-two. They are placed about two inches apart from each other to admit the passage of hot gases from the furnace. The metal which condenses in these gently-sloping pipes, requires to be raked out every two hours to prevent them from being choked up, and twelve hours are required to work off a charge. Perhaps the various parts of an English zinc oven may not be quite so suggestive of a distillatory process; nevertheless they are representatives of a form of distillatory apparatus perhaps more ancient than any—a form known to the alchemists, and described by them under the name of *destillatio per descensum*, (Fig. 3). A vertical section is given of this apparatus. They are sometimes round, sometimes square, having six or eight crucibles inserted in one furnace, an iron pipe inserted into the bottom of the crucible conducting the metal into a reservoir, which is filled with water.

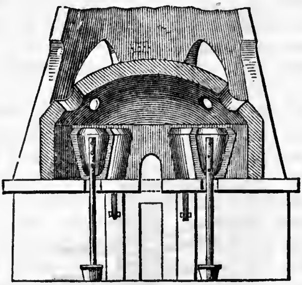


Fig. 3.

The theory of this process is very simple: the oxide of zinc mixed with carbon is reduced to metal on being ignited; and the metal, being volatile, passes in the form of vapor to the receiver, where it is condensed in the form of a crude impure metal, which requires a further process of refining before it is fit for commercial purposes.

FLUXES.—Assuming the process of roasting to have been necessary and to have been applied, and that a metallic substance still remains to be extracted from the non-volatile residue, a process of fusion must be had recourse to; it is called *smelting*. A slight chemical consideration of the materials wherewith metals are ordinarily combined, will bring to mind the fact that some are really or practically infusible. But fusion the metallurgist must have: the theoretical choice was before him of choosing between the moist or solvative, and the dry or igneous process of effecting liquidity. He was driven by practical considerations to accept the latter; therefore fusibility is a condition so indispensable to success in his future operations that he must have it. How, then, was he to solve the problem of effecting the fusibility of things which are by their nature infusible? Chemistry renders the solution of this problem easy: there are many substances which, though infusible when heated by themselves, fuse readily enough when heated in combination; hence arises the theory of *fluxes* and *fluxing*, these terms being respectively applied to substances which impart igneous fluidity, when heated with other substances, and to the manner of using them. Silica, or silicic acid, is an infusible body when heated alone; nevertheless it fuses when sufficiently heated in contact with potash, soda, or their respective carbonates; and less readily when heated in contact with alkaline earths. Hence if the metallurgic problem were to present itself, of extracting a metal by fire from a mixture of the same with silica (chemically silicic acid), potash, or soda, or their respective carbonates, would be had recourse to in preference to all others, if considerations of profit and loss did not intervene. The price of the alkalies and carbonates of alkalies does not admit of their common application to the purposes of a flux on the large metallurgic scale; wherefore the smelter, not being able to use the flux which chemistry proclaims to be the best, contents himself with a substitute as near to the theoretic quality as may be practicable. Thus where alkalies, or carbonates of alkalies, would have been employed to facilitate igneous fusion in the laboratory, and on the small scale—probably lime, or carbonate of lime, would be employed in the larger representation of the process as performed by the metallurgist.

Not only do the alkalies and their carbonates perform the functions of fluxes to silicic acid, but also to several metallic oxides; amongst which those of lead, copper, and iron, may be cited as familiar examples. Every person knows that flint-glass, as it is called, contains oxide of lead; that black bottle-glass contains oxide of iron,—combinations which illustrate, perhaps, as well as any we could adduce, the quality of the alkalies which imparts to them the power of a flux. When it is considered that nearly all the colors which can be imparted to glass, nay, which *are* imparted to porcelain and enamel, are referable to combinations of metallic oxides with silicic acid, a still further notion will be conveyed of the extensive range of combination which may be produced by silicic acid under the influence of igneous fusion.

Next, perhaps, to potash and soda, in respect to its large range of agency as an igneous flux, comes borax. Seldom is it that the assayer in his laboratory operations on mineral ores by fire dispenses both with alkalies and with borax; but here in this case, again, considerations of expense restrict the application of this material to the laboratory, and the smelter is obliged to content himself with fluxes much lower in the scale of chemical power and efficiency. Perhaps, however, there may not be so many advantages lost from the non-employment of laboratory fluxes on the large scale as is sometimes imagined. To adopt soda, or potash, or borax, though compatible with the economical arrangements of the laboratory chemist, who will not hesitate to ruin a crucible at each operation, might still accord very ill with the economy of furnace-building. The alchemists tried to discover a fluid which should have the property of dissolving all things wherewith it might come into contact. They neglected to reflect that a necessity would arise for a vessel to keep it in. It might be thus with metallurgists on the large scale, if laboratory fluxes were cheap enough, and plentiful enough, to be adopted on the large scale.

Though the number of fluxes which the metallurgist has at his command for large operations of smelting be inconsiderable by comparison with those employed in laboratory operations, nevertheless the process of assaying is one so important to the metallurgist that every flux known to the chemist deserves his consideration. Under the subject of assaying, therefore, to be adverted to hereafter, the chemical agents will be fully discussed.

The preliminary operation of dressing having been performed on a mineral, also the further operation of roasting if necessary, the final operation of smelting naturally follows. After the general statement we have given of the nature and properties of fluxes, it will be seen that the operation of extracting metal from a metallic ore by smelting, consists in subjecting it to furnace-heat in admixture with some flux,—the object of the latter being twofold. Primarily to liquefy and dissolve away refuse matters by themselves infusible; and, secondarily, in some cases to aid the decomposition, by the result of which the metal is evolved from its combinations. It remains now, for the completion of our sketch of the appliances of metallurgy, that we indicate the peculiarities of the different furnaces, and the appendages by means of which the operation of smelting is effected.

FURNACES.—The various forms of furnaces admit of division into two well-marked primary classes. One class in which the material to be acted upon is brought in direct contact with fuel; the other class in which the acting fuel and the material acted upon are separated from each other.

Either of these furnaces may be supplied with air from a blast of some kind, or they may depend for their supply of air on the draught of a chimney-shaft. Accordingly, in reference to these peculiarities we establish a division of furnaces into blast-furnaces and wind-furnaces. The first class of furnaces, or those in which the material and the fuel are placed in contact, differ in form and general intention, according to certain obvious peculiarities of construction. Some merely consist of a flat expansion or hearth, upon which the fuel may either smoulder and develop a long-continued gentle heat, as in the ordinary lime-kiln; in the kiln or hearth upon which copper pyrites and copper matte are heated or roasted, and in many similar forms of hearth-furnace employed by metallurgists, chiefly to accomplish roasting operations; or the fuel may be urged to almost the highest degree of heat of which a furnace is capable, as we see exemplified in the smith's forge. A modification of this form of furnace is employed in Great Britain in the smelting of considerable quantities of lead ore. If, however, it be desired to raise the intensity of furnace-heat to the highest point, the hearth-construction of furnace must give place to others on the type of a cylindrical or conoidal vessel. Perhaps the highest degree of furnace-heat known, is yielded by large iron blast-furnaces.

Usually the aid of an artificial blast is only sought for the first division of furnaces, namely, those in which the fuel and the material to be acted upon are employed together. This, however, is by no means universal. To furnaces in which the substance acted upon does not come into contact with the fuel used, the term reverberatory furnace is applied. Amongst other metallurgic applications of this third kind of furnace, those of iron puddling and balling may be especially mentioned.

Still more important than an acquaintance with the various terms conventionally applied to furnaces, to the form of their construction, or the objects they are intended to subserve, is a full comprehension of the chemical principles upon which their efficiency depends; aud with that we have to deal here. A furnace may be said to be a contrivance for giving the best practical effect to the laws of combustion as directed to some practical end. It will hence be proper that we take a casual glance at these laws, as a branch of chemical physics applied to metallurgy. All ponderable bodies are conventionally divided into combustibles and supporters of combustion; thus, for example, coal is said to be combustible, and air, or rather the oxygen contained in the air, is said to be the supporter of combustion under the usual circumstances involved in the ordinary combustion of coal. This division, though usual, is purely conventional; the function of combustion being, in point of fact, a result of chemical action between two agents, and appertaining to both; whence, in strict language, coal or the materials of coal and atmospheric oxygen gas are equally the subjects of combustion, and therefore combustible. Nevertheless the conventional distinction between combustibles and supporters of combustion has attained a certain significance, rendering it convenient of application in a practical sense. If we mentally review the substances of combustion they are such as most obviously present themselves to common observation. Before the employment of hydrogenous gas for heating and illuminative purposes, all popularly known combustibles presented the qualities of being visible and tangible; their combustive property was known long before the theory of combustion had been suspected, and at periods when the existence of gases was looked upon as matter to be doubted or disbelieved; no wonder, then, that the new power involved in the combustive operation was so long unsuspected, and, when discovered, allowed a subordinate place only. Though all material bodies be impressed with the quality of ministering to the combustive function, either in the sense of a combustible or a supporter of combustion—nevertheless, the bodies which are of a nature enabling man to realiee them as combustibles are few. Above all things it is necessary to the efficiency of a combustible, practically considered, that the result of its combustion shall be gaseous. When pure charcoal burns, no residue or ashes are left; the sole result of combustion is a gas, which, by reason of its nature, passes away. Even when ordinary charcoal is used, the ashes are but inconsiderable; and if coke or coal be the fuel employed, the amount of solid residue still bears but inconsiderable proportion to the mass of fuel originally used. Guided by the limiting consideration of gaseous products, it is easily seen that the only class of bodies having any claim to be regarded as combustible, in a practical sense, are two—the hydrogenous and the carbonaceous forms. All the naturally occurring fuels present us with a mixture of these: coal in all its varieties, wood, and peat, so obviously bearing out the proposition that no illustration is required. Reference to the chemical condition of carbon and of hydrogen respectively when burned will bring to mind the fact, that in proportion as hydrogen predominates, so will the combustion be more flaming; and conversely, in proportion as hydrogen is absent, so will the resulting combustion be of the incandescent or glowing kind, like that of ignited charcoal. Of late much attention has been devoted to the problem of ascertaining the comparative value of fuels; but we may here remark that the deductions have not been attended with a corresponding amount of practical success, chiefly because of their too literal and exclusive application.

The real amount of heat capable of being developed by the given weight of a combustible by refined chemical means, is so involved with other conditions in practice as to be of itself little worth. The mechanical aggregation of any particular combustible, is at least an element of consideration of equal value to its real chemical power of evolving heat. The truth of this proposition is amply borne out by the familiar operations of coking and charcoal making. Weight for weight, coal has more combustible heat-generating matter, than coke and wood, or than the charcoal made from wood. Nevertheless the mechanical or physical conditions of coal and wood are such, that they are totally unadapted to many of those heat-generating operations which coke and charcoal efficiently subserve. The fixedness of carbon and the volatility of hydrogen suggest the cases in which the superior absolute heat-developing power of the former would be more than compensated by the inferior localized heat-generating power of the latter. Accordingly, theory indicates, and practice confirms the indication, that in all cases wherever it is desired to bring the fuel and the material to be fused into actual contact, a non-hydrogenous fuel, such as coke and charcoal, is to be sought. When, however, the substance to be acted on is situated apart from the fuel, then the latter may, though not necessarily so, be hydrogenous. Even the carbonaceous fuels may be made to yield flame by particular treatment. If atmospheric air be supplied to the extent of ministering to the full wants of carbonaceous combustion, there is no flame, because the carbon is immediately and entirely changed into carbonic acid; if, however, the supply of air be more scanty, or if the fuel be so arranged that the carbonic acid originally formed has to permeate white-hot carbon, it is practically deoxidized, changed into carbonic oxide, a combustible gas: hence flame ensues. So important did it seem to obtain a strongly-flaming fuel for use in the reverberatory furnace operation of iron puddling, that not merely gas-yielding bodies, but gaseous mixtures have actually been proposed, and to a limited extent carried into practice; moreover, the unconsumed inflammable gases which escape from iron-blast smelting furnaces is sometimes collected, and applied as a heating agent. Probably, however, the latter application is one in a wrong direction. It may be, and probably is true, that if an escape of combustible gas take place from one of these furnaces sufficient to be of consequence as a heat-giving agency, this circumstance suggests an imperfection in the economy of the furnace. Instead of endeavoring to collect the escaping gas to be used as a combustible therefore, it might be preferable to take measures for burning the gas while yet in the furnace, thus rendering the heat developed by its combustion effective in the furnace operation. Many iron-manufacturers who at one time used the inflammable gases of their furnaces as a heating agent, have since abandoned the practice; and a sort of inferential testimony to the disadvantage of the process is afforded by the well-marked and ingenious effects developed in the primary operation, if the collecting of the gaseous results be made lower down in the body of the furnace than a line coincident with the termination of the first third of the vertical height of the furnace shaft. If the gases be withdrawn higher up than this, they are mixed with so much combustible material such as nitrogen and carbonic acid, that they are worthless as heating agents; if they are withdrawn lower down, the smelting operation is prejudiced by the removal of carbonic oxide —an important agent in accomplishing the reduction of iron ore.

The subjoined table will show the composition of the gases thus withdrawn from iron furnaces in three different works, *i. e.* Veckerhagen, Clerval, and Bärum:

	(I.) 15½ ft.		(II.) 18 ft.	
Nitrogen	62·47	58·115	64·28	63·20
Carbonic acid	3·44	13·76	4·27	12·45
Carbonic oxide	30·08	22·65	29·17	18·57
Carburetted hydrogen	2·24	0·00	1·23	1·27
Hydrogen	1·77	1·77	1·05	4·51
	100·00	100·00	100·00	100·00

Regarding the composition of the gases from Veckerhagen and the gases from Bärum (I.) and those from Clerval and Bärum (II.) as almost mutually identical, a mean may be taken in hereafter calculating their relative values. The following table represents the mean composition by volume:

	Veckerhagen and Bärum (I.)	Clerval and Bärum (II.)
	Mean.	Mean.
Nitrogen	63·4	60·7
Carbonic acid	3·9	13·1
Carbonic oxide	29·6	20·6
Carburetted hydrogen	1·7	0·6
Hydrogen	1·4	5·0
	100·00	100·00

A composition by volume which accords with the following composition by weight:

	A.	B.
Nitrogen	63·4	59·7
Carbonic acid	5·9	19·4
Carbonic oxide	29·6	20·2
Carburetted hydrogen	1·0	0·3
Hydrogen	0·1	0·4
	100·00	100·00

The former, however, are not the only gaseous constituents which are evolved unconsumed from coal and coke-burning furnaces. Occasionally hydrogen and carburetted hydrogen are developed, as was found to be the case by Ebelmen in the gaseous evolutions of furnaces at Vienne and Port L'Eveque.

While on the subject of the utilization of combustible gases which escape from iron-furnaces, it may be well to indicate that the idea first originated in 1812, at which date Abberlet obtained a patent for the application of gases thus developed to metallurgical purposes. In 1830 an attempt was made at Holsbrücke, near Freiberg, to employ the flame of coal-gas as the source of heat for cupellation. In neither case, however, was the proposition carried out to complete success, or, indeed, fully inaugurated. The merit of accomplishing the latter is due to Faber du Faur, who, about the year 1838, tested the value of the suggestion on the furnaces of some iron-works at Würtemberg.

However doubtful the advantages may be of collecting gaseous matters from iron furnaces and utilizing them as fuel, the prospective advantages of employing combustive gases in this way have seemed considerable enough to warrant the invention of several contrivances with this end specially in view. In France, and more especially in Silesia, combustible materials are gasefied with special reference to employment of the resulting gas in furnace operations. We have already adverted to the disadvantages which the iron-master encounters from the necessity he is under of smelting with a fuel holding injurious quantities of sulphur, phosphorus, and some other impurities. Reflection on these conditions will indicate the advantages which should theoretically accrue from the substitution of gaseous combustibles devoid of such matters. Practically, however, much cannot be said in favor of gaseous iron-smelting.

Some few years since considerable interest was excited by a patent taken out by Mr. Reece for the conversion of peat into valuable products by a modified process of destructive distillation. One of the subsidiary propositions involved by this patent was the employment of the gaseous matters evolved to effect the smelting of iron. It was hoped that the result would be equal to Swedish charcoal wrought-iron, and that we should be rendered totally independent of that source for our supply. The process of Mr. Reece, however, has in no way answered the expectations entertained of it. One of the most powerful incentives to the employment of gaseous combustibles has arisen in countries where charcoal fuel is much used,—and from the consideration of the circumstance that the mechanical conditions of powdered charcoal render it unadapted to furnace operations. Every person who has been accustomed to work with charcoal as fuel, even on the smallest scale, must have experienced the loss which arises from the pulverulent quality of that substance, and can readily imagine that this disadvantage increases when charcoal is employed on the manufacturing scale. Now the powder thus resulting, though unfit to be employed in the condition of furnace fuel, is in the best state of mechanical disaggregation to be converted into gas. Perhaps the most successful apparatus for effecting the gasification of charcoal is one used in France, and constructed on the model of an iron-smelting furnace.

It consists of a funnel or hopper into which the powdered charcoal is thrown, which latter sinks by its own weight into the body of the furnace, and is there exposed to a current of air forced upwards through it, by a blast-pipe, which enters the furnace underneath. If the hopper be kept well filled with charcoal powder, no gas will escape from its orifice; but the entire result of gasification will find exit by a tuyere, and this under considerable pressure. The apparatus in question is specially designed for the combustion of charcoal powder; lump charcoal may however be used if the furnace or hopper be supplied with a cover to retain the gaseous products of combustion. Independently of the mere question as to the advantages or disadvantages of gaseous combustibles abstractly considered, the process of gas generation by the transmission of atmospheric air through burning materials is attended with collateral difficulties. If care be not

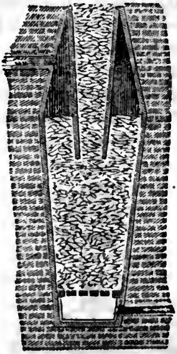


Fig. 4.

taken to prevent the admission of more atmospheric air than is actually required to subserve the process of slow combustion, an explosive mixture is formed, and danger from that cause is imminent. On the other hand, if the gaseous materials be allowed to escape unconsumed, the attendant workmen are liable to be poisoned.

NATURAL AND ARTIFICIAL BLASTS.—Next in relation to furnace-heat, we have to consider the various means had recourse to for producing atmospheric currents. These admit of division into natural and mechanical,—the former comprehending the various forms of chimney draughts; the latter all those various applications of compressive means which will be presently set forth in detail. The action of chimney draughts is immediately referable to and dependent upon the circumstance that atmospheric air, like all other gases and most other bodies of whatever cohesive state, is expanded and rendered specifically lighter by heat. Thousands of examples of this result continually present themselves, from which we shall select a few prominent illustrations. An illustration of the diminution of specific gravity of a gaseous mixture, is furnished by the blowing of soap-bubbles. The function of respiration causes a portion of the air taken into the lungs by the act of breathing to be robbed of its oxygen, which, by combining with the carbon of the blood, forms carbonic acid, and is in this state of combination expired. Seeing, then, that the air expired from the lungs is not pure atmospheric air, but a mixture of the latter with nitrogen, carbonic acid, and aqueous vapors, it follows that the specific gravity of the gaseous material expired is heavier (at equal temperatures) than that of the unchanged atmospheric air. Although, then, a soap-bubble, blown with warm air from the lungs, rises, this rising cannot depend on any quality of diminished specific gravity as a function of the gaseous matter wherewith they are filled, inasmuch as we have seen the latter to be specifically heavier by the amount of carbonic acid present. It depends on the circumstance that the gaseous materials are expanded by heat, owing their increased lightness to that cause. Hence it is that, although for a time the bubbles ascend, their ascension is not continuous—as would have been the case had they been filled with hydrogen gas—but only temporary. As soon as their gaseous contents become cooled to such a degree that they are specifically heavier than the external air, they descend.


Fig. 5.

An instructive toy, demonstrating the ascensive tendency of heated air, is represented in Fig. 5. A circular disc of card-board being cut, a piece of thread is attached to the centre; and being fixed to a hook, the card is suspended from a fixed support. Thus treated, the cut card unravels, and becomes a conoidal screw helix, susceptible of rotation when an upward force is applied.

If now any small source of flame be placed underneath, the helix will rotate, thus demonstrating the agency of an upward force, which evidently is that of air ascending, on account of the diminished specific gravity referable to expansion by heat. On precisely similar principles is constructed the smoke-jack, as it is called,—an instrument whose rotation is totally independent of smoke, and is altogether referable to the ascensive force resulting from the expansion of atmospheric air. Manifested in a different way, though referable to the same primary cause, is the force which causes the ascent of a mongolfier or fire-balloon.

Chimney-draught is a natural and very obvious consequence of the expansion of air by heat, to which our attention has been directed. The combustible materials cannot, as is well known, burn without the contact of air. Part of the air concerned is separated into its constituents,—one part of oxygen uniting with carbon to form carbonic acid; another part with hydrogen to generate water: a final portion of air remaining undecomposed, and escaping as it went in. Whatever the gaseous or vaporous constituents which escape from burning materials may be, they are heated by the fire to which they have been exposed, and are for that reason expanded. Hence they have become specifically lighter, and ascend, leaving a partial vacuum in the chimney or shaft, to be made good by a further flow of atmospheric air, or, more properly speaking, the gaseous results of its decomposition. A consideration of the principles on which the draught of a chimney depends, will render manifest the fact that a chimney may be too long for the most complete activity of which a chimney is susceptible. If it be so tall that the upward currents of air have time to cool until its specific gravity becomes lower than the specific gravity of the external air, or even coincident with it, the practical, no less than the theoretical, length has been exceeded. It will be evident, moreover, that in order to obtain the maximum heat for any given fuel of which a furnace is susceptible, no more air should be allowed to permeate the burning materials than the amount absolutely necessary to promote the highest rate of combustion. Any amount of passing air in excess of this theoretical quantity, whatever it may be, acts as a cooling agent; and instead of augmenting the power of combustion, diminishes it.

All furnaces which rely on mere chimney-draught for determining the passage of atmospheric air through the materials of combustion, are under the necessity of sacrificing a portion of fuel to the object of producing the necessary flow of air; hence for the greater number of operations requiring a very intense heat, chimney-draught as a means of effecting aërial transfusion is dispensed with in favor of some form of blast. There are some purposes, however, for which the application of a blast, in the ordinary sense of the term, would be inconvenient; in which a chimney-draught must be relied upon to some extent; its power being increased by some collateral means. Iron tubular chimneys do not answer well, because of the rapidity wherewith heat is lost through this substance, and the specific gravity of the gaseous matter which they pour forth diminished. Nevertheless iron or at least metallic chimneys are a necessity in the case of steam-vessels and locomotive carriages. Neither one nor the other can dispense, therefore, with a powerful draught, which is accomplished by the upward pressure of a steam-jet.

The effect of this liberation is to drive a column of atmospheric air violently before it, thus compensating not alone for the cooling tendency of the materials of the chimney, but for the inadequate height to which the chimney itself is limited by the necessities of steam-ships and locomotive-carriages.

The pressure of steam applied as above-mentioned is very great. Perhaps considered as a means of air propulsion, without regard to the moisture imparted, there is no method of producing a blast equally effective. Necessarily, however, the steam must impart moisture to the air, thereby deteriorating the latter for all combustive operations.

BLAST-MACHINES.—The most primitive method of generating an air-blast is by some modification of the leather bellows. Originally bellows were nothing more than the skin of an animal closely sewn except at one part, to which a spout or delivery-tube was attached, also serving to admit a further charge of air when the sides of the bag were pulled asunder. From this primitive instrument to the valved single bellows, and thence to the valved double bellows, used at this time by blacksmiths, and yielding an uninterrupted stream, the transition is obvious. The great advantages of bellows are economy of first cost, and facility of employment. They serve perfectly well for blacksmiths' forges and small furnaces; but the use of bellows in metallurgic operations on the large scale is limited, and gradually decreasing.

The blowing apparatus now generally employed on the large scale is that of compression cylinders. It is obvious that a metallic cylinder, like the cylinder of a steam-engine, may be converted by a simple arrangement of valves and piston work into a powerful apparatus for delivering compressed air. An usual form of compression cylinder is represented in Fig. 6.

The effective power of a blowing cylinder—or, in other words, the quantity of air of specified density which it contributes in a given time, may be arrived at in two distinct ways. The first consists in ascertaining the actual capability of the cylinder, and determining the number of times it can be filled with air and the air discharged in a given time. The second method is by ascertaining the velocity or power of the first, determined by taking into consideration the circumstances of barometric pressure, moisture, and temperature at the time of the experiment.

As regards the former method of investigation, it must be borne in mind, that the number of times per minute, or for any other given period, that a blowing cylinder is filled, would be a very false criterion of the actual amount of air which finds its way into the furnace. Owing to the elasticity of the air, ineffective space in the cylinder, loss of air between the cylinder and piston, added to further losses in the windways and regulators, the actual amount of air which finds its way into the furnace is always some 20 or even 25 per cent. less than the total amount subjected to compression. This loss occurs even in the best blowing cylinders. In wooden blowing-chests—a common form of apparatus—the loss not unfrequently amounts to nearly double. Being aware of the loss incurred, the appended formula may prove serviceable. It teaches the amount of air of natural atmospheric density taken into a blowing cylinder in one minute of time.

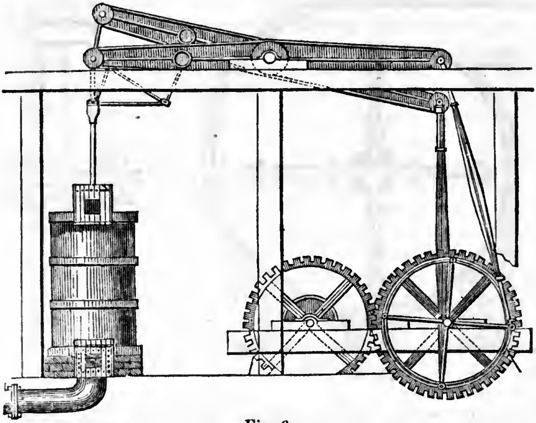


Fig. 6.

$$Q = \frac{g^2 . \pi . h}{4} \cdot \frac{60}{d} \cdot 4$$

in which

Q represents the amount of atmospheric air sought—in cubic feet.

g the diameter of the piston in feet.

π ratio of circumference to diameter (*i. e.* the number 3.1515).

h length of piston-stroke expressed in feet.

d number of revolutions expressed in terms of seconds.

Though compression-cylinders furnish the most powerful and the most certain means of delivering air in a blast, there are others of great practical importance. The ventilator or fan-blast is one of the most useful, and at the same time most simple. It is represented in the two following diagrams sectionally. Fig. 7 represents a cylinder or drum, cut transversely to its axis, and displaying the sectional view of four vanes. Fig. 8 represents the same cylinder cut parallel to its axis, and displaying two central openings, one on each side.

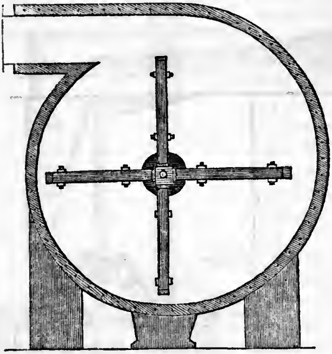


Fig. 7.

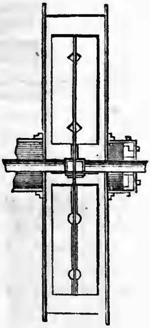


Fig. 8.

When the vane is put in motion, air enters by the central apertures, and is forcibly and continuously driven out through the aperture, thus constituting the blast. This form of apparatus has been so familiarized by being substituted for domestic bellows, that its description is almost unnecessary.

Notwithstanding the disadvantages, practical no less than theoretical, which attach to the employment of moist air in furnace operations, hydraulic blasts of simple description are amongst the most ancient; whilst modern variations on the principle of hydraulic blowing have given rise to some simple and curious machines.

The trompe, as it is called, is a simple and ingenious method of determining a current of wind by a falling current of water. It is a form of apparatus very prevalent in Catalonia: hence the appellation "Catalan trompe," which is sometimes applied to it. The instrument, however, slightly modified, is employed in Italy and Switzerland, being applicable to mountainous regions where high falls of water can be commanded, and the amount of atmospheric pressure required is inconsiderable.

An examination of the accompanying figure will render evident the construction and principles on which the trompe is founded.

The diagram (Fig. 9) represents a cistern above, containing water, and communicating with the vertical pipes which respectively terminate in two chests. Between these chests, and placing them in aërial connection, is a semicircular pipe; and the part of the apparatus on the left, sectionally represented, shows a transverse plank, on which the water is broken in its fall. The action of the trompe is this: The vertical column of water, in its descent, carries before it, and mingled with it, considerable portions of atmospheric air: striking against the transverse plank, a separation between the air and water is effected, the former passing into the arched tube and escaping as a blast through a tubular orifice corresponding with O, whilst the water passes into the lower reservoir. This form of apparatus would be quite inoperative if applied to furnaces heated with coke or coal; but it answers sufficiently well in cases where charcoal is the fuel employed.

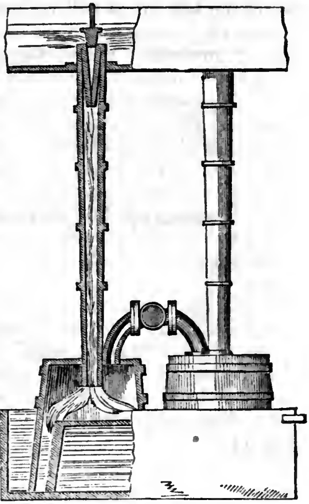


Fig. 9.

CHAIN BLAST.—This is a somewhat elaborate application of hydraulic laws to the purpose of creating an air-blast. It is depicted in the accompanying diagram (Fig. 10), and its construction is as follows: An endless chain, furnished with certain appendages, the motive of which we shall presently explain, is seen to pass over a wheel or pulley, and through a pipe which terminates in an air-chamber below. This air-chamber communicates with a bent tube, as represented: and a lateral tube pointing towards the left is also seen to be connected with the upper part of the vertical tubular shaft. Glancing, now, at the transverse appendages to the endless chain, placed at regular intervals throughout its length, they consist of cylindrical boxes quite open at one end, and capable of being opened or shut at the other end, each by two flaps

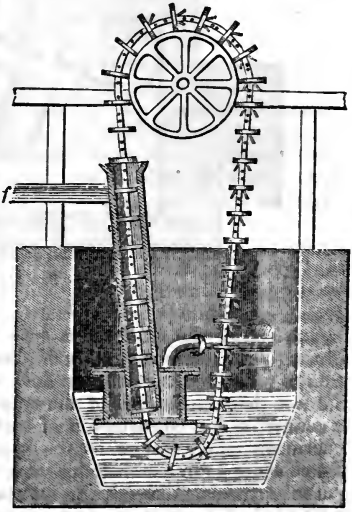


Fig. 10.

or valves. The latter fall by their own weight when the cylinders are on the left, or, as will be hereafter seen, at every part of their downward descent, and open (as represented in the diagram) when moving upwards. When it is now explained that water enters by the lateral orifice *f*, the action of the machine will be made evident. The water pressing successively on each cylinder, causes it to descend through the vertical pipe, conveying with it the air with which it is filled, and which cannot escape, because the valves are shut. Each cylinder, therefore, liberates its contents of air into the air-chamber below, and thence through the associated blast-tube. Passing on, the valve side of each cylinder again looks downwards, and the valves open, only to shut once more, and to act as before described, so soon as they again take their downward course.

A still more powerful and not less ingenious method of creating a hydrostatic blast, is furnished by the machine known in Europe by the name of "*Cagniardelle.*" This instrument may be generally described as consisting of a cylindrical screw, the shaft of which fits air-tight to a cylinder in which it is inclosed,—the cylinder being diagonally placed in a reservoir partially filled with water (Fig. 11).

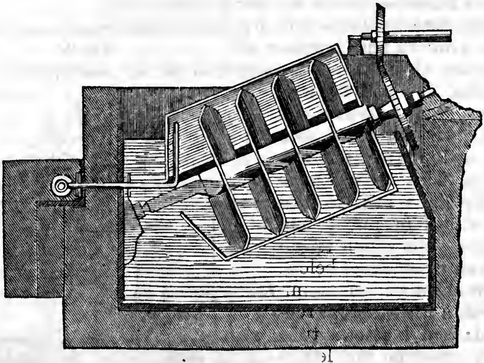


Fig. 11.

One end of the cylinder is seen to be flat, the other conoidal. Through the truncated apex of the conoid a delivery-pipe is also seen to pass; but the diagram does not represent what is actually the fact, that the flat end of the cylinder is open. It follows as a necessity of the construction of this instrument, that the atmospheric air which enters by the open flat end is screwed along by the combined force of rotation and water-pressure until it reaches the tube passing through the truncated apex, which tube is a delivery tube for air.

CHAPTER III.

RECENTLY PATENTED REFINING PROCESSES.

We now come to deal with a class of metallurgic processes which have recently much occupied the public attention—an attention which their importance fully justifies. We allude, of course, to the processes patented or otherwise having for object the conversion of ordinary cast-iron into malleable iron, by the application of air, or air and steam combined, without the intervention of fuel. We cannot but regret that necessity compels us to take up the subject in its present unsettled state, as we hoped to have communicated more exact information on these important inventions than is at present attainable.

The processes by which iron has hitherto been converted, are of the most laborious character; more especially, when the gigantic efforts required on the part of the workmen in the puddling and refining processes are considered; and it is difficult to overestimate the importance of any discovery by which even a portion of this laborious operation can be dispensed with. Nor when the economical considerations which enter into the question are borne in mind, will it surprise the reader that the change in the iron manufacture, which it was presumed would at once follow the announcement of Mr. Bessemer's discovery, should have created an excitement almost amounting to a panic in the principal iron districts. It was not in the nature of things, however, that such startling and rapid changes should at once develop themselves in perfection. The process, therefore, although watched with much interest by those interested, is at present only felt to be a step in advance of the older processes, which will be welcomely received, should the experiments now preparing on a large scale fulfil the expectations entertained of it. The inventions to which we have alluded we shall take in their chronological order, beginning with the earliest of them, namely:

Mr. Plant's Process.—Of this process no specification has been published. We must, therefore, avail ourselves of the condensed report given of it in the "London Journal of Arts." The patent is dated July 18, 1849. In it the patentee claims to have made an improvement in making bar-iron by the use of either hot or cold blasts, with steam-jets and atmospheric air, or with steam-jets by themselves, to be used in regulating the heat in the puddling-chambers, either with the ordinary damper in the draught of the chimney, or with a special damper and apparatus adapted to his invention.

This apparatus consists of a puddling-furnace of ordinary dimensions, having three lines of tuyeres across the top of the furnace, each line consisting of three tuyeres one inch in diameter,—

the line furthest from the chimney being for the blast, the other two being steam-tuyeres for the puddling and preparatory chambers. The blast-tuyeres are to be capable of a pressure of one pound and upwards to the square inch; the steam to be used at a pressure of ten pounds and upwards.

The blast is to be introduced at the top of the puddling-chamber, in a slanting direction, just behind the fire-bridge, so as to draw the flame down upon the whole surface of the metal as it enters the puddling-chamber; the steam being introduced as nearly as possible at the same spot, and thrown in like manner upon the whole metal.

By these means, it is stated, the heat of the furnace and preparatory-chambers can be regulated with great nicety, without employing the damper usually inserted in the chimney of a puddling-furnace. When the metal is melted, the blast is shut off, and steam introduced through the tuyeres until the iron boils; the steam is then turned off and the blast brought into action till the iron appears above the cinder, when the blast is again shut off and the iron finished in the usual manner by the ordinary draught. The heat of the puddling-chamber is raised or lowered from time to time by raising or lowering the damper over the fire-bridge.

In this process, a greater separation of the metal is caused, it is presumed, by the blast of air and jets of steam thrown *upon* the metal; and the carbon and other impurities are supposed to be more thoroughly removed by the infusion of the oxygen of the atmosphere.

MARTIEN'S PROCESS, to which we shall now call attention, is that patented by Joseph Gillot Martien, of Newark, New Jersey, in September, 1855, and has for its object the purification of iron when in the molten state from the blast or refining-furnace, either by air or steam, or vapor of water applied from below, so that it may rise up amongst, and completely penetrate and search every part of the metal previous to congelation, and prior to its being run into a reverberatory-furnace for puddling. By this means the manufacture of wrought-iron by puddling, and the manufacture of steel from cast-iron in the ordinary manner, are stated to be greatly improved.

In carrying out his invention, Mr. Martien employs channels, or gutters, so arranged that the numerous streams of air, of steam, or of vapor of water, are passed through and amongst the melted metal, as it flows from the blast-furnace. This is done by subjecting the metal to the action of streams of air or steam, as it passes from the blast-furnace before it congeals. The apparatus recommended, consists of cast-iron channels or gutters, having the bottom made hollow to receive steam or air, or both. This gutter is perforated with numerous holes, obliquely inclined in the direction of the flowing metal, so that the streams of air or steam may be forced through it as it flows along the gutter. The stream of air, however, may also be passed up through the metal; or the holes may be inclined in the opposite direction, so as to oppose the flow of the molten metal. When the hot or cold-blast is used, the hollow bottom of the gutter may be connected with the air-pipes used for supplying the blast; or, when steam is employed, the gutter may be connected with the boiler. By these means, the air or steam introduced rises up through the metal in numerous streams, and the iron is stated to be perfectly purified after it has come from the blast-furnace, and before congelation takes place. The iron thus purified may be allowed to cool in the mould, or it may run from the gutter into a reverberatory or other refining furnace, to be heated and puddled in the usual manner. In this process, the novelty claimed is that of purifying iron from a blast-furnace while still in a molten state, without the intervention of fuel; thus preparing it for the puddling process in a state of greater perfection than by the old process. The perceptive faculties of James Nasmyth, to use the words of Mr. Bridges Adams, the eminent civil engineer, "detected the absurdity of setting a number of human beings to stir up a metallic puddling in order to throw off the scum in the shape of slag or cinder. His remedy was a mechanical one—to cause the mass to boil like a pot, by forcing steam into it from below, the issue of steam beginning before the molten mass was poured in, so as to insure against the stoppage of the passages. But steam is not exactly fuel, and, instead of increasing, tends to lower the temperature of the mass of iron."

MR. CLAY'S PROCESS.—Among other ingenious inventions, we may here mention that of Mr. Clay of the Mersey Iron Works,—an invention for which a patent was taken out and a specification lodged, as applicable both to malleable iron and cast steel; although all claim for the latter purpose has since been withdrawn in favor of Captain Uchatius's process. Mr. Clay proposes to refine the crude iron by a process of granulation, produced by dropping iron in a molten state from a lofty tower into a water-tank, after the manner in which small lead-shot is cast. In this process, he states that the highly separated metal is purified by contact with the air in its lengthened descent, and by the chemical change produced by immersion in the water, so that, when again melted for the puddling furnace, it is divested of most of the impurities of crude iron.

For the purposes of this invention, iron may be obtained either from the blast-furnace, from which it may be run out in a molten state, or it may be melted down from pig or scrap cast-iron. The granulation of the iron is effected by causing the metal, when in a molten state, to run through a perforated plate of metal or other material, placed at the top of a tower-shaft or well; by this means it will be divided into small shot-like particles. In its descent in this state from a suitable height, varying according to the nature and quality of the iron operated upon, the metal will, during its passage through the air, be partially decarbonized, inasmuch as the oxygen of ordinary atmospheric air acts with considerable force in decarbonizing the metal as it falls through it; it will thus be rendered more suitable for working up by puddling into malleable bar-iron.

It is sometimes advisable to charge the air in the shaft, through which the molten metal is to pass, with artificially prepared oxygen, or with some other decarbonizing gas or vapor, which will produce a more vigorous decarbonizing action upon the iron. This may be effected by the decomposition of the salts of potash, such as chlorate of potash, or nitrate of potash, both of which contain considerable quantities of oxygen; and their decomposition may be effected either by dropping the red-hot metal, in a granulated or finely-divided state, upon a bed of the salts of potash, or by heating the salts in a retort until oxygen is given out. Other minerals, also, such as manganese, may be employed, either alone or in combination with other substances, as oxygenating agents. The patentee also employs the more simple means of increasing the oxygenizing powers of atmospheric air, by introducing a blast or draught of air, either hot or cold, as may be found most effective, into the tower down which the iron is descending. Dry steam may also be applied to effect the object in view.

Mr. Clay has found that by allowing the molten metal to fall through the air a distance of about seventy feet, a satisfactory result has been obtained; this, however, depends both upon the quality of the iron and upon the state of preparation in the shaft. With atmospheric air at the ordinary pressure, the metal requires to fall through a greater distance, than if charged with the artificial means above referred to. The granulated particles of molten iron may either fall into water at the bottom of the tower or well, or they may be collected in a vessel or reservoir placed for the purpose.

The decarbonized metal thus obtained, it is scarcely necessary to add, is collected together and remelted into ingots or bars, preparatory to undergoing the ordinary treatment of hammering and rolling.

Mr. Bessemer's Process.—We have now to speak of that process of Mr. Bessemer's, which has arrested so much attention, even of the ordinary reader, in the last few months. Mr. Bessemer's first patent is dated January 4, 1856. Others he has since taken out bearing date February 12, May 15 and 31, 1856. To the most complete of these, namely, that of February 12, 1856, we shall direct our attention. In the specification now before us the invention is said to consist in the decarbonization and refinement, in whole or part, of the crude iron, which is either obtained in a fluid state from the furnaces in which the iron ore has been reduced, or in the decarbonization and refinement of crude pig or finery iron, by remelting the pigs in a suitable furnace so as to obtain fluid metal capable of being treated by the process we are about to describe. This consists, firstly, in running the fluid iron from the furnace into a close or nearly close vessel or chamber, formed of iron, perforated with openings to receive the tuyeres, and lined with firebrick or other material which is a slow conductor of heat. When this vessel is almost half filled, numerous small jets of atmospheric air, or gaseous matter capable of evolving sufficient oxygen to cause combustion of the carbon of the iron, are forced into and among the fluid metal, either in a cold or previously heated state. "Atmospheric air or oxygen is thus introduced into the metal, in sufficient quantities to produce a vivid combustion among the particles of the fluid metal; and to retain and increase its temperature to such a degree, that the metal will continue fluid during its transition state from crude iron to that of cast steel or malleable iron without the application of fuel."

Mr. Bessemer stated in the paper with which he ushered his invention to the British Association, that for the last two years his attention had been almost exclusively directed to the manufacture of malleable iron and steel, in which, however, he had made but little progress until within the last eight or nine months. The constant pulling down and rebuilding of furnaces, and the toil of daily experiments with large charges of iron, had already begun to exhaust his stock of patience; but the numerous observations made during this very unpromising period all tended to confirm an entirely new view of the subject, which at that time forced itself upon his attention—viz., that he could produce a much more intense heat without any furnace or fuel, than could be obtained by either of the modifications hitherto used, and consequently not only avoid the injurious action of mineral fuel on the iron under operation, but at the same time avoid the expense of the fuel. Some preliminary trials were made on from 10 lb. to 20 lb. of iron, and, although the process was fraught with considerable difficulty, it exhibited such unmistakable signs of success as to induce him at once to put up an apparatus capable of converting about 7 cwt. of crude pig-iron into malleable iron in thirty minutes. With such masses of metal to operate on, the difficulties which beset the smaller experiments entirely disappeared. On this new field of inquiry, he set out with the assumption that crude iron contains about five per cent. of carbon; that carbon cannot exist at a white heat in the presence of oxygen without uniting therewith and producing combustion; that such combustion would proceed with a rapidity dependent on the amount of surface of carbon exposed: and, lastly, that the temperature which the metal would thus acquire, would be also dependent on the rapidity with which the oxygen and carbon were made to combine, and consequently that it was only necessary to bring the oxygen and carbon together in such a manner that a vast surface should be exposed to their mutual action, in order to produce a temperature hitherto unattainable in our largest furnaces. With a view of testing practically this theory, he constructed a cylindrical vessel of three feet in diameter and five feet in height, somewhat like an ordinary cupola furnace, the interior of which was lined with fire-bricks, and at about two inches from the bottom of it five tuyere-pipes were inserted, the nozzles of which were formed of well-burnt fire-clay, the orifice of each tuyere being about three-eighths of an inch in diameter; they were so put into the bricklining (from the outer side) as to admit of their removal and renewal in a few minutes when they were worn out. At one side of the vessel, about half way up from the bottom, there is a hole made for running in the crude metal; and on the opposite side there is a tap-hole stopped with loam, by means of which the iron is run out at the end of the process.

The apparatus by which it is now proposed to carry out this process, differs somewhat from that described above: it is a cylindrical vessel, mounted on axes *not* placed at the centre of gravity. Of this vessel, Fig. 12 is an end elevation. The vessel is formed of stout plates, secured by angular iron flanges to the cast-iron plates *a′*, strengthened by webs or ribs of iron. *c c* are iron frames secured by bolts *d* to the masonry, or foundation on which the operation rests. The frame *c′* rises higher than the others, and has plummer blocks *e e* bolted to it, on which the shaft *f* revolves. A worm-wheel *g* is keyed firmly on to the axis *b*, and receives motion from the worm *h* when moved by the handle *i*. At the point of junction of two of the webs *a*, will be seen a boss; into this boss a stud is fixed, to which a chain, or tension-rod, may be attached, suspended over a pulley from the roof, for supporting a counter-balance weight, so as to facilitate the movement of the vessel on its axis, and assist the worm-wheel gearing *g h*.

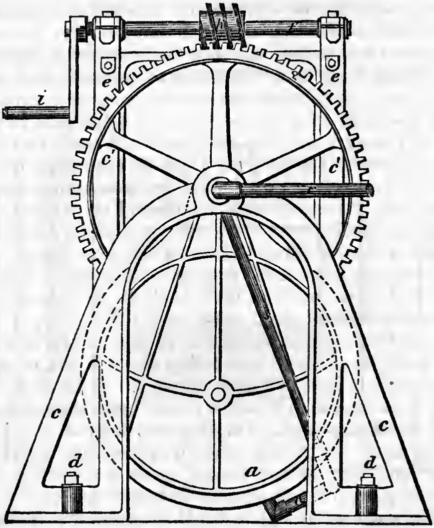


Fig. 12.

The intention in having the refining vessel thus mounted on axes, is the convenience it offers for pouring out the fluid metal into the ingot-mould, for which purpose it is furnished with a lip or spout, which is placed in a line with the mould, the latter being kept in a proper position for removing the fluid contents. The air, or other gaseous matters, which are to operate on the metal, must be compressed with a force greater than will balance the weight of a column of fluid metal of a height equal to the depth of immersion of the jets below the surface of the fluid metal. This air, as will afterwards be shown, is introduced at the sides or ends of the vessel, through small holes formed in the fire-clay lining; so that, by moving the chamber on its axis, the holes in the fire-clay may be made to descend beneath the surface of the metal, or raised above it as may be desired.

In Fig. 13 is represented a longitudinal section of the converting vessel, in order to give a more correct idea of its construction.

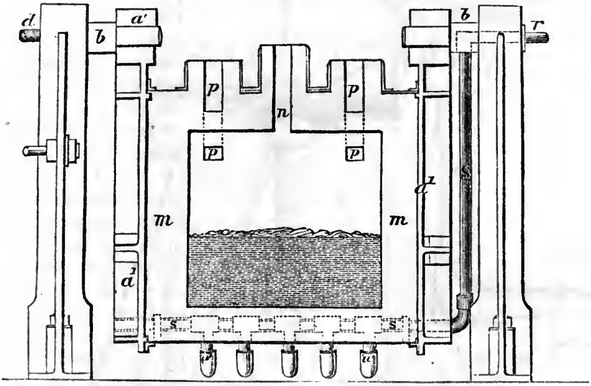


Fig. 13.

The section presents, at one side of *a'* and at a point beyond the outer edges, the bosses *a'*, which are bored out truly, and fitted and keyed to the axes *b b*; and on these the vessel is made to move when turned by the worm-gearing *g h* (Fig. 12). At *r* there is a pipe which communicates either with a blast-engine or steam-boiler, or it may be made to communicate with a reservoir of oxygen gas, or any other gaseous matter capable of evolving oxygen, either in a cold or heated state. The pipe *r* is fitted to one end of the trunnion or axis *b*, which is hollow, and provided with a stuffing-box, or other joint, so as to allow of the movement of the axis without interfering with the passage of the air or other matters through it. This pipe is continued to S, and along the outside of the vessel S, where it requires to be turned truly on its exterior surface, having fitted to it several small branch-pipes *u*, each of which has a **T** piece connected to it, which is bored out truly, so as accurately to fit the exterior of the pipe S; thus admitting of the pipe u being moved on the pipe S into its proper position. The object here, is to connect the blast-engine with the converting vessel, along one side of which there is a row of square holes: into these, small blocks of well-burnt fire-clay are closely fitted, and held in position by ramming a little loam into the joint formed between them and the lining m. At one of these blocks or tuyeres, the pipe u is fitted by a simple cone joint, the other ends of the tuyere-blocks having several small perforations leading into one larger passage communicating with the pipes u; a communication is thus established between numerous points of the interior surface of the converting vessel and the blast-engine or other apparatus used. A sluice-cock on the pipe r, enables the workman to turn this off or on as required.

The manner in which these pipes and tuyeres act will be better understood by the following engravings, where Fig. 14 represents a section of the pipe u, and the mode of fitting it into the pipe S; while Fig. 15 shows them in their ordinary working position. It will be seen by Fig. 14 that the pipe S has an opening at x opposite the orifice of the pipe u. When these pipes occupy their ordinary position, as in Fig. 15, the air passes freely through the opening; but when the tuyere-blocks require renewing, the pipe u can be turned upon the union joint formed at the junction x: free access to the tuyere is thus obtained. The manner in which these pipes act upon the metal in the converting vessel is shown in Fig. 16, and again in Fig. 17.

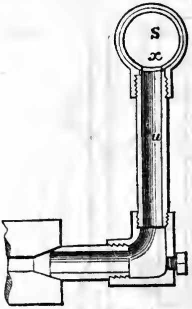


Fig. 14.

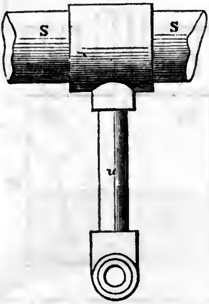


Fig. 15.

The tuyere-blocks may be formed of one or of several smaller apertures, one being found to answer perfectly well in practice; they must, however, be made to fit exactly into the pipe. These passages sometimes get obstructed. To provide for this, a screw-plug (Fig. 14) is fitted at the back of the elbow of the pipe u, which may be removed if necessary, and a steel rod thrust through the aperture, so as to remove any accumulations of matter.

The interior of the converting vessel itself is lined with firebrick or fire-stone, as shown at m (Fig. 13); and arrangements are made by which this lining may be renewed or repaired either by removing one of the end plates *a′*, which can be bolted on again; or a man-hole may be devised in the side of the vessel through which the lining may be repaired without this removal. The peculiarities of the vessel itself we shall now describe; and in order to convey a correct idea of it, we give two illustrations (Figs. 16 and 17): one a vertical section, exhibiting the vessel while the metal is in a molten state,

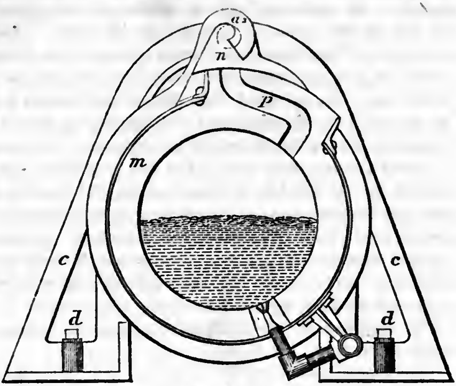


Fig. 16.

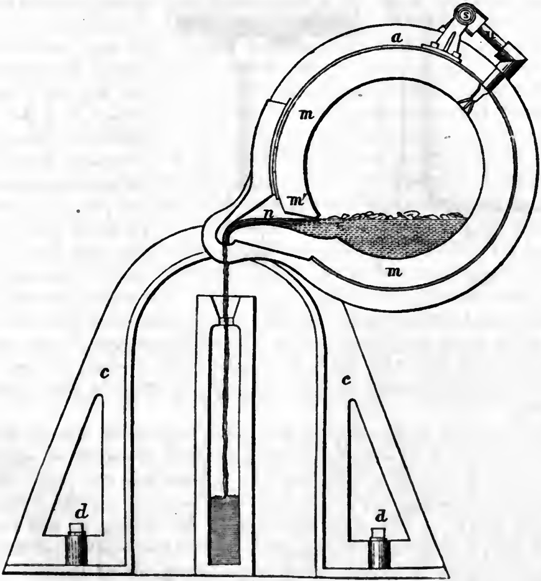


Fig. 17.

with the tuyeres in full operation; the other, a similar section, where the fluid metal is presumed to be purified, and in the act of being poured out into the moulds and formed into ingots. In each of these sections the peculiar lip-like form of the spout *n* of the vessel is shown. This projecting spout is for the purpose of running out the fluid metal, and is made to project from the vessel so far as to bring it in a line with the axis, so that into whatever position the vessel *a* may be moved, the extremity of the lip *n* may retain the same position, or nearly so; thus allowing the stream of metal flowing over it to fall into the ingot-mould. By reference to Fig. 17 it will be seen that at *m′* the lining is formed so as to prevent the slag and other impurities floating on the surface from flowing out until after the metal itself has run out. On each side of the spout *n* there is a curved passage *p* (Fig. 16), by means of which the flame and gaseous products evolved during the process may escape; but the plashes of metal thrown up by jets of air are, for the most part, prevented from escaping by the serpentine form of these outlets in the converting vessel.

Having thus minutely described this apparatus, let us follow its author through the process. When the chamber is about half-filled with fluid metal drawn from a smelting or remelting furnace, atmospheric air, either in a cold or heated state, or gaseous products capable of evolving combustion of the carbon contained in the iron, is blown or forced into and among the fluid metal; and this is found sufficient to keep up the required temperature during the process.

The size and number of jets or tuyere-pipes required for this purpose vary according to the quantity of metal operated upon at a time, and also with the condition and quality of the metal; thus forge, pig, or refined plate metal, will not require so much oxygen to complete its carbonization and conversion into malleable iron, as is required for the conversion of crude iron of the quality known as No. 1 or No. 2 foundry-iron. To these qualities of metal a tuyere is required having an outlet larger by about twenty per cent. than is used for the white qualities of iron. The patentee hesitates, however, in giving any fixed rule where so much depends upon the force or pressure of the blast and the quality of the iron, preferring to give the following example from his own practice as a guide to the workmen. "When using foundry-iron of the quality No. 2," he says, "I run one ton into the converting vessel, in which it rises to the height of about a foot above the orifices of the tuyere pipes; and then force into the fluid metal, atmospheric air in its natural state, under a pressure of about ten pounds to the square inch, employing from six to twelve tuyere-pipes for its distribution, the united area of the pipes being two square inches. The quantity of blast admitted by this area of inlet, will in general be found sufficient to effect the conversion of the crude iron into a malleable condition in about thirty minutes. Where a mixture of oxygen gas with atmospheric air or steam, or steam alone; or where other gaseous fluids capable of evolving oxygen are preferred in lieu of atmospheric air; then the size of the tuyere-pipes should be regulated according to the quantity of oxygen present, diminishing the area of the pipes where the oxygen is in excess, and increasing the area where the quantity is short of the above proportion."

When the vessel is new, or newly lined, it may be heated by the waste gases of the blast-furnaces, or any other convenient means, previous to the crude iron being poured in. The patentee sums up the substance of his discovery in the following terms: "It is well known that molten crude iron, under ordinary circumstances, will soon become solidified unless a powerful fire is kept up, and is applied direct to the fluid metal, or to the exterior of the vessel containing it. It is also well known that if the quantity of carbon which is usually associated with crude iron is diminished, that the temperature necessary to maintain its fluidity also rises in like manner, so that when iron has lost the whole or the greater part of its combined carbon, the metal can only be kept in a fluid state by the heat of powerful furnaces. But I have discovered that if atmospheric air or oxygen is introduced into the metal in sufficient quantities, it will produce a vivid combustion among the particles of fluid metal, and retain and increase its temperature to such a degree that the metal will continue fluid during its transition from crude iron to the shape of cast-steel or malleable iron without the application of fuel, the high temperature being obtained by the oxygen uniting with and causing a combustion of the carbon in the crude iron, and by the combustion of small portions of the iron itself."

As a matter of convenience, the patentee suggests, while reserving his right to apply modifications of the apparatus described, that the converting vessel should be placed near to the discharge-hole of the blast or remelting furnace, from which the crude iron is to be drawn; that the interior of the chamber should be heated by burning gases, or by introducing wood-charcoal or coke at the passages *p* (Fig. 16); and that a blast of air be turned on through the tuyere-pipes, by which their combustion may be kept up and the vessel dried before turning the crude metal into it. For this operation the vessel is placed in the position shown by Fig. 16, having a movable gutter leading from the tap-hole of the smelting furnace into the upper end of one of the passages *p*, the tuyere-pipes being now in operation. As soon as the metal covers the orifices of the tuyere-blocks, a violent ebullition is produced, the air dividing into globules, and diffusing itself among the particles of fluid iron, and thus coming in contact at numerous points with the carbon consumed in the crude iron, and producing thereby a vivid combustion, while the gaseous products escape by the passages *p*.

In about fifteen minutes from the time of commencing the process, large frothy slags are thrown violently out of the passages *p*, accompanied by a rush of bright flame. After a few minutes' duration this eruption ceases, but copious flame still continues to escape by the passages. At this stage of the process the crude metal has thrown off the bulk of its impurities, and is, in all probability, in the state of cast-steel; its exact state, however, can be ascertained by turning the handle-shaft *f*, so as to bring the vessel round on its axis, as in Fig. 17, when a portion of the metal may be discharged into an ingot-mould, where it is quickly cooled and examined. If not sufficiently decarbonized, the vessel is restored to its original position, and the process continued until completed, —from five to ten minutes' blowing being generally found sufficient to convert the metal from the condition of cast-steel to malleable iron. When it is necessary to suspend the operation of blowing for a short time, the vessel should be brought into a position halfway between Figs. 16 and 17, so that the orifice of the tuyere-pipes may be above the surface of the metal, otherwise the tuyeres will be stopped up with the fluid metal. The whole process of conversion from crude pig-iron No. 1 to malleable iron, occupies from thirty to thirty-five minutes, varying according to the quality of the pig; but the exact point when the process should cease, will soon be acquired by the workmen, since the color and volume of the flame issuing from the passages vary with the condition of the metal, thus forming a good guide for the workmen; while the facility with which trial-ingots may be taken affords an infallible test.

The heat, in some cases, is so excessive that the metal, even when reduced to malleable iron, is still so far above the melting point that its temperature requires to be reduced before casting. For this purpose, the vessel is brought into the position half-way between that shown in Figs. 16 and 17, the tuyeres being above the surface of the metal, the supply of air stopped, and a fire-brick placed over the orifice of the passage *p*, so as to prevent the heat from escaping with too much rapidity. In this way the temperature gradually subsides, and the metal is brought into a proper state for casting; or, if that is preferred, for taking out of the vessel in masses after cooling down by stirring.

We have now to deal with a part of the refining process in which it occurs to us that Mr. Bessemer has been altogether misunderstood, both by those who have criticised his inventions most severely, and by the general public. The notion generally entertained, we believe, is that by means of combustion alone, and without fuel, that gentleman professes to produce malleable iron. This is not so. He only professes to have discovered, that the rapid union of carbon and oxygen which takes place at the temperature which has now been attained, still further increases the temperature of the metal, while the diminished quantity of carbon present allows a part of the oxygen to combine with the iron, which undergoes combustion, and is converted into an oxide.

At the excessive temperature which the metal has now acquired, he continues, the oxide undergoes fusion, and forms a powerful solvent of those earthy bases that are associated with the iron.

The violent ebullition which is going on mixes most intimately the scoria and metal, every part of which is thus brought in contact with the fluid oxide, which will thus wash and cleanse the metal most thoroughly from the silica and other earthy bases which are combined with the crude iron, while the sulphur and other volatile matters which cling so tenaciously to iron at ordinary temperatures are driven off, the sulphur combining with the oxygen and forming sulphurous acid gas,—producing by this means a purer iron by the application of atmospheric air to the fluid metal than could be produced in the puddling-furnace by a large consumption of that costly material. Beyond that, the process recommended very much resembles the mechanical appliances by which malleable iron is produced by the older methods: namely, by subjecting the ingots at a welding heat to a forge-hammer or squeezer of a peculiarly powerful construction.

During the interval occupied in cooling down the boiling metal, the workman has to prepare his ingot-moulds. A convenient mode of doing this is to place them in an iron truck, mounted on wheels, which may be moved under the spout of the vessel, and passed out under the arched openings left in the furnace. The ingots thus prepared, are now in a fit state for being hammered, tilted, or rolled into bars, rods, or plates. In some cases the ingots are found to contain cells and cavities; in this case they are subjected at a welding heat to the action of squeezers, or they are subjected, in a suage or die, to repeated blows under a powerful hammer, so that the parts are forcibly driven together, and the cells welded before being subjected to the rolling-mill or tilt-hammer.

The squeezers, and other apparatus recommended by Mr. Bessemer, differ considerably from those generally in use. The squeezer has transverse grooves, both on the upper and lower jaws, as represented in Fig. 18: A A being the grooves or hollows, B an ingot placed between the jaws. In this operation the ingot, or mass of metal, is brought to such a temperature in a suitable furnace as

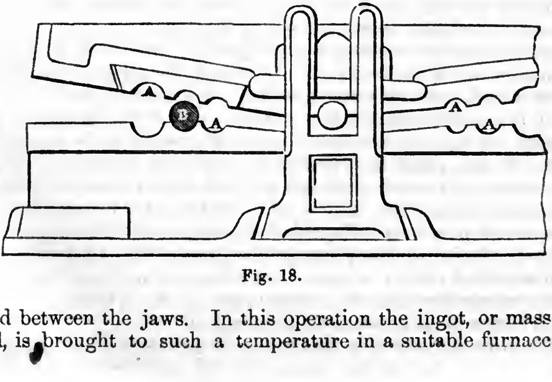


Fig. 18.

will sufficiently soften it to admit of its being pressed into a solid homogeneous body.

The same effect may be produced by hammering the ingot on a suage or die, as illustrated in Fig. 19, where P represents the lower portion of a steam-hammer, having a grooved block Q fitted into it; a similar block N is secured to a heavy mass of metal O, which forms the bed of the hammer; M being a wrought-iron hoop, lined with steel, which is made so as to slide up or down by means of the rods S. The workman, having heated the ingot G, holds it with a pair of tongs in the groove of the lower block, while the upper one falls upon it with such force as is necessary. By the use of these grooved surfaces, or suages, the ingot of metal is less liable to be crushed than when hammered between two parallel flat surfaces, which give no support to its sides. In this operation the workman will move the ingot backwards and forwards, turn it over on its side, and so work and compress the metal while at a welding heat, as thoroughly to solidify the iron and render it fit for the tilt hammer or rolling-mill.

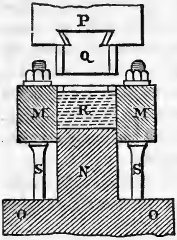


Fig. 19.

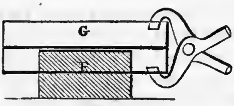


Fig. 20.

Other modifications of the steam-hammer are mentioned by Mr. Bessemer, all however having one principle, viz., that the ingot is placed upon a block or anvil; supported on both sides by strong rests, while the hammer falls into the groove formed by these supports. By this means the tendency of the ingots to crush out laterally is prevented, while the metal is left at liberty to expand itself in length, thus undoubtedly encouraging the fibrous condition inseparable from malleable iron. This effect is produced by many modifications of apparatus, the details of which are unimportant, provided the dies or suages are so constructed, and the ingot of spongy or cellular metal so confined, that when the hammer is brought forcibly in contact with it the tendency is to have its various parts forcibly squeezed, pressed, or driven together, the pores closed, and the surfaces united or welded together.

In the probationary state of these patented processes it is impossible to draw any decided conclusions as to their probable results. There is that in Mr. Bessemer's process which has strongly impressed the public mind, and which only the conviction of complete success or failure will satisfy. While the popular view has thus, sometimes with little knowledge of the subject, magnified the discovery far beyond its merits, there have not been wanting others who would divest it of any merit whatever, and treat it as altogether unworthy of serious consideration. As in most other cases, truth seems to lie between these extremes.

We have already seen that the principal impurities in cast-iron consist of carbon, sulphur, phosphorus, silicon, and some other substances of less importance. These substances, Mr. Bessemer asserts, combine with oxygen at a high temperature, forming volatile compounds, which are incapable of again entering into combination with the metal. The principle of Mr. Bessemer's process is to take advantage of this tendency of the substances to unite with oxygen. By forcing atmospheric air into the fluid metal, intense combustion is produced; the volatile gases unite with the oxygen, and disappear through the channels prepared for their exit. This, say some of the objectors, is unsound in theory—that practically neither sulphur nor phosphorus, the two substances most injurious to iron, are separated by the process.

In support of these views, a writer in the "Birmingham Journal," to whom we are indebted for some excellent remarks on this process, some of which have been imported into these pages, thus reiterates his objections. Recurring to objections formerly urged against the process in the pages of the same journal, the writer says:

"Especially important too, is it, that accurate chemical analysis should be resorted to, to show the composition of this iron, and to prove that the new process will truly purge it of sulphur and phosphorus, as we understand Mr. Bessemer to say it will—elements, the presence of one per cent. of which is fatal to the quality of the iron.

"So far as we are aware, this important information has not been communicated to the public; and so long a time has now elapsed that we despair of receiving it from the quarter it was most naturally expected from. In the hope of contributing to the settlement of a question which has already too long disturbed the public mind, we have imposed upon ourselves a task which we think should have been spared us, and present to our readers such an analysis of Mr. Bessemer's iron as we have been daily hoping to see published by that gentleman himself. The specimen we have experimented upon possesses those physical properties which, from repeated descriptions, the public are sufficiently familiar with. The iron consists of an agglutinated mass of large brilliant crystalline grains, possessed of a very imperfect malleability; flattening under the blow of a hammer; but almost invariably cracking at the edges. It is wholly destitute of a fibrous structure, and only after having been repeatedly heated and drawn out in a smith's forge, exhibits the properties of an inferior wrought iron. On analysis it was found to have the following composition:

Iron	98·9
Phosphorus	1·08
Sulphur	0·16
Carbon	0·05
Silicon	traces
	100·12

"This composition is so accordant with the physical properties of iron, that, the composition being given, the chemist would have no difficulty in predicating its more marked characteristics. Its crystalline structure and fusibility are very satisfactorily accounted for. In order more exactly to illustrate the nature of the change effected by Mr. Bessemer's treatment, we append an analysis of refined iron produced at a large establishment in the neighborhood of Birmingham. We are indebted to the courtesy of Dr. Percy for this analysis. It was made in his laboratory by one of his assistants, Mr. Dick. The iron was obtained only a few months ago, and may be regarded as representing the average composition of refined iron as made at the present moment in this neighborhood:

Iron	95·14
Carbon (combined)	3·07
Phosphorus	0·734
Silicon	0·63
Sulphur	0·157
Manganese	trace
Residue, insoluble in hydrochloric acid	0·53
	100·261

The residue, insoluble in hydrochloric acid, yielded:

Silica	0·3
Alumina, with a little peroxide of iron	0·14
	0·44

"In contrasting the change effected by Mr. Bessemer's treatment with that of the refinery, the following particulars force themselves strongly upon our notice. Mr. Bessemer's method removes most effectually the carbon and silicon, while in the refinery these are but little diminished. The carbon is eliminated with a perfection which we should scarcely have thought possible, but we are without information as to the sacrifice at which this has been effected. The amount of iron oxidized by the vivid combustion which Mr. Bessemer induces, we are unable to ascertain. The point which most prominently strikes the chemist in Mr. Bessemer's iron, is the large amount of phosphorus which it contains—an amount utterly fatal, we fear, to the value of Mr. Bessemer's method. His treatment, we suspect, does not sensibly diminish the amount of this element; but this, too, is a point on which we must be dependent on Mr. Bessemer. We have had no opportunity of examining the slag produced in the treatment; but we learn from an eminent chemical authority, that at least one sample of it contains no sensible amount of phosphoric acid. We have previously explained that it is by the puddling process that the phosphorus and sulphur are mainly removed; the chemical examination of the tap-cinder of the puddling furnace disclosing an abundance of phosphoric acid. As yet, so far as we can learn, Mr. Bessemer has done nothing towards the removal of this pernicious element, phosphorus; and in this important respect his process must be regarded as a failure."

We have elsewhere incidentally alluded to the strange oversight committed by the objectors to Mr. Bessemer's process—all allusion to his hammering and squeezing processes are invariable suppressed; consequently certain magical results are expected, to which, as it appears to us, he does not lay claim. On the contrary, his specification distinctly claims the peculiar squeezing and hammering process already described; lateral compression and elongated fibrous expansion being the results sought for. It is true, he only mentions this portion of his improvements incidentally, when he claims for the new process facilities for forming large masses of iron capable of producing bars that could not have been obtained by the old process by means of powerful machinery not yet matured, whereby great labor will be saved and the operation greatly expedited. It is obvious, therefore, that great importance is attached by the patentee to the subsequent operations. Nevertheless, with all our desire to see Mr. Bessemer's process crowned with success, we cannot avoid seeing that it has yet much to overcome. Early in October, Mr. Bessemer sent ingots of his pneumatically refined iron to the Dowlais iron-works, where it was operated upon, the result being a fair-faced iron, equal, apparently, on the outer surface, to any ever rolled. It stood the lever or dead test well; but the sharp blow of the ram, and the sharp squeeze of the eccentric straightener, it could not bear, for which its steely or crystalline structure probably accounts. Practical men observed, that along the surface of the rail a stratum of fibrous iron—evidently the result of elongation through the rolls—presented itself; and this was considered great encouragement for Mr. Bessemer to prosecute his idea to perfection.

In reference to this railway bar, Mr. Bessemer states, that it was rolled direct from a ten-inch square ingot, having passed through the rolls fourteen times. The metal was not previously piled or in any way wrought; but, notwithstanding the extremely difficult section, not the smallest portion of the flange was torn up. To render the fabrication of the same form of rail practicable on the old plan, twice-rolled iron is used to form the flange, and ten shillings per ton extra is being paid for it in consequence.

The process is stated to have been successfully applied to the manufacture of iron for tin-plating. The best puddle-iron has heretofore failed to produce the requisite toughness, and charcoal-smelted iron has in consequence been used for this purpose at a considerable extra cost per ton; but we have examined sheets rolled from ingots prepared by the new process, remarkable for their thinness, and affording proofs of the great ductility and toughness of its product.

We have also inspected, as instances of the extreme tenacity capable of being produced by this process, rolled out metal of such extreme thinness and pliability as to bear, when annealed, a close resemblance in fabric to paper, with much greater toughness and tenacity.

We shall conclude these remarks by quoting the concluding portion of Mr. Bessemer's address to the British Association:—"One of the most important facts," he says, "connected with the new system of manufacturing malleable iron is, that all the iron so produced will be of that quality known as charcoal iron; not that any charcoal is used in its manufacture, but because the whole of the processes following the smelting of it are conducted entirely without contact with, or the use of, mineral fuel. The iron resulting therefrom will, in consequence, be perfectly free from those injurious properties which that description of fuel never fails to impart to iron that is brought under its influence. At the same time, this system of manufacturing malleable iron offers extraordinary facility for making large shafts, cranks, and other heavy masses; it will be obvious that any weight of metal that can be founded in ordinary cast-iron by the means at present at our disposal may also be founded in molten malleable-iron, and be wrought into the forms and shapes required, provided that we increase the size and power of our machinery to the extent necessary to deal with such large masses of metal. A few minutes' reflection will show the great anomaly presented by the scale on which the consecutive processes of iron-making are at present carried on. The little furnaces originally used for smelting ore, have from time to time increased in size, until they have assumed colossal proportions, and are made to operate on 200 or 300 tons of materials at a time, giving out ten tons of fluid metal at a single run. The manufacturer has thus gone on increasing the size of his smelting furnaces, and adapting to their use the blast apparatus of the requisite proportions, and has, by this means, lessened the cost of production in every way; his large furnaces require a great deal less labor to produce a given weight of iron, than would have been required to produce it with a dozen furnaces; and in like manner he diminishes his cost of fuel, blast, and repairs, while he insures a uniformity in the result that never could have been arrived at by the use of a multiplicity of small furnaces. While the manufacturer has shown himself fully alive to these advantages, he has still been under the necessity of leaving the succeeding operations to be carried out on a scale wholly at variance with the principles he has found so advantageous in the smelting department. It is true that hitherto no better method was known than the puddling process, in which from 400 to 500 weight of iron is all that can be operated upon at a time, and even this small quantity is divided into homœopathic doses of some 70 lbs. or 80 lbs., each of which is moulded and fashioned by human labor, carefully watched and tended in the furnace, and removed therefrom one at a time, to be carefully manipulated and squeezed into form. When we consider the vast extent of the manufacture, and the gigantic scale on which the early stages of the progress are conducted, it is astonishing that no effort should have been made to raise the after processes somewhat nearer to a level commensurate with the preceding ones, and thus rescue the trade from the trammels which have so long surrounded it."

CHAPTER IV.

REFINING AND WORKING OF IRON.

THE iron furnaces of the United States are, generally speaking, superior to those of England or the rest of Europe. On this point and for the smelting of iron we refer our readers to "OVERMAN on the MANUFACTURE OF IRON," and will here introduce one of the many American improvements in refining. This is a method of making wrought-iron directly from the ore, patented by ALEXANDER DICKERSON, of Newark, N.J., 22d July, 1850. We have seen some of the iron produced—it is apparently of the best quality.

Of this furnace, Fig. 21 represents a side view when complete. Fig. 22, a longitudinal section of the same. Fig. 23, top view of cylinders, partly open. Figs. 24, and 25, large and small water plates occupying places F and E respectively, through which small jets of water continually flow, to prevent the flame from burning the

Fig. 23.

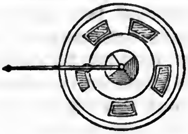
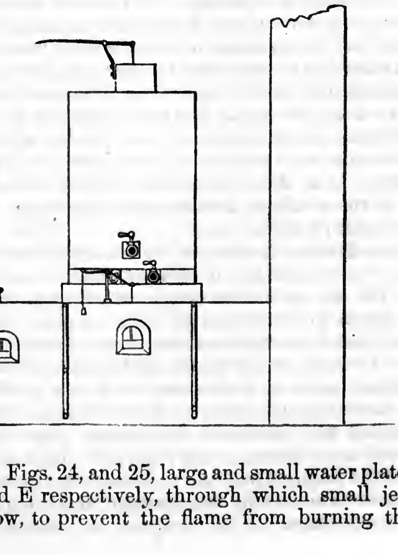
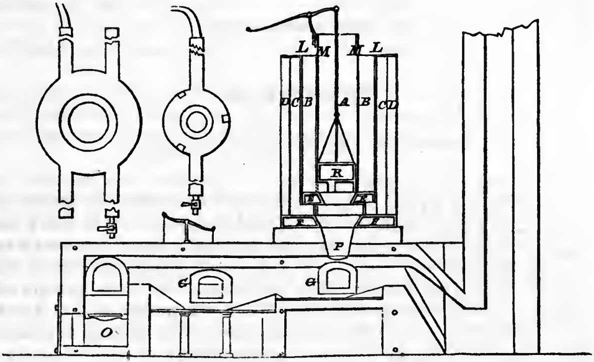


Fig. 21.



cylinders. L and M, two upright cylinders, standing on the water plates; and between which cylinders in space B are placed in equal

Fig. 24. Fig. 25. Fig. 22.



alternate layers, the pulverized ore and charcoal, or 25 per cent. in weight of anthracite if that is substituted for charcoal.

The escape heat passes through an opening P in the arch freely through space C between the masonry work D and the outer cylinder L, and also within the inner cylinder M through space A, whereby the ore mixed with the coal is completely and uniformly surrounded by the flame of heat and deoxidized, and yet perfectly protected from the air, flame and noxious gases. When thus deoxidized, one charge of the ore, by elevating valve R, is readily precipitated on the preparatory bottom G; where it is stirred and freed from the small particles of coal that accompany it from the cylinders. It is then passed over on the puddling bottom G, where it is further stirred and made up into balls, when it is ready for the hammer or rolls.

In the fire chamber O, the heat and flame may be produced from wood, anthracite or bituminous coal.

The whole furnace much resembles an elongated ordinary puddling furnace, with the addition of a preparatory bottom, over which are placed the cylinders and their appendages.

While in operation, the cylinders are charged from the top with the ore and coal pulverized and mixed. The cylinders are kept at a red heat. The ore is thoroughly deoxidized in them, and deposited from them in successive charges on the preparatory and puddling bottoms, as rapidly as the balls are taken from the latter for the hammer or rolls. Thus the operation is continuous and economical, as only the escape heat of the furnace is employed in the cylinders.

The whole is easily managed and worked, the operation is steady, and the product *certain* and *uniform*. The iron produced is represented to be extremely pliable, ductile, and malleable, and applicable to all the arts. It is produced at a saving of about 40 per cent. of any other process. A ton and a half of anthracite coal, and two and half to three tons of ore make a ton of blooms in twelve hours. A furnace complete costs from $1,200 to $1,500.

MANUFACTURE OF MALLEABLE IRON.—Formerly, wrought-iron was obtained either directly from the ore, or from cast-iron, by a process still in extensive operation, in which wood charcoal is required.

PUDDLING.—The crude cast-iron is remelted in quantities of from half a ton to one ton, in a furnace called the chafery, or refinery, blown with blast; it is kept fluid for about half an hour, and then cast into a plate about four inches thick, which is purer, finer in the grain than pig metal, and also much harder and whiter; it is then called *refined metal*. The plate when cold is broken up, and from two to four hundred weight of the fragments, with a certain proportion of lime, are piled on the hearth of the puddling furnace, which is a reverberatory furnace without blast.

In about half an hour the iron begins to melt, and whilst it is in the semi-fluid state, the workman stirs and turns it about with iron tools; he also throws small ladles full of water upon it from time to time. In this condition the metal appears to ferment, and heaves about from some internal change; this is considered to arise from the escape of the carbon in a volatilized form, which ignites at the surface with spirits of blue flame: in about twenty minutes the pasty condition gives way, and the iron takes a granulated form without any apparent disposition to cohesion; the fire is now urged to the utmost, and before the metal becomes a stiff conglomerated mass, the workman divides it into lumps or balls of about fifty pounds in weight.

These balls are taken out one at a time, and *shingled*, or worked under a massive helve or forge-hammer, that weighs six or eight tons, and is moved by the steam-engine: this compresses the ball, squeezes out the loose fluid matter, and converts it into a *bloom*, or short rudely-formed bar. The bloom is then raised to the welding heat in a reheating furnace, and again passed under the hammer, or through grooved rollers, or it is submitted to both processes, by which it is elongated into a rough bar. The shingling is sometimes performed by large squeezers, somewhat like huge pliers, or by roughened rollers that also serve to compress the iron; but the ponderous flat-faced helve is considered the more effectively to expel the dross and foreign matters from the bloom, and to weld the same more perfectly at every point of its length.

The machine for compressing and rolling puddler's balls, invented by John F. Winslow of Troy, New York, is very effective and possesses many advantages, of which may be mentioned: 1.

Great expedition in shingling puddler's iron, one of these machines being sufficient to do the work of twenty-five puddling furnaces. 2. The saving of shinglers' wages; no waste of iron; turning out the blooms while very hot, enabling the roller to reduce them to very sound bars. 3. The ends of the blooms are thoroughly upset, a very small amount of power operates the machine, and little or no expense for repairs.

The nature of the first part of this invention consists in rolling and compressing puddler's balls or loops of iron into blooms, etc,. by means of a rotating cam-formed compresser, combined with two or more rollers placed near to one another, and at the same distance from the axis of motion of the compresser, so that the compression and elongation of the loops will be due entirely to the eccentricity of the compresser, the whole being so geared that the rollers shall turn in the direction opposite to the motion of the compresser, that the loop may be rotated and retained between the rollers and the compresser: the surfaces of the rollers are formed with slight projections to take hold of and turn the loop of iron, and the surface of the cam-formed compresser with teeth, which are very large at first, or on that part of the compresser which first acts on the loop, to squeeze out the impurities, and at the same time insure the turning of the loop, and then gradually diminished until the surface becomes quite or nearly smooth to finish the bloom.

And the second part of this invention consists in combining with the compresser and rollers two cheeks, one on each side, and provided with springs that force them towards one another that they may yield to the ends of the loop of iron as it is lengthened out by the action of the compresser and rollers, and at the same time to make sufficient resistance to give a proper form to the ends of the blooms, etc.

And the third part of this invention consists in combining with the compresser and rollers a feeder or sliding frame, operated by a projection on the compresser or the shaft thereof, to carry in the ball of iron between the compresser and roller, as that part of the compresser which is recessed for that purpose comes round to the proper place for the introduction of the ball, and the discharge of the bloom; and also in combining in like manner a follower for discharging the bloom after it has been completed.

(*a*) represents the frame of the machine properly adapted to the intended purpose, but which may be varied at pleasure. In appropriate boxes (*bb*) between the standards of this frame run the journals of an eccentric roller (*c*), the periphery of which is cam-formed and provided with cogs, for the purpose of squeezing the ball of iron and forcing out the impurities, and gradually reducing its diameter and elongating it. Below this squeezing roller are arranged two fluted rollers (*dd*) whose journals are fitted to appropriate boxes in the frame. These rollers constitute the concave on which the ball of iron rests during the operations of the squeezer; cog wheels (*e f g h*) being employed to connect the shaft of the rollers with the shaft of the squeezer in such a manner that the peripheries of the two rollers (*dd*) shall turn in the same direction, and that of the squeezer in a reverse direction, and thus cause the ball or mass of iron during the operation of squeezing

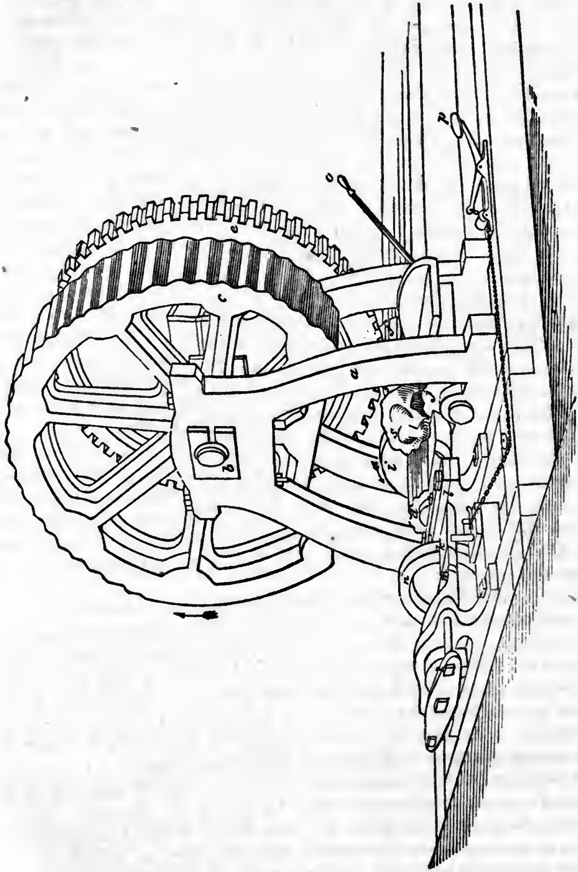


Fig. 26.

to rotate about its axis, or nearly so,—the requisite power for this purpose being communicated to the machine from some first mover in any efficient manner. One of the bottom rollers (*d*) has a strong flanch (*i*) on one side which projects sufficiently to pass within the periphery of that part of the squeezer which acts on the iron, after it has been so much elongated as to have one of its ends approach the flanch, and therefore towards the end of the operation of the squeezer that end of the bloom or mass of iron which is towards this flanch will be upset by it and properly formed. On the side of the machine opposite to the flanch (*i*) is a hammer (*j*) on the end of the bar (*k*) which slides in collars (*l*). The face of this hammer is smooth, and made as hammers for working iron usually are, and its edges are adapted to the peripheries of the two rollers (*dd*) and to that part of the periphery of the squeezer which acts on the bloom at the time the hammer is to strike the ends of the bloom. A strong helical spring surrounds the bar (*k*) of the hammer, one end bearing against one of the collars (*l*), and the other against the back of the hammer, so that its tension will always force the hammer towards the flanch (*i*) of the roller (*d*); and towards the outer end, the said bar (*k*) is provided with a spur (*m*), the inner face of which is slightly rounded to bear against the face of a cam (*n*), so formed that at each revolution of the bottom rollers it gives the hammer two blows upon the bloom, and at every revolution of the rollers the spring is liberated and the hammer strikes the bloom, and thus upsets the ends, the flanch (*i*) in this part of the operation performing the office of an anvil; the face of the cam is then made in the form of an inclined plane to draw back the hammer preparatory to another operation.

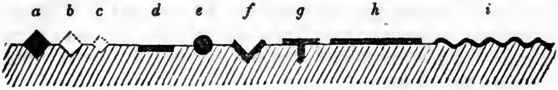
Instead of forcing the hammer towards the bloom by a spring and drawing it back by a cam, this arrangement may be reversed by making the spring simply of sufficient length to draw back the hammer, and reversing the cam that it may force the hammer towards the bloom at the required time. And if desired, a lever, operated in any desired manner, such as by a cam or crank, may be used to operate the hammer instead of a cam, and under this latter modification the spring may be dispensed with altogether by connecting the hammer bar with the lever.

The bars are next cut into short pieces, and piled in groups of four to six; they are again raised to the welding heat in a reheating furnace, and passed through other rollers to weld them throughout their length, and reduce them to the required sizes; and sometimes the processes of cutting and welding are again repeated in the manufacture of still superior kinds of iron.

A similar process of manufacture is still carried on, partly with wood charcoal, in place of coals and coke; the iron thus manufactured, called charcoal iron, is much purer, but it is also more expensive in England; it is sometimes, by way of distinction, left in ridges from the hammer, when it is called dented iron.

The rollers or *rolls* of the iron works are turned of a variety of forms, according to the section of the iron that is to be produced; in general one pair is used exclusively for each form of iron required; although in the imaginary sketch, Fig. 27, it is supposed that the shaded portion represents the upper edge of the bottom roll; and that the top roll, which is not drawn, almost exactly meets the bottom one, with the exception of the grooves, and which are in general turned partly in each roll, in the manner denoted by the black figures.

Fig. 27.



One pair will have a series of angular grooves for square iron, gradually less and less, as *a, b, c,* Fig. 27, so that the bar may be rapidly reduced without the necessity for altering the adjustment of the rolls, which would lose much valuable time; the flat bars are prepared square, and then flattened in grooves, such as that at *d*; round, or bolt iron, requires semicircular grooves, *e*; but round iron often shows a seam down one side, from the thin waste spread out between the rolls being afterwards laid down without being welded, when the iron is turned one quarter round and sent again through the rollers: therefore the best round works are mostly forged from square bars.

Figs. *f* and *g* are described as angle, and T iron; these are particularly used in making boilers, the ribs of iron steam-vessels; also frames, sashes, and various works requiring strength with lightness. Plain cylindrical rollers serve for producing plate and sheet iron, which vary in thickness from one inch to that of writing-paper, and rolls turned like Fig. *i*, are employed for curvilinear ribbed plates, or the corrugated iron, an elegant application lately patented for roofs. Other rollers composed of two series of steeled discs, placed upon spindles, are used to slit thin plates of iron about six inches wide, into a number of small rods for the manufacture of nails, and similar rods are also made of larger sizes called slit iron, they always exhibit two ragged edges, and from being tied up in small parcels, are also known as bundle iron.

Figs. 28 29 30 31 32





Figs. 28, 29, 30 and 31, represent four amongst numerous other sections of railway iron; these bars are produced in rollers turned with counterpart grooves; as before, the shaded portions represent fragments of the lower rollers, and the upper rollers are supposed to occupy the spaces immediately adjoining the section of the rails. For these also, three, four, or more grooves, varying gradually from that of the roughly prepared bar, to that of the finished rail, are employed, and this in like manner saves the necessity for adjusting the distance between the rollers during the progress of the work.

All the foregoing rolls are supposed to be concentric, and to produce parallel bars and plates of the respective sections; but in making fish-bellied railway bars (no longer used), taper plates for coach springs, and similar tapered works, the rollers, whether plain or grooved, are turned eccentrically, so as to make the works respectively thicker or deeper in the middle, as in Fig. 32; this requires additional dexterity on the part of the workman to introduce the material at the proper time of the revolution, upon which it is unnecessary to enlarge.

The general effect of the manufacture of malleable iron is to deprive the cast-iron of its carbon; this is done in the puddling furnace; the original crystalline structure gives way to the fibrous, from the working under the hammer and rollers, by which every individual particle or crystal is drawn out as it were into a thread, the multitude of which constitute the fibrous bar or metallic rope, to which it has some resemblance except in the absence of twist. The rod may now be bent in any direction without risk of fracture; and the superior kinds, even when cold, may be absolutely tied in a knot, like a rope, when a sufficient force is applied.

Should it however occur that the first operation, or shingling process, were imperfectly performed, the error will be extended in a proportional degree throughout the mass, which will account for the general continuance of any imperfection throughout the bar of iron, or a considerable length of the wire in which the reduction or elongation is further extended; and to which evil all metals and alloys subjected to these processes of elongation are also liable.

Malleable iron is divided into three principal varieties. First, red-short iron; secondly, cold-short iron; thirdly, iron partaking of neither of these evils, and which may be so far denominated pure malleable iron.

The first kind is brittle when hot, but extremely soft and ductile whilst cold. This is considered to result from the presence of a little carbon. The cold-short withstands the greatest degree of heat without fusion, and may be forged under the heaviest hammers when hot, but it is brittle when cold. This is attributed to the presence of a little silex. The third kind is considered to be entirely free from either carbon or silex, etc., and to be the pure simple metal; but in the general way the characters of iron are intermediate between those described.

From one and a half to two tons of pig-iron have been used to produce one ton of malleable iron; but the average quantity is now from twenty-six to twenty-seven tons for each twenty tons of produce. The forge pig, ballast, and white cast-iron, is the kind principally used, as it contains least carbon, the whole of which should be ex-expelled in the conversion of the cast metal into wrought-iron.

It appears to be unnecessary to attempt any minute description of the different marks and qualities of iron. First, as these descriptions have been minutely given in many works; and secondly, as in common with most other articles, the quality of iron governs the price.

I will only add, that little can be known of the character of iron from its outside appearance, beyond that of its having been well or ill manufactured, so far as regards its formation into *bars*. The smith is principally guided by the fracture when he *breaks down* the iron, that is, when the bar is nicked on opposite sides with the cold chisel, laid across the anvil upon a strip of iron near to the cut that it may stand hollow, and the blows of the pane of the sledge-hammer are directed upon the cut.

The judgment will be partly formed upon the force thus required in breaking the iron; the weakest and worse kinds will yield very readily,—when small, sometimes even to the blow of the chisel alone, and will then show a coarse and brilliant appearance, entirely granular or crystalline. This iron would be called very common and bad. If, on the other hand, the iron breaks with difficulty, and the line of separation, instead of being moderately flat, is irregular, or presents what may be called a hilly surface, the sides of which have a fibrous structure and a sort of lead-colored or a dull-gray hue, this kind will have a large proportion of *fibre,* and it will be called excellent tough iron. Other kinds will be intermediate, and present partly the crystalline and partly the fibrous appearance, and their relative values will depend upon how nearly they approach the one or other character.

Another trial is the extent to which iron, when slightly nicked, may be bent to and fro without breaking. The coarse brittle kind will scarcely bend even once, whereas superior kinds, especially stub, charcoal, and dented irons, will often endure many deflections before fracture, and when nicked on the outside only and doubled flat together, will bend as an arch and partly split open through the centre of the bar, somewhere near the bottom of the cut made with the chisel, the entire fracture presenting the beautiful fibrous appearance and dull leaden hue before described.

CHAPTER V.

MANUFACTURE OF STEEL.

STEEL is manufactured from pure malleable iron by the process called cementation. The Swedish iron from the Dannemora mines, marked with the letter L in the centre of a circle, and called "Hoop L," is generally preferred. Irons of a few other marks are also used for second-rate kinds of steel. The bars are arranged in a furnace that consists of two troughs, about fourteen feet long and two feet square. A layer of charcoal-powder is spread over the bottom, then a layer of bars, and so on alternately. The full charge is about ten tons. The top is covered over first with charcoal, then sand, and lastly with the waste or slush from the grindstone trough, applied wet, so as to cement the whole closely down, for the entire exclusion of the air.

A coal fire is now lighted below and between the troughs; and at the end of about seven days the bars are found to have increased in weight the one hundred and fiftieth part, by an absorption of carbon, and to present, when broken, a fracture more crystalline, although less shining, than before. The bars, when thus converted, are also covered with blisters, apparently from the expansion of the minute bubbles of air within them; this gives rise to the appellation, blistered steel.

The continuance of the process of cementation introduces more and more carbon, and renders the bars more fusible, and would ultimately cause them to run into a mass if the heat were not checked. To avoid this mischief a bar is occasionally withdrawn and broken to watch the progress; and the work is complete when the cementation has extended to the centre of the bars. The conversion occupies, with the time for charging and emptying the furnace, about fourteen days.

A very small quantity of steel is employed in the blistered state, for welding to iron for certain parts of mechanism, but not for edge-tools. The bulk of the blistered steel is passed through one of the two following processes, by which it is made either into shear-steel or cast-steel.

Shear-steel is produced by piling together six or eight pieces of blistered-steel, about thirty inches long, and securing the ends within an iron ring, terminating in a bar about five feet long by way of a handle. They are then brought to a welding heat in a furnace, and submitted to the helve or tilt hammer, which unites and extends them into a bar called shear-steel, from its having been much used in the manufacture of shears for cloth mills, and also German steel, from having been in former years procured from that country. Sometimes the bars are again cut and welded, and called double-shear steel, from the repetition.

This process of working, as in the manufacture of iron, restores the fibrous character, and retains the property of welding: the shear steel is close, hard, and elastic; it is much used for tools, composed jointly of steel and iron; its superior elasticity also adapts it to the formation of springs, and some kinds are prepared expressly for the same under the name of spring-steel.

In making cast-steel, about twenty-six or twenty-eight pounds of fragments of blistered-steel, selected from different varieties, are placed in a crucible made of clay, shaped like a barrel, and fitted with a cover, which is cemented down with a fusible lute that melts after a time the better to secure the joining. Either one or two pots are exposed to a vivid heat, in a furnace like the brass-founders' air-furnace, in which the blistered-steel is thoroughly melted in the course of three or four hours; it is then removed by the workman in a glowing state, and poured into a mould of iron, either two inches square for bars, or about six by eighteen inches, for rolling into sheet-steel. For large ingots the contents of two or more pots are run together in the same mould, but it requires extremely great care in managing the very intense temperature, that it shall be alike in both or all the pots.

. The ingots are reheated in an open fire much like that of the common forge, and are passed under a heavy hammer weighing several tons, such as those of iron-works; the blows are given gently at first, owing to the crystalline nature of the mass, but as the fibre is eliminated the strength of the blows is increased.

Steel is reduced under the heavy hammer to sizes as small as three-quarters of an inch square. Smaller bars are finished under tilt hammers, which are much lighter than the preceding, move considerably quicker, and are actuated by springs instead of gravity alone; these condense the steel to the utmost. Rollers are also used, especially for steel of round, half-round, and triangular sections, but the tilt hammer is greatly preferred.

Cast-steel is the most uniform in quality, the hardest, and altogether the best adapted to the formation of cutting tools, especially those made entirely of steel; but much of the cast-steel will not endure the ordinary process of welding, but will fly in pieces under the hammer when struck.

In respect to steel, the same general remarks offered upon iron may be repeated, namely, that price in a great measure governs quality. Steel when broken does not show the fibrous character of iron, and in general the harder or *harsher* the steel, the more irregular or the less nearly flat will be its fracture.

The blistered-steel should appear throughout its substance of an uniform appearance, namely, crystalline and coarse, much like inferior iron, but with less lustre and less of the bluish tint; when but partially converted, the film of iron will be readily distinguished in the centre. The blistered-steel when it has been once passed through the fire and well *hammered*, assumes as may be supposed a much finer grain, as in fact the operation converts it (although in the small way) into shear-steel.

Shear-steel breaks with a much finer fracture, but the crystalline appearance is still readily distinguished. Cast-steel is in general the finest of all in its fracture, and unless closely inspected, its separate crystals or granulations should be scarcely observable, but the appearance should be that of a fine, light slaty-gray tint, almost without lustre.

The quality of steel is considerably improved, especially as regards cutting tools, when after being forged it is hammer-hardened, or well worked with the hammer until quite cold, as this tends to close the "pores" and to make the material more dense; above all things excess of heat should be avoided, as it makes the grain coarse and shining, almost like that of bad iron, and which deterioration can be only partially restored, by good sound hammering under a peculiar management. The particular degrees of heat at which different samples of iron and steel, bearing the same name, should be worked, can only be found by trial; and it would be hardly possible to describe the shades of difference.

It would have been incompatible with the nature of this work to have entered more largely into the manufacture of iron and steel, or to have attempted the notice of all the various alloys of steel which have received many attractive denominations, especially when so much has been already written on the subject.

Of all the works published on the manufacture of iron and steel, those of the most importance are "Overman on Iron," Lesley's "Iron Manufacturers' Guide," Truran's "Manufacture of Iron," "Reports of Experiments on Metals for Cannon," by Officers U. S. Army, Captain Rodman's Reports on the same subject, "Karsten on Iron," and Dr. Hartmann's "Iron Manufacturers' Hand Book,"* the two latter in German, and the collection of Mushet's papers, which have appeared in the "Philosophical Magazine" at various times subsequent to 1798, and were collected and published by himself under the title "Papers on Iron and Steel."

Of the more brief and popular accounts of this subject, the best are Aikin's Dictionary of Chemistry and Mineralogy; three volumes on the Manufactures in Metal, in Lardner's Cyclopedia; and Ure's Dictionary of Manufactures and Mines, which contain a very large store of information on the metals generally. The reader will also consult with advantage Aikin's "Illustrations of Arts and Manufactures," and an admirable article in Appleton's "New American Cyclopedia."

CHAPTER VI

FORGING IRON AND STEEL.

In entering upon this subject, which performs so important and indispensable a part in every branch of mechanical industry, it is proposed first to notice some of the general methods pursued, commencing with the heaviest works, and gradually proceeding to those of the smallest proportions. This arrangement however shall not prevent us for greater convenience, giving in a chapter subsequent to this general view, a very thorough one on Wrought-Iron in large Masses, alone.

After this, the management of the fire, and the degrees of heat required for various purposes, will be described; and then the elementary practice of forging will be attempted: those works made principally in one piece will be first treated of, and afterwards such as are composed of two or more parts, and which require the operation of welding.

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* A translation of this important work will shortly appear, from the Industrial Press of Henry Carey Baird, Philadelphia.

The heaviest works of all, are generally heated in air furnaces of various descriptions, some of which resemble but greatly exceed in size those employed in the works where iron is manufactured, and in which the process of forging may be truly considered to commence with the very first blow given upon the *ball*, as it leaves the puddling furnace for being converted into a *bloom.*

At these works, in addition to the ordinary manufacture of bar, plate, and hoop iron in all their varieties, the hammer-men are employed in preparing masses, technically called "*uses*," which mean pieces to be *used* in the construction of certain large works, by the combination or welding of several of these masses. A square shaft, to be used at an iron-works, was made by laying together sixteen square pieces, measuring collectively about twenty-six inches square, and six feet long. These were bound together, and put into a powerful air furnace, and the ends of the group were welded into a solid mass under the heavy hammer weighing five tons; the weld was afterwards extended throughout the length. The paddle-shafts of the largest steam-ships are wrought by successive additions at the one end, as follows: A slab or *use* is welded on one side close to the end, and when drawn down to the common thickness, the additional matter becomes thrown into the length; the next *use* is then placed on the adjoining side of the as yet square shaft, and also drawn into the length, and so on until the full measure is attained.

These ponderous masses are managed with far more facility than might be expected by those who have never witnessed such interesting proceedings. First, the "*heat*" has a long iron rod attached to it in continuation of its axis, to serve as a "*porter*" or guide rod; the mass is suspended under a traversing crane at that point where it is nearly equipoised: the crane not only serves to swing it round from the fire to the hammer, but the traverse motion also moves the work endways upon the anvil, and small changes of elevation are sometimes affected by a screw adjustment in the suspending chain. The circular form is obtained by shifting the work round upon its axis by means of a cross lever fixed upon the porter, and moved by one or two men, so as to expose each part of the circumference to the action of the helve; this is readily done, as the crane terminates in a pulley, around which an endless band of chain is placed, and the work lies within the chain, which shifts round when the work is turned upon the anvil: the precision of the forgings produced by these means is very surprising. (See p. 110).

A similar mode of work is adopted on a smaller scale for many of the spindles, shafts, and other parts of ordinary mechanism, which are forged under the great hammer, often of several bars piled together and *fagoted;* a suitable term, as they are frequently made of a round bar in the centre, and a group of bars of angular section, called *mitre iron*, around the same, which are temporarily wedged within a hoop, somewhat after the manner of a fagot of wood. Such works are likewise made of scrap-iron, which consists of a strange heterogeneous medley of odd scraps and refuse from a thousand works, scarcely two pieces of which are alike.

A number of these fragments are enveloped in an old piece of sheet iron, and held together by a hoop, the mass is raised to the welding heat in a blast or air furnace, and the whole is consolidated and drawn down under the tilt-hammer; one long bar that serves as the porter being welded on by the first blow. The mingling of the fibres in the scrap-iron is considered highly favorable to the strength of the bar produced. The scrap-iron is sometimes twisted during the process of manufacture, to lay all the filaments like a rope, and prevent the formation of *spills*, or the longitudinal dirty seams found on the surface of inferior iron.

Sometimes the formation of the scrap-iron is immediately followed by the production of the shafts and other heavy works for which it is required; at other times the masses are elongated into bars sold under the name of scrap-iron, although it is very questionable if all the iron that is so named is produced in the manner implied.

The long furnaces are particularly well suited to straight works and bars, but when the objects get shorter and of more complex figures, the open fire or ordinary smith's hearth is employed. This, when of the largest kind, is a trough or pit of brickwork about six feet square, elevated only about six inches from the ground; the one side of the hearth is extended into a vertical wall leading to the chimney, the lower end of which terminates in a hood usually of stout plate iron, which serves to collect the smoke from the fire. The back wall of the forge is fitted with a large cast-iron plate, or a *back*, in the centre of which is a very thick projecting nozzle also of iron, perforated for admitting the wind used to urge the fire; the aperture is called the *tuyere*.

The blast is sometimes supplied from ordinary bellows of various forms; at other times, by three enormous air-pumps, which lead into a fourth cylinder or regulator, the piston of which is loaded with weights, so as to force the air through pipes all over the smithy, and every fire has a valve to regulate its individual blast; but the more modern and general plan is the revolving fan, also worked by the engine, the blast from which is similarly distributed.

In some cases the cast-iron forge back is made hollow, that a stream of water may circulate through it from a small cistern; the *water-back* is thereby prevented from becoming so hot as the others, and its durability is much increased. In other cases the air, in its passage from the blowing apparatus, flows through chambers in the back plate so as to become heated in its progress, and thus to urge the fire with *hot blast*, which is by many considered to effect a very great economy in the fuel.

Some heavy works of rather complex form, such as anchors, are most conveniently managed by hand forging; many of these require two gangs of men with heavy sledge-hammers, each consisting of six to twelve men, who relieve each other at short intervals, as the work is exceedingly laborious. Their hammers are swung round and made to fall upon one particular spot with great uniformity; the conductor of this noisy, although dumb concert so far as relates to voice, stands at a respectful distance, and directs the blows of his assistants with a long wooden wand. The Hercules, or crane, used for transferring the work from the fire to the anvil, which is at about the same elevation as the fire itself, is still retained.

The square shanks of anchors are partly forged under a vertical hammer of very simple construction, called a "*monkey*." It consists of a long iron bar running very loosely through an eye or aperture several feet above the anvil, and terminating at foot in a mass of iron, or the ram. The hammer is elevated by means of a chain, attached to the rod and also to a drum overhead, which is put into gear with the engine, and suddenly released by a simple contrivance, when the hammer has reached the height of from two to five feet, according to circumstances. The ram is made to fall upon any precise spot indicated by the wand of the foreman, as it has a horizontal range of some twenty inches from the central position, and is guided by two slight guy rods, hooked to the ram and placed at right angles; the guys are held by two men, who watch the directions given. This contrivance is far more effective than the blows of the sledge-hammers, and although now but little used is perhaps more suitable to such purposes than the helve or lift-hammer, which always ascends to one height, and falls upon one fixed spot.

The square shank of the anchor, and works of the same section, are readily shifted the exact quarter circle, as the sling-chain is made with flat links, each a trifle longer than the side of the square of the work, which, therefore, bears quite flat upon one link, and, when twisted, it shifts the chain the space of a link, and rests as before.

Many implements and tools, such as shovels, spades, mattocks, and cleavers, are partly forged under the tilt-hammer; the preparatory processes, called moulding, which include the insertion of the steel, are done by ordinary hand forging. The objects are then spread out under the broad face of the tilt-hammer, the workman in such cases being sometimes seated on a chair suspended from the ceiling, and, by paddling about with his feet, he places himself with great dexterity in front or on either side of the anvil with the progressive changes of the work: the concluding processes are mostly done by hand with the usual tools. A similar arrangement is also adopted in tilting small-sized steel.

With the reduction of size in the objects to be forged, the number of hands is also lessened, and the crane required for heavy work is abandoned for a chain or sling from the ceiling; but, for the majority of purposes, two men only are required, when the work is said to be *two-handed*. The principal, or the fireman, takes the management of the work both in the fire and upon the anvil; he directs and assists with a small hammer of from two to four pounds weight; the duty of his assistant is to blow the bellows and wield the sledge-hammer, that weighs from about ten to fourteen pounds, although sometimes more, and from which he derives his name of hammer-man.

As the works to be forged become smaller, the hearth is gradually lessened in size, and more elevated, so as to stand about two and a half feet from the ground; it is now built hollow, with an arch beneath serving as the ash-pit to receive the cinders and clinkers. The single hearths are made about a yard square, and those forges which have two fires under the same hood, measure about two yards by one; a double trough, to contain water in the one compartment and coals in the other, is usually added, and the ordinary double bellows is used. In proportion as the hearth is more elevated, so is the anvil likewise, that in ordinary use standing about two feet or two and a half feet from the ground, its weight being from two to four hundred-weight.

Numerous small works are forged at once from the end of the bar of iron, which then also serves the office of the *porter* required for heavy masses; but when the small objects are cut off from the bar, or the pieces are too short to be held in the hand, tongs of different forms are needful to grasp the work. These are made of various shapes, magnitudes, and lengths according to circumstances; but the annexed figures will serve to explain some of the most general kinds, although variations are continually made in their form to meet peculiar cases.

Figs. 33 and 34 are called *flat-bit* tongs; these are either made to fit very close, as in Fig. 34, for thin works, or to stand more open, as in Fig. 33, for thicker bars, but always parallel; and a ring, or coupler, is put upon the handles, or *reins*, to maintain the grip upon the work; others of the same general form are made with hollow, half-round bits; but it is much better they should be angular, like the ends of Fig. 35, as then they serve equally well for round bars,

Figs. 34.

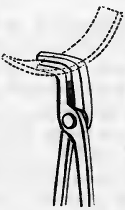
35.

36.

37.

38.

39.



40.

Fig. 33.

or for square bars held upon their opposite angles. Tongs that are made long, and swelled open behind, as in Fig. 35, are very excellent for general purposes, and also serve for bolts and similar objects with the heads placed inwards. The *pincer* tongs, Fig. 36, are also applied to similar uses, and serve for shorter bolts.

Fig. 37 represents tongs much used at Sheffield, amongst the cutlers; they are called *crook-bit* tongs; their jaws overhang the side so as to allow the bar of iron or steel to pass down beside the rivet, and the nib at the end prevents the rod from being displaced by the jar of hammering; these are very convenient. Fig. 38, or the *hammer* tongs, are used for managing works punched with holes, such as hammers and hatchets: as the pins enter the holes, and maintain the grasp, they should be made stout and long, so as to admit of being repaired from time to time, as the bits get destroyed by the fire.

Fig. 39, or *hoop* tongs, are very much used by ship-smiths, for grasping hoops and rings, which may be then worked either on the edge, when laid flat on the anvil, or on the side when upon the beak-iron: and lastly, Fig. 40 represents the smith's *pliers*, or light tongs, used for picking up little pieces of iron, or small tools and punches, many of which are continually driven out upon the ground in the ordinary course of work; they are also convenient in hardening small tools.

In addition to the hearth, anvil, and tongs, the smithy contains a number of chisels, punches, and swages or striking tools, called also top and bottom tools, of a variety of suitable forms and generally in pairs; these may be considered as reduced copies of the grooves turned in the rollers, and occasionally made on the faces of the tilt-hammers of the iron-works for the production of square, flat, round, T form iron, angle iron, and railway bars, as referred to. The bottom tools of the ordinary smith's shop, have square tangs to fit the large hole in the anvil; in using them the fireman holds the work upon the bottom tool, and above the work he places the top or rod tool, which is then struck by the sledge-hammer of his assistant.

In fitting the hazel rods to the top tools the rods are alternately wetted in the middle of their length, and warmed over the fire to soften them, that portion is then twisted like a rope, and the rod is wound once round the head of the tool and retained by an iron ferrule or coupler; a rigid iron handle would jar the hand.

When these tools are used for large works, a square plate of sheet-iron, with a whole punched in the middle of it, is put on the rod towards the tool, to shield the hand of the workman from the heat; and it not unfrequently happens with such large works that the rod catches fire, and the tool is then dipped at short intervals in the slake trough to extinguish it.

The smith who works without any helpmate is much more circumscribed as to tools, and he is from necessity compelled to abandon all those used in pairs, unless the upper tools have some mechanical guide to support and direct them. In addition to the anvil he only uses the fixed cutter and heading tools; he may occasionally support the end of the tongs in a hook attached to his apron-string, or suspended from his neck, whilst he applies a hand-chisel, a punch, or a name-mark in the left hand, and strikes with the hammer held in the right. The method is however ample for a variety of small works, such as cutlery, tools, nails, and small ironmongery, which are wrought almost exclusively by the hand-hammer.

Attempts to work small tilt-hammers with the foot have been found generally ineffective, as the attention of the individual is too much subdivided in managing the whole, neither is his strength sufficient for a continued exertion at such work; but the "*Oliver*," which we shall now describe, is one of the best tools of this class.

THE OLIVER, OR SMALL LIFT-HAMMER.—Fig. 41 represents a species of lift-hammer worked by the foot. The hammer head is about two and a half inches square and ten long, with a swage tool having a conical crease attached to it, and a corresponding swage is fixed in a square cast-iron anvil block, about twelve inches square, and six deep, with one or two round holes for punching, etc. The hammer handle is about two to two and a half feet long, and mounted in a cross spindle nearly as long, supported in a wooden frame between end screws, to adjust the groove in the hammer face to that in the anvil block. A short arm, five or six inches long, is attached to the right end of the hammer axis, and

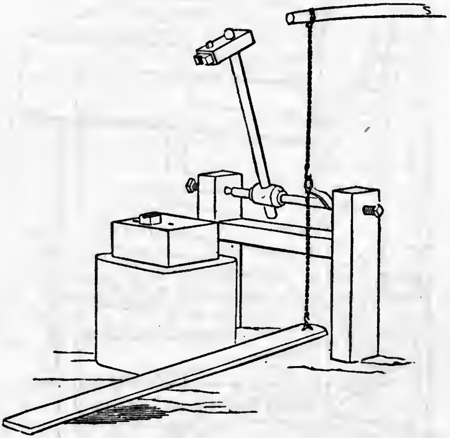


Fig. 41.

from this arm proceeds a cord to a spring pole overhead, and also a chain to a treadle a little above the floor of the smithy.

When left to itself the hammer handle is raised to nearly a vertical position by the spring, and it is brought down very readily with the foot, so as to give good hard blows at the commencement of moulding the objects, and then light blows for finishing them. The machine was used when the author first saw it, in making long stout nails, intended for fixing the tires of wheels, secured within the felloes by washers and riveting; the nails were made very nicely round and taper, and were forged expeditiously.

For single hand-forging, the fire becomes still further reduced in size, and proportionally elevated from the ground. A portable forge of suitable dimensions for such work, and made entirely of iron, is represented in Fig. 42. The bellows are placed beneath the hearth and worked by a treadle.

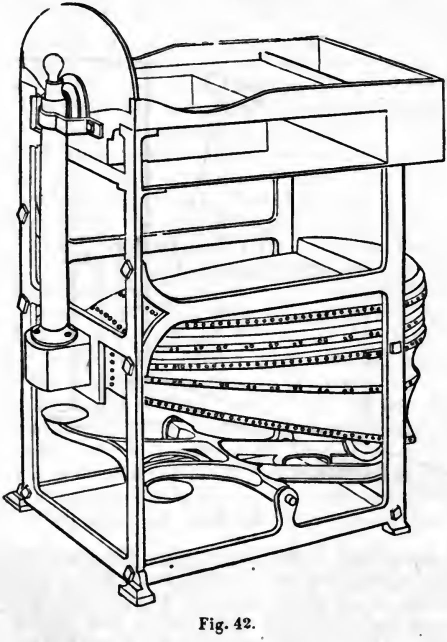


Fig. 42.

This forge is also occasionally fitted with a furnace for melting small quantities of metal, and with various apparatus for other applications of heat, such as soldering, either with a small charcoal fire, or a lamp and blowpipe, which are likewise urged with the bellows. These applications, and also that of hardening and tempering tools, which will be severally returned to at their respective places, are much facilitated by the bellows being worked with the foot, as it leaves both hands at liberty for the management either of the work or fire, with the so-called fire-irons, which include a poker, a slice or shovel, and a rake, in addition to the supply of tongs of some of the former shown.

The forge represented is sufficiently powerful for a moderate share of those works which require the use of the sledge-hammer; but, when the latter tool is used, the anvil should not fall short of one hundred pounds in weight; and the heavier it is, the less it will rebound under the hammer.

MANAGEMENT OF THE FIRE: THE DEGREES OF HEAT.—The ordinary fuel for the smith's forge is coal, and the kinds to be preferred are such as are dense and free from metallic matters, as these are generally accompanied with sulphur, which is highly detrimental.

Copper is usually forged in a coke fire—silver and gold in those made of charcoal; but the hearths do not materially differ from those used for iron. Compressed peat charcoal has been strongly recommended on account of its freedom from sulphur—one of the greatest enemies in nearly all metallurgic operations.

The fire is sometimes made open, at other times hollow, or like a tunnel; and the larger the fire is required to be, so much the more distant is it situated from the *tuyere* iron. Before lighting the fire, the useful cinders are first turned back on the hearth, and the exhausted dust or *slack* is cleared away from the iron back and thrown into the ash-pit; a fair-sized heap of shavings is then lighted, and allowed to burn until the flame is nearly extinguished, when the embers are covered over with the cinders, and the bellows are urged A dense white smoke first rises, and, in two or three minutes, the flame bursts forth, unless the fire be choked, when the poker is carefully passed into the mouth of the tuyere. The work is now laid on the fire, and covered over with green or fresh coals, which are beaten around the tuyere and the work, the blast being continued all the while; the whole mass will soon be in a state of ignition. A heap of fresh coals is always kept at the outside wall of the fire, and they are gradually advanced at intervals into the centre of the flame to make up for those consumed.

In making a large hollow fire, after a good-sized fire has been lighted in the ordinary way, the ignited fuel is brought forward on the hearth to expose the tuyere iron, into the central aperture of which the poker is introduced. A mass of small wetted coal is beaten hard round the poker to constitute the *stock*, the magnitude of which will depend on the distance at which the fire is required to stand off, and a second stock is also made opposite the first, the two resembling two hills with the lighted fuel lying between them. The durability of the fire will depend on the stocks being hard rammed, which, for large works, is often done with the sledge-hammer. The work is now laid in the hollow just opposite the blast-pipe, and covered on its two sides and top with thin pieces of wood, and a heap of wetted coals is carefully banked up around the same and beaten down with the slice or shovel. When carefully done, the heap is made to assume the smooth form of an embankment of earthwork. The bellows are blown gently all the time, and the work is not withdrawn until the wood is consumed, and the flame peeps through at each end of the aperture, so as to cake the coals well together into a hard mass; after which the work may be removed or shifted about without any risk of breaking down the fire.

In localities where wood is scarce, small iron rods are placed around the principal mass, often designated the *heat;* the small rods are first withdrawn when the fire has burned up, to allow room for the removal of the work.

Sometimes when a fire is required only for hardening, the centering of the arch is made entirely of wood, either in one or several pieces: and in this manner it may be built of any required form, as angular for knees, circular for hoops, and so on (although such works are usually done in open fires, which resemble the above in all respects, except the covering-in or roof): small coal is thrown at intervals into the hollow fire to replace that which is burned, and by careful management one of these combustible edifices will last half a day, or even the entire day, without renewal. Occasionally, the stock around the tuyere iron will serve with a little repair for a second day, if, when the fire is turned back at night, that part is allowed to remain, and the fire is extinguished with water.

When a small hollow fire is required, the same general methods are less carefully followed, and an iron tube introduced amidst the coals, makes a very convenient muffle or oven for some purposes.

In forging, the iron or steel is in almost every case heated to a greater or less degree, to make it softer and more malleable by lessening its cohesion; the softening goes on increasing with the accession of temperature, until it arrives at a point beyond that which can be usefully employed, or at which the material, whether iron or steel, falls in pieces under the blows of the hammer, but which degree is very different with various materials, and even with varieties bearing the same name.

Pure iron will bear an almost unlimited degree of heat. The hot short iron bears much less, and is in fact very brittle when heated. Other kinds are intermediate. Of steel, the shear-steel will generally bear the highest temperature, the blistered-steel the next, and the cast-steel the least of all. But all these kinds, especially cast-steel, differ very much according to the processes of manufacture, as some cast-steel may be readily welded, but it is then somewhat less certain to harden perfectly.

Without attempting any refined division, I may add, the smith commonly speaks of five degrees of temperature, namely:

The black-red heat, just visible by daylight;
The low-red heat;
The bright-red heat, when the black scales may be seen;
The white-heat, when the scales are scarcely visible;
The welding-heat, when the iron begins to burn with vivid sparks.

Steel requires on the whole very much more precaution as to the degree of heat, than iron. The temperature of cast-steel should not generally exceed a bright-red heat; that of blistered and shear-steel that of a moderate white-heat. Although steel cannot in consequence be so far softened in the fire as iron, and is therefore always more dense and harder to forge; still from its superior cohesion it bears a much greater amount of hard work under the hammer when it is not over-heated or burned; but the smallest available temperature should be always employed with this material, as in fact with all others.

It has been recommended to try by experiment the lowest degree of heat at which every sample of steel will harden, and in forging always to keep a trifle below that point. This proposal however is rarely tried, and still less followed, as the usual attempt is to lessen the labor of forging by softening the steel so far as it is safely practicable.

Iron is more commonly worked at the bright-red and the white-heats, the welding-heat being reserved for those cases in which welding is required; or others in which, from the great extension or working of the iron, there is risk of separating its fibres or laminæ, so as to cause the work to become unsound or hollow from the disrupture of its substance; whereas the same processes being carried on at the welding temperature, the work would be kept sound, as every blow would effect the operation of welding rather than that of separation. The cracks and defects in iron are generally very plainly shown by a difference in color at the parts when they are heated to a dull-red. This method of trial is often had recourse to in examining the soundness both of new and old forgings.

When a piece of forged work is required to be particularly sound, it is a common practice to subject every part of the material in succession to a welding heat, and to work it well under the hammer, as a repetition of the process of manufacture to insure the perfection of the iron; this is technically called *taking a heat over it*—in fact, a heat is generally understood to imply the welding heat. For a two-inch shaft of the soundest quality, two and a half inch iron would be selected, to allow for the reduction in the fire and the lathe. Some also twist the iron before the hammering to prevent it from becoming "*spilly.*"

The use of sand sprinkled upon the iron is to preserve it from absolute contact with the air, which would cause it to waste away from the oxidation of its surface, and fall off in scales around the anvil. If the sand is thrown on when the metal is only at the full red heat it falls off without adhering; but, when the white heat is approached, the sand begins to adhere to the iron; it next melts on its surface, over which it then runs like fluid glass, and defends it from the air. When this point has been rather exceeded, so that the metal nevertheless begins to burn with vivid sparks and a hissing noise like fireworks, the welding temperature is arrived at, and which should not be exceeded. The sparks are, however, considered a sign of a dirty fire or bad iron, as the purer the iron the less it is subject to waste or oxidation, in the course of work.

In welding two pieces of iron together, care must be taken that *both* arrive at the welding heat at the same moment; it may be necessary to keep one of the pieces a little on one side of the most intense part of the fire (which is just opposite the blast), should the one be in advance of the other. In all cases, a certain amount of *time* is essential, otherwise, if the fire be unnecessarily urged, the outer case of the iron may be at the point of ignition before the centre has exceeded the red heat. In welding iron to steel, the latter must be heated in a considerably less degree than the iron, the welding heat of steel being lower from its greater fusibility. But the process of welding will be separately considered under a few of its most general applications, when the ordinary practice of forging has been discussed, and to which we will now proceed.

◆

ORDINARY PRACTICE OF FORGING.

THE general practices of forging works from the bar of iron or steel are, for the most part, included in the three following modes; the first two occur in almost every case, and frequently all three together, namely:

By *drawing-down*, or reduction;

By *jumping*, or *up-setting;* otherwise, thickening and shortening;

By *building-up*, or welding.

When it is desired to reduce the general thickness of the object, both in length and width, then the flat face of the hammer is made to fall level upon the work; but, where the length or breadth alone is to be extended, the pane or narrow edge of the hammer is first used, and its blows are directed at the right angles to the direction in which the iron is to be spread. To meet the variety of cases which occur, the smith has hammers in which the panes are made in different ways—either at right angles to the handle, parallel with the same, or oblique.

In order to obtain the same results with more precision and effect, tools of the same characters, but which are struck with the sledge-hammer, are also commonly used. Those with flat faces are made like hammers, and usually with similar handles, except that, for the convenience of reversing them, they are not wedged in; these are called *set-hammers*; others, which have very broad faces, are called *flatters;* and the top tools, with narrow round edges like the pane of the hammer, are called *top-fullers.* They all have the ordinary hazel rods.

When the sides of the object are required to be parallel, and it is to be reduced both in width and thickness, the flat face of the hammer is made to fall parallel with the anvil, as represented in Fig. 43, or oblique, for producing taper pieces, as in Fig. 44, and, action and reaction being equal, the lower face of the work receives the same absolute blow from the anvil as that applied above by the hammer itself. It is not requisite, therefore, to present every one of the four sides to the hammer, but any two at right angles to each other. This is only true for works of moderate dimensions; in large masses, such as anchors, the soft doughy state of the metal acts as a cushion, and greatly lessens the recoil of the anvil, and on this account such works are presented to the hammer on all four sides. It is also very injudicious in such cases to continue the exterior finish, or *battering-off*, too long, as this extends the outer case of the metal more than the inner part, and sometimes separates the two. When imperfect forgings are broken in the act of being proved, the inner bars are sometimes found not to be even welded together, and the outside part is a detached sheath, almost like the rind or bark of a tree.

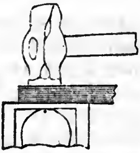
In twisting the work round the quarter circle, some practice is called for, in order to retain the rectangular section, and not to allow it to degenerate into the lozenge or rhomboidal form, which error it is difficult to retrace.

This indeed may be considered the first stumbling-block in forging, and one for which it is difficult to provide written rules. Of course in converting a round bar into a square with the hammer, the accuracy will depend almost entirely upon the change of exactly ninety degrees being given to the work, and this the experienced smith will accomplish with that same degree of feeling, or intuition, which teaches the exact distances required upon the finger-board of a violin, which is defined by habit alone.

In the original manufacture of the iron, the carefully turned grooves, *a, b, c,* of the rollers, page 81, produce the square figure with great truth and facility; and under the tilt-hammer the two opposite sides are sure to be parallel, from the respective parallelism of the faces of the hammer and anvil; and the tietrs, from constant practice, apply the work with great truth in its second position. So that under ordinary circumstances the prepared materials are true and square, and the smith has principally to avoid losing that accuracy.

First, he must acquire the habit of *feeling* when the bar lies perfectly flat upon the anvil, by holding it slenderly, leaving it almost to rotate in his grasp, or in fact to place *itself*. Next, he must cause the hammer to fall flat upon the work; with which view he will neither grasp its handle close against the head of the hammer, nor at the extreme end of the handle, but at that intermediate point where he finds it comfortably to rebound from the anvil, with the least effort of, or jar to his wrist. And the height of the wrist must also be such as not to allow either the front or back edge of the hammer-face to strike the work first, which would indent it, but it must fall fair and parallel, and without bruising the work.

Figs. 43.



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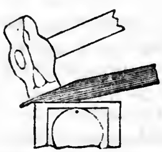

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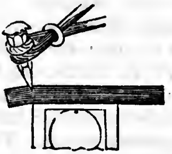


It would be desirable practice to hammer a bar of cold iron, or still better one of steel, as there would be more leisure for observation, the indentations of the hammer could be easily noticed; and if the work, especially steel, were held too tightly, or without resting fairly on the anvil, it would indicate the error by additional noise and by jarring the wrist; whereas, when hot, the false blows or positions would cause the work to get out of shape, without such indications.

As to the best form of the hammer, there is much of habit and something of fancy. The ordinary hand-hammer is represented in Figs. 43 and 44, but most tool makers prefer the hammer without a pane, and with the handle quite at the top, the two forming almost a right angle, or from that to about eighty degrees; and sometimes the head is bent like a portion of a circle. Similar but much heavier hand-hammers, occasionally of the weight of twelve or fourteen pounds, are used by the spade-makers for planishing; but the work being thin and cold, the hammer rises almost exclusively by the reaction, and requires little more than guidance. Again, the farriers prefer for some parts of their work, a hammer the head of which is almost a sphere; it has two flat faces, one rounded face for the inside of the shoe, and one very stunted pane at right angles to the handle, used for drawing down the clip in front of the horse-shoe; in fact, nearly a small volume might be written upon all the varieties of hammers.

To return to the forging: the flat face of the hammer should not only fall flat, but also centrally upon the work; that is, the centre of the hammer, in which point the principal force of the blow is concentrated, should fall on the centre of the bar otherwise that edge of the work to which the hammer might lean would be the more reduced, and consequently the parallelism of the work would be lost. It would also be bent in respect to length, as the thinned edge would become more elongated, and thence convex; and when the blows were irregularly scattered, the work would become twisted or put in winding, which would be a still worse error.

I will suppose it required to *draw down* (the technical term for reduction), six inches of the end of a square or rectangular bar of iron or steel; the smith will place the bar across the anvil with perhaps four inches overhanging, and not resting quite flat, but tilted up about a quarter or half an inch at the near side of the anvil, as in Fig. 44, but less in degree, and the hammer will be made to fall as there shown, except that it will be at a very small angle with the anvil.

Having given one blow, he will as the only change, twist the work a quarter turn, and strike it again; then he will draw the bar half an inch or an inch towards him, and give it two more similar blows, and so on until he arrives at the extreme end, when he will recommence; but this will be done almost in the time of reading these words. The descent of the hammer, the *drawing* the work towards himself (whence perhaps the term), and the quarter turn backwards and forwards, all go on simultaneously and with some expedition. At other times the work is drawn down over the beak iron, in which case the curvature of this part of the anvil makes it less material at what angle the work is held or the blows given, provided the two positions be alike.

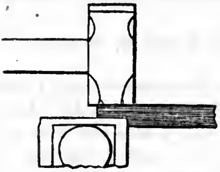
In smoothing off the work, the position of Fig. 43 is assumed; the work is laid flat upon the anvil, and the hammer is made to fall as nearly as possible horizontally; a series of blows are given all along the work between every quarter turn, the hammer being directed upon one spot, and the work drawn gradually beneath it.

The circumstances are exactly the same as regards the sledge-hammer, which is used *up-hand* for light work; the right hand being slid towards the head in the act of lifting the hammer from off the work, and slipped down again as the tool descends; and the conditions are scarcely altered when the smith swings the hammer about in a circle, the signal for which is "*about sledge;*" whereas when, in either case, the blows of the sledge hammer are to be discontinued, the fireman taps the anvil with his hand-hammer, which is, I believe, an universal language.

In drawing down the tang or taper-point of a tool, the extreme end of the iron or steel is placed a little beyond the edge of the anvil, as in Fig. 44 by which means the risk of indenting the anvil is entirely removed, and the small irregular piece in excess beyond the taper is not cut off until the tang is completed. Fig. 45 shows the position of the chisel in cutting off the finished object from the bar of which it formed a part; that is, the work is placed betwixt the edge of the anvil, and that of the chisel immediately above the same; the two resemble in effect a pair of shears. Sometimes the edge of the anvil alone is used for small objects, first to indent, and then to break off the work, but this is likely to injure the anvil, and is a bad practice.

When it is required to make a *set-off,* it is done by placing the intended shoulder at the edge of the anvil: the blows of the hammer will be effective only where opposed to the anvil, but the remainder of the bar will retain its full size and sink down, as represented in Fig. 46. Should it be necessary to make a shoulder on both sides, a flat-ended set hammer, struck by the sledge, is used for *setting* down the upper shoulder, as in Fig. 47, as the direct blows of the hammer could not be given with so much precision. In each of these cases some precaution must be observed, as otherwise the tools, although so much more blunt than the chisel, Fig. 45, will resemble it in effect, and cripple or weaken the work in the corner. On this account the smith's tools are rarely quite sharp at the angles. This mischief is almost removed when the round fullers, Fig. 48, are used for reducing the principal bulk, and the sharper tools are only employed for trimming the angles with moderate blows.

Figs. 46



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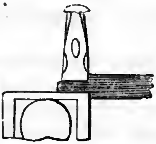

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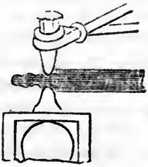
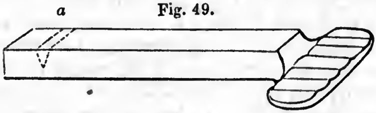


When the iron is to be set down, and also spread laterally, as in Fig. 49, it is first nicked with a round fuller as upon the dotted line at *a*, and the piece at the end is spread by the same tool, upon the short lines of the object, or parallel with the length of the bar. The first notch greatly assists in keeping a good shoulder at the bottom of the part set down, and the lines are supposed to represent the rough indications of the round fuller before the work is trimmed up.

Fig. 49.

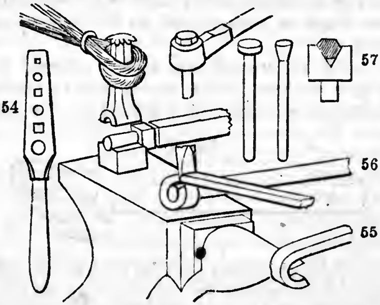


There is often considerable choice of method in forging, and the skillful workman selects that method of proceeding which will produce the result with the least portion of manual labor. Thus an ordinary screw-bolt, that I will suppose to measure five-eighths of an inch in diameter in the stem, and one inch square in the head, may be made in either of the three following ways adverted to in the outset:

First, by drawing-down:—A bar of iron is selected one inch square, or of the size of the *head* of the bolt, and a short portion of the same is set down, according to Fig. 48, by a pair of fullers that are convex in profile as shown, and also slightly concave upon the line at right angles to the paper. This prepares the shoulder or joining of the two dimensions. The bolt is made cylindrical, and of proper diameter between the rounding tools, Fig. 50; and lastly, it is cut off with the chisel, as in Fig. 45, so much of the original square bar as suffices for the thickness of the head being allowed to remain.

Secondly, by jumping:—A piece of bolt-iron of five-eighths of an inch in diameter, or of the size of the *stem* of the bolt, is cut off somewhat longer than the intended length: "*a short heat*" is taken upon it, that is, the extreme end alone is made white-hot, then placed perpendicularly upon the anvil, and the cold end is struck with the hammer as in driving in a nail. This thickens the metal or upsets it, and makes a thick conical button. The head is completed by driving the bolt into a heading tool with a circular hole of five-eighths diameter. The thickened part of the head prevents the piece from passing through, and the lump is flattened out by the hammer into an irregular button or disk, which is afterwards beaten square to complete the bolt. Figs. 51, 52, and 53, explain these processes. The latter is a single tool, but the heading tool, Fig. 54, with several holes, is also used.

Figs. 50 53 52 51



In upsetting the end of the work, if more convenient, it may be held horizontally across the anvil and struck on the heated extremity with the hand hammer; or it can be jumped forcibly upon the anvil, when its own weight will supply the required momentum. If too considerable a portion of the work is heated, it will either bend, or it will swell generally; and therefore to limit the enlargement to the required spot, should the heat be too long, the neighboring part is partially cooled by immersing it in the water trough, as near to the heat as admissible.

Thirdly, the same bolt may be made by building-up or welding:—An eye is first made at the end of a small rod of square or flat iron; by bending it round the beak iron, as in Fig. 55, it is placed around the rod of five-eighths round iron, and the curled end is cut off with the chisel, as in Fig. 56, enough iron being left in the ring, which is afterwards *welded* to the five-eighths inch rod to form the head of the bolt, by a few quick light blows given at the proper heat. The bolt is then completed by any of the tools already described that may be preferred. A swage at the angle of sixty degrees, Fig. 57, will be found very convenient in forming hexagonal heads, as the horizontal blow of the hammer completes the equilateral triangle, and two positions operate on every side of the hexagon; Fig. 57 is essential likewise in forging triangular files and rods.

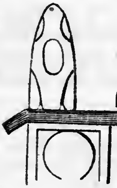
Of these three modes of making a bolt, and which will apply to a multitude of objects somewhat analogous in form, the first is the most general for small and short bolts; the second for small but longer kinds; and the third is perhaps the most common for large bolts, although the least secure; it is used for bolts for ordinary building purposes, but is less generally employed for the parts of mechanism.

For works of the same character, in which a considerable length of two different sections or magnitudes of iron are required, the method by drawing down from the large size would be too expensive; the method by upsetting would be impracticable; and therefore a more judicious use is made of the iron store, and the object is made in two parts, of bars of the exact sections respectively. The larger bar is reduced to the size of the smaller, generally upon the beak iron with top fullers, and with a gradual transition or taper extending some few inches, as represented in Fig. 58; the two pieces are *scarfed* or prepared for welding, but which part of the subject is for the present deferred, in order that the different examples of welding may be given together.

The Fig. 58 is also intended to explain two other proceedings very commonly required in forging. Bars are bent down at right angles as for the short end or corking of the piece, Fig. 58, by laying the work on the anvil, and holding it down with the sledge-hammer, as in Fig. 59; the end is then bent with the hand-hammer, and trimmed square over the edge of the anvil; or when more precision is wanted, the work is screwed fast in the tail-vice, which is one of the tools of every smith's shop, and it is bent over the jaws of the vice. When the external angle, as well as the internal, is required to be sharp and square, the work is reduced with the fuller from a larger bar to the form of Fig. 60, to compensate for the great extension in length that occurs at the outer part, or *heel* of the bend, of which the inner angle forms as it were the centre.

The holes in Fig. 58, for the cross bolts, are made with a rod-punch, which is driven a little more than half way through from the one side whilst the work lies upon the anvil, so that when turned over, the cooling effect of the punch may serve to show the place where the tool must be again applied for the completion of the hole; the little bit or *burr* is then driven out, either through the square hole in the anvil that is intended for the bottom tools, or else upon the bolster, Fig. 61, a tool faced with steel, and having an aperture of the same form and dimensions as the face of the punch.

Figs. 59



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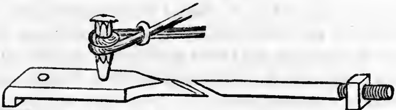

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64

60

65

Fig. 64 shows the ordinary mode of making the square nuts for bolts. A flat bar is first nicked on the sides with the chisel, then punched, and the rough nuts if small, are separated and strung upon the end of the poker (a slight round rod bent up at the end), for the convenience of managing them in the fire, from which they are removed one at a time when hot, and finished on the triblet, Fig. 65, which serves both as a handle, and also as the means of perfecting the holes.

For making hexagon nuts, the flat bar is nicked on both edges with a narrow round fuller; this gives a nearer approach to the hexagon: the nuts are then flattened on the face, punched, and dressed on the triblet within the angular swage, Fig. 57, before adverted to. Thick circular collars are made precisely in the same way, with the exception that they are finished externally with the hammer, or between top and bottom rounding tools of corresponding diameter.

It is usual in punching holes through thick pieces, to throw a little coal-dust into the hole when it is partly made, to prevent the punch sticking in so fast as it otherwise would: the punch generally gets red-hot in the process, and requires to be immediately cooled on removal from the hole.

In making a socket, or a very deep hole in the one end of a bar, some difficulty is experienced in getting the hole in the axis of the bar, and in avoiding to burst open the iron; such holes are produced differently, by sinking the hole as a groove in the centre of a flat bar by means of a fuller; the piece is cut nearly through from the opposite side, folded together lengthways, and welded. The hole thus formed will only require to be perfected by the introduction of an appropriate punch, and to be worked on the outside, with those tools required for dressing off its exterior surface, whilst the punch remains in the hole to prevent its sides from being squeezed in : this method is very good.

For punching square holes, square punches and bolsters are used, and Fig. 62, the split bolster, is employed for cutting out long rectangular holes or mortises, which are often done at two or more cuts with an oblong punch.

Mortises, when of still greater length, are usually made by punching a hole of their full width at each end, and cutting out a strip of metal between them, by two long incisions made with the rod-chisel; at other times one cut only is made, and the mortise is *opened out;* this retains all the iron, but makes the ends narrower than the middle. In finishing a mortise, a parallel plate or drift is inserted in the slit; the drift is laid across the chaps of the vice, whilst the bar of iron lies partly between its jaws, in order that the blows of the hammer may be effective, on the upper and under surfaces of the one rib at the same time. The drift serves as a temporary anvil; the other rib is completed in the same manner, and the work is finally closed to its true width upon the anvil, the drift still lying in the mortise.

When a thick lump is wanted at the end of a bar, it is often made by cutting the iron nearly through and doubling it backwards and forwards, as in Fig. 63; the whole is then welded into a solid mass as the preparatory step.

Fig. 66.

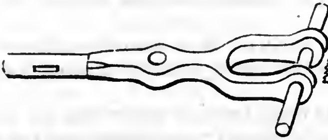
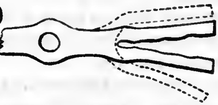


Fig. 67.



A piece with three tails, such as Fig. 66, is made from a large square bar; an elliptical hole is first punched through the bar, and the remainder is split with a chisel, as in Fig. 67, the work at the time being laid upon a soft iron cutting plate in order to shield the chisel from being driven against the hardened steel face of the anvil; the end is afterwards opened into a fork, and moulded into shape over the beak-iron, as indicated by the dotted lines.

The concave lines about the object are principally worked with the fuller, or half-round set-hammer; and in making all the holes, narrow oval punches are used as described at the commencement, and the slits are enlarged into circular holes by conical mandrels; these bulge the metal out, and the holes are more judiciously formed in this manner than if the metal were wasted by cutting out great circular holes, which would sever a large quantity of the fibres and reduce the strength

The mandrels are left in the holes whilst the parts around them are finished, which tends to the perfection of both parts; as the holes more closely copy the mandrels, and the marginal parts are better finished when the apertures are for the time rendered solid. Supposing a hole to be wanted in the cylindrical part of the work that should be finished between the rounding tools, the mandrel could not be allowed to remain in; and therefore a short piece of iron is forged or *drawn down* to the size of the hole, cut off in length to the diameter of the part, and inserted in the hole to preserve it from being compressed, yet without interference with the completion of the cylindrical portion; which accomplished, this little bit, called by the un-mechanical name of a *devil*, is driven out, unless by a very careless use of the welding temperature it should have been permanently fastened in. Towards the conclusion a long mandrel is passed through the two holes in the fork of Fig. 66, to show whether their common axis is at right angles to the main rod, otherwise the one or other arm is drawn out, or upset, according as the work may err in respect to deficiency or excess of length. Such a piece as Fig. 66, if of large dimensions, would be made in two separate parts, and welded through the central line or axis.

Should it happen the two arms are not quite parallel, that is, when viewed edgeways should they stand oblique to each other, or to the central bar, an error that could scarcely be corrected by the hammer alone; the work would be fixed in the vice with the two tails upwards, and the one or other of these would be twisted to its true position by a *hook wrench* or *set*, made like the three sides of a square, but the one very long to serve as a lever; it is applied exactly in the manner of a key, spanner, or screw wrench, in turning round a bolt or screw. The hook wrench is constantly used for taking the twist out of work, or the error of winding, as the hammer can only be successfully employed for correcting the curvatures of length.

Some bent objects, such as cranks and straps, are made from bar-iron, bent over specific moulds, which are sometimes made in pairs like dies, and pressed together by screw contrivances. When the moulds are single, the work is often retained in contact with the same, at some appropriate part, by means of straps and wedges; whilst the work is bent to the form of the mould by top tools of suitable kinds.

Objects of more nearly rectilinear form are cut out of large plates and bars of iron with chisels; for example, the cranks of locomotive engines are faggoted up of several bars or uses laid together, and pared to the shape; they are sometimes forged in two separate parts, and welded between the cranks, at other times they are forged out of one parallel mass, and afterwards twisted with a hook-wrench, in the neck between the cranks, to place the latter at right angles. The notches are sometimes cut out on the anvil whilst the work is red-hot; or otherwise by machinery when in the cold state.

A very different method of making rectangular cranks and similar works is also recommended, by bending one or more straight bars of iron to the form, the angles, which are at first rounded, are perfected by welding on outer caps. In this case the fibre runs round the figure, whereas when the gap is cut out, a large proportion of the fibres are cut into short lengths, and therefore a greater bulk must be allowed for equal strength: this method is however seldom used.

All kinds of levers, arms, brackets and frames, are made after these several methods, partly by bending and welding, and partly by cutting and punching out; and few branches of industry present a greater variety in the choice of methods, and which call the judgment of the smith continually into requisition.

CHAPTER VII.

ON WROUGHT-IRON IN LARGE MASSES.

The manufacture of wrought-iron in large masses cannot boast of a very early origin. Although we read in the most ancient of Books that Tubal Cain, before the Flood, was an instructor of every artificer in brass and iron, it would doubtless have puzzled even that great founder of the iron trade, had he been furnished with an order to make the large masses of wrought-iron required for a "Niagara," "New Ironsides," "Roanoke," or "Great Eastern" steam-ship; and he would have been equally at a loss with many modern craftsmen, had he been requested to forge a monster gun or a double-throw crank-shaft for engines of 1000 horse-power. Were he again permitted to visit the world, the mighty machinery at work on every hand would compel the admission that his trade had made great strides during his absence. These advances in the manufacture of wrought-iron in large masses have taken place almost entirely within the present century, if not, indeed, within the last thirty years. Up to that period, the improvements upon Tubal Cain's (we presume original) inventions were of so limited a nature, that, in the year 1820, the manufacture of a shaft—say of about 6 inches diameter, and weighing 15 or 20 cwt.—required the concentrated exertions of a large establishment, and was considered a vast triumph if successfully accomplished; whereas we are now accustomed to forgings of 20 and 30 tons' weight, as matters of every-day occurrence, scarcely exciting the slightest notice. Nor do we stop even here: much larger masses will no doubt, ere long, be manufactured for the construction of iron ships, which in future years, owing to the increased size and strength of the plates, will be built upon a scale that would but recently have been deemed fabulous. This consideration, combined with the requirements of rapid communication, which demand more colossal engines, call for renewed energy in conducting this important manufacture.

It may, perhaps, not be out of place to mention here, as a fact having few parallels in other branches of the industrial arts, that, almost without exception, all the improvements that have latterly crowded upon each other in this trade have originated with the "hammermen" or workmen themselves, and have been worked without even the protection of an exclusive patent-right.

Our subject naturally divides itself into two chief heads, viz., the materials of which forgings are made, and the tools with which the manufacture is accomplished. We purpose treating of the latter first.

Description of Forge-tools.—A forge has necessarily three principal divisions, viz., the furnace, the crane, and the hammer; and they compose the chief fixtures. The furnace (Fig. 68) is, in this country, of the ordinary reverberating description, strongly bound together with plates and binders of iron, of a proportionate size to the description of work intended to be performed. A very great deal more depends upon the furnace than might be supposed by those who are not thoroughly conversant with the practical working of one. Variations in the slightest detail in their construction or working are followed by such great differences in the results, that even a good and experienced furnaceman, if set to manage a strange

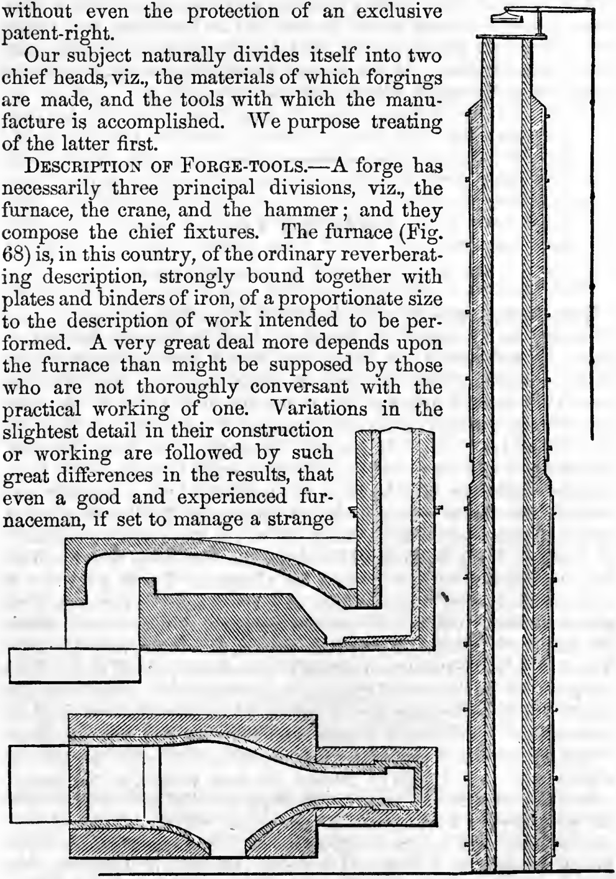


Fig. 68.

furnace, will find some difficulty until he has made himself thoroughly acquainted with its peculiarities.

The selection of a proper description of fire-brick with which to construct the furnace is a matter of considerable importance. Without attempting to enter into the merits of different fire-bricks, we would observe that the question of expense is infinitesimal when compared with the consequences of using cheap and inferior bricks, which would be costly at the lowest price, from the great wear and tear upon them, and from the annoyance and loss caused by the often-repeated stoppages for repairs. It is, therefore, the wisest and best economy always to use the very best fire-bricks that money can procure. In some cases where large work is intended to be made, a furnace, with a grate at each end, and having the stack or chimney in the centre, has been tried; but, as it has not been generally introduced, we presume it possesses few, if any, advantages over the ordinary furnace. In fact, for the largest forgings that have ever been made, furnaces with single grates have proved successful, where double-grated furnaces have failed. The sketch we have given in Fig. 68 is a furnace such as is generally used, and which is found very effective for the purposes required.

With anthracite coal, furnaces with closed ash-pits, and blown with a fan, are used, and which answer very well.

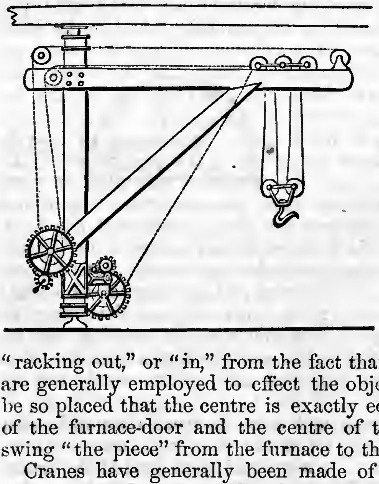
Mr. Mallet, in his work on the "Construction of Artillery," page 114, states, that "at length the limit is found when with our present known modes of working wrought-iron (even with the heaviest and best appliances) we can no longer add to its size. The limit is reached by the failure of power to heat the mass, or the required part of it, to the welding heat. The time required for the piece to remain in the furnace to effect this, continually increases as its bulk grows, and with it the sources through which heat is lost and dissipated; but a certain proportion of iron is burned away, or melted from the surface at the part requiring to be brought to welding, as equals the weight of the 'slab' or mass laid on, and the labor is then in vain: the work, like that of the embroidery of Penelope, becomes an endless task, and the limit has been reached beyond which the piece can be forged no bigger. The point at which this limit is reached can be stretched a good deal by the extreme skill of the operative forge man, and the skilful construction of his furnace; but, however great these may be, the limit is at length reached by all; and, with our existing tools, in Great Britain is probably reached in every case at a diameter (of a cylindrical mass) of about four feet, and about twenty feet in length."

There is considerable truth and force in these observations as applied to existing machinery: but the paragraph seems to convey the impression that we are not expected to exceed the limits laid down by Mr. Mallet. We should be sorry to indorse this opinion, or to believe that we have even approached the maximum size in our forgings, having so frequently and so recently seen that which is in one year deemed impracticable in the manufacture of forgings, accomplished with the utmost ease in the succeeding one; while the necessary requirements of that year are again followed by still further improvements, even where invention and mechanical skill had apparently reached their highest development. And so it will continue to the end of the chapter. We might as well attempt to obstruct the progress of the engineer, and say to him, "Thus far canst thou go, but no farther" as attempt to limit the sizes to which forgings may be made in future years. If larger forgings are required, and money is forthcoming to pay the cost of their manufacture, the work will not stand still for the want of workmen to undertake it, or machinery wherewith to handle it, however large it may be. The only real obstacle to the production of forgings of larger size is the cost; the bugbear set up in the above extract, that more iron is wasted than is added, being but another mode of accounting for inexperience and bad workmanship.

CRANE.—The crane is a very useful auxiliary in the working of the forge. Without its aid it would be impossible to fabricate those large masses of iron, the almost daily manufacture of which has ceased to excite surprise at their magnitude.

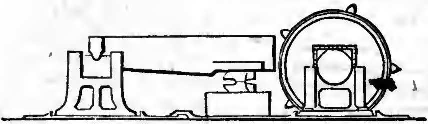
The crane (Fig. 69), as is well known, is composed, first of a strong upright, either independently fixed in a solid foundation in the ground, or dependent on the walls or roof of a building; next, of the top pieces, called "cheeks," and the "stays," to which is attached a winch of ordinary construction; and a strong pair of blocks, with a chain leading to the winch. It is necessary that the blocks should be capable of working backward and forward on the cheeks, which is technically called "racking out," or "in," from the fact that a rack and pinion-wheel are generally employed to effect the object. The crane must also be so placed that the centre is exactly equidistant from the centre of the furnace-door and the centre of the anvil, its use being to swing "the piece" from the furnace to the anvil, and *vice versâ*.

Fig. 69.



Cranes have generally been made of wood, although very few sorts of wood are capable of resisting the great heat to which cranes for forging are subjected. Others, however, have lately been made of iron, or of a mixture of iron and wood. Cast-iron, being comparatively brittle, is decidedly objectionable and unsafe, in consequence of the great weight they have to bear, and the excessive jar of the forge-hammer. There is less objection to wrought-iron, which, if rightly proportioned, is we believe the best material for the purpose.

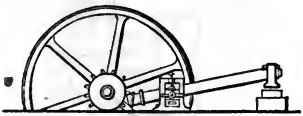
Fig. 70.



HAMMERS. — We now come to what is, perhaps, the most important, or, at any rate, what is considered the most important tool in the forge, viz., the hammer; and we purpose giving a slight description of the various sorts in use at the present time, including the beautiful direct-acting tool known as the Nasmyth or steam-hammer. We are unable, in the limits of this work, to consider the merits, or give any description of the various improvements that have been attempted on the original steam-hammer; some of them being confined to matters of detail, while others introduce defects so palpable, that we gladly return to the original Nasmyth.

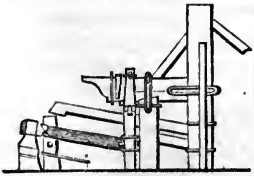
The most ancient form of forge-hammer was probably that technically called the "tennant-helve," Fig. 70, known in France as the "Marteau frontal," from its being lifted at the front end. This hammer is a heavy mass of cast-iron, which was lifted by projecting arms, fixed in a ring of iron, called the "cam-ring," falling through a certain space by its own gravity. The pivots behind, on which it rested, were of a curved form, to allow its being easily worked. This was, and still is in many works, a very effective tool, performing its work with regularity, and seldom getting out of order.

Fig. 71.



The "tennant-helves" being found inconvenient for certain descriptions of work, the "tilt-hammer," Fig. 71, was introduced. Instead of being raised at the front end, this hammer is depressed by a similar "cam-ring" from a part projecting behind. It is composed of wood and iron, the shank being of good tough oak, wedged into a ring in which it works; the hammer-head being also wedged on to the shank. The shank is surmounted by a beam of wood, which, acting as a powerful spring, gives greater force and rapidity to the blow. This form of hammer was peculiarly adapted to the "tilting" of the different sorts of steel.

Fig. 72.



Another improvement on the original "tennant-helve," was to lift the helve between the head of the hammer and the pivots on which it worked (Fig. 72), an advantage being thus given to the hammerman, which the tilt also possesses, by enabling him to go all round the end of his hammer. But the last and greatest improvement was that known to the trade as the "belly-helve," Fig. 73; a not very euphonious name, but one which indicates the nature of the tool. It was lifted, as its name indicates, under the bottom part of the helve, by means of a "bray," which could be lengthened or shortened according to the size of the "piece" to be acted upon. With some of the largest size a very effectual blow is struck with a piece of iron of from 3 feet to 4 feet in diameter—the "helve" being raised, and the "bray" being lengthened in proportion. This hammer also permits the hammerman to go completely round his hammer, to inspect the work under operation. For plain ordinary work it is not surpassed in efficiency, even by the direct-acting steam-hammer. It is of very great importance that the foundation be perfectly firm, and capable of resisting the force of the blows to which it is subjected. The most usual way of securing this end, is by placing under the anvil-block—which of itself is a very massive casting, weighing, with the cup upon which it rests, from twelve to fifteen tons—a considerable mass of timber, carefully placed and fitted cross-wise. This foundation must be strongly secured, for unless the anvil-block is very firm, a considerable portion of the blow will be dissipated, and its value lost.

Fig. 73.

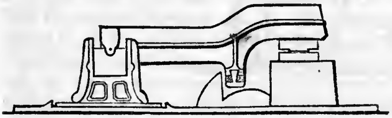
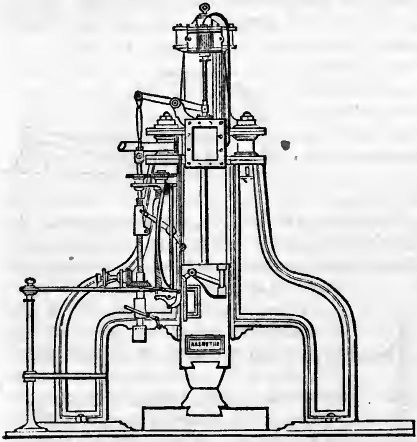


Fig. 74.



We come, lastly, to Nasmyth's steam-hammer, Fig. 74, a tool which has deservedly come into very general use. Although many of the very largest forgings have been made by the old-fashioned helves, especially the "belly-helve" above described; nevertheless, the invention has been of immense importance, not only to the forgemasters, but in many other branches of manufacture. The steam-hammer, like other great inventions, has its faults as well as its merits. The first great merit of the steam-hammer is, that it is a simple direct-acting machine, dispensing with much of the cumbrous wheel-work required with the old helves. It takes up little room, and requires no "gagger," as the attendant workman is called, who attends to the hammer. The presence of the "gagger" we object to, not so much on account of the expense, which is partly counterbalanced, in the case of the steam-hammer, by the necessity of employing an engineer; but on account of the almost insufferable torture from heat which the "gagger" has to endure: for if the "gag" is not inserted and the hammer stopped at the critical moment, a valuable piece of work may be damaged. Another of the excellences of the steam-hammer is, that the blow can be varied according to the size of the "piece" under operation, and the force of the blow required. This is not, practically, such a great advantage as might at first appear; but in small works it is of considerable importance. We would, however, ourselves rather see the different sizes and classes of work effected under different sized hammers—with hammers perfectly proportioned to each description of work. Excepting in very large establishments, however, where there are a considerable number of hammers employed, this cannot always be accomplished. The consequence is that the hammer is used more as a squeezer, frequently crushing the iron at the heart instead of drawing it in a sound manner under a hammer proportioned to its size. Where the works, therefore, are not extensive, or where the number of hammers is limited, the facility of regulating the stroke by the steam-hammer is an important advantage in many descriptions of work. Another advantage is, that the hammer is always working parallel with the "piece" under operation, which is not the case with the old-fashioned helves, in using which the hammerman has to resort to many ingenious plans, such as employing thickness pieces, for overcoming this difficulty.

The hammerman is saved a great deal of trouble in regulating his tools, by using the steam-hammer. With the old-fashioned helve, almost every different heat requires an alteration of the tools employed; with the steam-hammer there is no necessity for any such change. This of itself is a considerable advantage. With the Nasmyth hammer he is also enabled to work on each side of the hammer, as it can be placed in such a position as to be accessible on both sides.

There are, however, a few defects even in this beautiful tool; and the first which presents itself to our mind is, that the same quantity of steam is consumed in striking a blow of one foot upon a piece, say of three feet diameter, as is required for a blow of three feet upon a piece one foot diameter; for, the stroke of the hammer being fixed, the cylinder takes the same quantity of steam in lifting the hammer the last foot as it does in lifting it the whole of the stroke. This might, no doubt, be remedied by some arrangement for raising or lowering the cylinder according to the height of the "piece" upon which the blow is to be struck, which would be somewhat similar to the arrangement in operating with the belly-helve, already described. Another defect, but one which attempts have been made to remedy in some modifications of the steam-hammer, arises from the difficulty of swinging the "piece" to be operated upon, from the furnace to the hammer, one of the legs of the hammer being sometimes in the way. This difficulty might be overcome by allowing the hammer to stand upon one strong leg, which would in many cases be a considerable improvement. We have, also, a great objection to the amount of gearing connected with the working of the valves. They are certainly very beautiful, and of most ingenious construction: but in all forging tools it is desirable that the greatest simplicity, combined with the greatest strength, should always be the first consideration. Arrangements have lately been made, we believe, for dispensing with these valves, and introducing in their place a simple balance-valve capable of being worked with great ease, and not so liable to get out of order.

We have thus given some slight description of the different hammers employed in a forge. It has not been our intention to enter into very minute details upon this subject, nor to advance any very decided opinion as to the relative merits of the different implements; for we are aware that opinions greatly differ upon these points. The improvements that have taken place in this description of tools during the last fifteen years have been very great; but we are prepared to witness still greater developments of mechanical application in connection with this branch of the art.

MATERIALS.—We now propose to give a short description of the materials consumed in the forge, the chief of which are the coals and the iron. It is of considerable importance that care should be used in the selection of the fuel for the manufacture of forgings, as great difference exists in this important mineral, some being very much more suitable for the manufacture than others. The best bituminous for the purpose is a strong, dense, durable coal, possessing a good body, and having a dull, dirty appearance. Coal of this kind with a bright clean look, easily broken, as a general rule is not suitable. Of course it is desirable that the coal should be as free from sulphur as possible, and that it should not contain any large proportion of those foreign matters which, having an affinity for iron, fuse on the bars in the shape of clinkers.

We now come to the consideration of the best description of iron for this manufacture. Scrap-iron is that most generally used; but, far from agreeing with the generally received opinion that it is the best, we think that it is the very worst description of iron for the purpose; and for more reasons than one. Engineers usually require, in their contracts with the forge-master, that their forgings shall be made from the best scrap-iron; and it is, of course, the duty of the forge-master to comply with the terms of his instructions and contract. Let us first endeavor to see how this almost universal belief in the superiority of scrap-iron has arisen. At the time when small forgings were first attempted to be made as an article of commerce, the manufacture of iron was in such an imperfect state, and the quality so indifferent, that large quantities of the best iron had to be imported from Sweden and Russia, and for a long time the scrap-iron *was* of a quality that could not be approached by our own iron of that period. Since that time, the use of Russian and Swedish iron has been almost entirely discontinued, except for the manufacture of steel; the greater part of the scrap-iron now produced, therefore, is of a very different quality to that formerly known as best scrap-iron. This material was deservedly considered the most proper material for the manufacture of forgings that could then be procured; but it must be borne in mind that, at the date we speak of, the forgings were so limited in size that the practical evils resulting from the use of scrap-iron, which we are about to explain, were not so perceptible.

In the ordinary manufacture of bar-iron it is the practice, in most works, in order to obtain it of the toughest and best description, to work and re-work it several times over. The number of workings the iron undergoes is marked by the number of "best" stamps that it bears, as "best, best best," "treble best," etc., each "best" indicating a better quality, an extra working, and with a correspondingly higher price. But this progressive improvement has its limits, as will be perceived, from a series of experiments which were instituted by the writer with the object of testing the correctness and limits of this improvement.

Taking a quantity of ordinary fibrous puddled-iron, and reserving samples marked No. 1, we *piled* a portion five feet high, heated and rolled the remainder into two bars marked No. 2; again reserving two samples from the centre of these bars, the remainder were piled as before, and so continued until a portion of the iron had undergone twelve workings. The following table shows the tensible strain which each number bore:

No.	1	puddled bar	43,904	lbs.
"	2	re-heated . .	52,864	"
"	3	"	59,585	"
"	4	"	59,585	"
"	5	"	57,344	"
"	6	"	61,824	"
"	7	"	59,585	"
"	8	"	57,344	"
"	9	"	57,344	"
"	10	"	54,104	"
"	11	"	51,968	"
"	12	"	43,904	"

It will thus be seen that the quality of the iron regularly increased up to No. 6 (the slight difference of No. 5 may perhaps be attributed to the sample being slightly defective); and that from No. 6 the descent was in a similar ratio to the previous increase. From these experiments it appears that scrap-iron, or any other iron, highly refined, is the very worst material for the construction of large forgings which can be used; and that if we take, in the first instance, a strong fibrous fresh-puddled iron, the ordinary workings required in the process of forging will be sufficient to improve it to the average maximum of strength required; whereas highly refined iron, such as Lowmoor or Bowling, although the very best description for many purposes, has already reached the highest point in its strength; from which it is more likely to be deteriorated by additional workings.

It may then be asked—how can we hope, with any degree of success, to manufacture large forgings, which require to be worked over perhaps a score of times, each working beyond a given number tending to vitiate the iron? We can conceive that this deterioration does not penetrate the iron to any great depth; that few forgings are heated more than six times in one place before fresh iron is added; and that the various layers thus successively added to the mass protect the under portion from the deteriorating influences of the successive heatings. It is also to be observed that any crystallization which might take place, commences from the outside of the mass; and as this is the portion which is most immediately acted upon by the blows of the hammer, the fibre is elongated in a greater degree, and thus restored to its original quality. As a proof of this, we may instance the manufacture of the monster gun, which was built up in seven distinct layers, the forging of which took seven weeks.

At the meeting of the British Association at Glasgow, in September, 1855, a question was raised in the mechanical section as to the causes of the deterioration of the metal of which the artillery of the present day was constructed. On this question a long and interesting discussion ensued, both in reference to the comparative weakness of cast-iron as now produced, and the adaptation of forged and malleable iron as being stronger and better adapted for this purpose. The accounts received from the Baltic and Black Seas of the bursting of guns and mortars of recent construction, indicated that something was wrong. These failures gave rise to conjectures on the part of the Government as well as of the public; and, in order to trace the cause of this apparent weakness to its source, an inquiry was instituted by the authorities at Woolwich; and subsequently the Association appointed a Committee to cooperate with the Government in the investigation of this very important question. In order that no time might be lost, the secretary of the section was directed to issue circulars to engineers, ironmasters, and manufacturers, requesting that they would forward to the members of the Committee such opinions and observations as they deemed advisable, in regard to the material itself, and to its treatment preparatory to the manufacture of ordnance."

It is to be regretted that these circulars were not made more general, and that more of them were not addressed to practical forge-masters; for we observe, among the replies elicited, the name of one man only practically and intimately connected with the manufacture of large masses of wrought-iron; and his reply is the only one indicating any hope of success in the application of wrought-iron for ordnance purposes. All the other writers who noticed wrought-iron at all (for many passed it by without the slightest attention) most unequivocally condemned it, and came to the conclusion, that "the tendency to crystallization which the long-continued heating produces is such, that powerful ordnance *cannot* be manufactured advantageously from malleable iron."

It was, perhaps, fortunate that the manufacturers of the monster gun were not aware of the adverse opinions thus pronounced against wrought-iron for ordnance; otherwise, they might have been discouraged in their attempt, aud what must now be considered the successful manufacture of large wrought-iron ordnance might have been postponed. The following table of the tensile strength of the iron before it entered into the composition of the gun; of the iron cut from it, and as it now is in the gun, both transverse and longitudinal to the grain; and of the borings from the gun, worked over again in different ways,—tend to show that, so far from deterioration or crystallization having taken place, the metal was improved by its long-continued heating and working:

Experiment	Description of Iron.		Breaking strain in lbs. per sq. in.	Average.	Sample bars 4 ins. long elongated.
No. 1.	Original iron of which the gun was made		48·384	.	½ in.
No. 2.	Ditto	ditto	50·624	49·504	½ in.
No. 3.	Cut across the grain from muzzle of gun		41·644	..	⅜ in.
No. 4.	Ditto	ditto	43·904	..	⅜ in.
No. 5.	Ditto	ditto	50·624	43·390	½ in.
No. 6.	Cut with the grain from muzzle of gun		48·384	..	⅝ in.
No. 7.	Ditto	ditto	50·624	..	⅜ in.
No. 8.	Ditto	ditto	52·864	50·624	½ in.
No. 9.	Borings from gun worked over with coal		60·584	..	½ in.
No. 10.	Ditto	ditto	62·824	61·704	½ in.
No. 11.	Borings from gun worked over with charcl.		76·584	76·584	$\frac{9}{16}$ in.
No. 12.	Swedish iron as imported, ¾ sq.	.	60·564	60·584	½ in.

From the above experiments it will be seen that the original iron put into the gun was of no extraordinary strength, which is accounted for by the fact that it was designedly selected, in consequence of the experiments already quoted, from what is commonly known as "No. 2 iron," or iron once worked over from the puddling-process, though of considerable strength and body, and commercially called "common iron." This iron, after seven weeks heating and shaping into a gun, was, as we have already stated, so far from being deteriorated by this "long exposure to great heat," as to be actually improved in quality; for we find that the average of the trials gives an increase of tensile strength from 49·504 lbs. per square inch to 50·624 lbs., both trials being longitudinal with the fibre or grain of the iron.

The strength of the iron across the grain can hardly be regarded as of much importance, although it exhibits a remarkable amount of cohesion, for it was laid in the direction of the strain. and therefore the cut transverse to the grain might have been expected to possess less cohesion in that direction than if the grain had been placed in its position accidentally.

If we follow this question further, and examine the result of working over again the borings from this forging, we find that the tensile strength is increased from 49·504 lbs. per square inch to 61·704 lbs. when treated with coke, and 76·584 lbs. when worked with charcoal; and we think with results such as these—without parallel in any English make of iron, even under the most favorable circumstances—we may be allowed to assert that the myth commonly called "crystallization from long exposure to great heats," does not apply to the fabrication of this the largest forging ever made. We have given these details to illustrate and enforce the preference given to puddled-iron over scrap-iron; but there is another very important reason why scrap-iron should not be used for the manufacture of forgings—scrap-iron is composed of many various qualities of iron, and all of them have their own special welding points. When worked together, one portion that is less refined is too much heated, and consequently deteriorated, before the more highly refined portions are at a welding heat; and we are thus placed in the awkward dilemma of either burning the one, or of being unable to weld the other. It may be said that this objection is a mere theoretical one, and that, practically, no such difficulty exists. This, however, is not the case, for the difference of temperature at which puddled-iron and a highly-refined iron weld is very considerable; although, from the difficulty of finding a really good pyrometer for these extreme heats, we are unable to give exact data in degrees. If any proof were required of this, which is a matter of every-day economy, it is only necessary to inquire into the heating of iron for our rolling-mills. It is a well-established fact, that, in the mixing of different descriptions of iron in the piles for that purpose, the hardest and most refined iron is always placed outside, and the puddled or common iron inside. Were a contrary practice pursued, and puddled-iron of ordinary quality placed at the outside, and the highly-refined or scrap placed in the centre of the pile, the outer or puddled-iron would be wasted and destroyed before the inner portion was sufficiently hot to weld.

We may also call attention to the various qualities found among scrap-iron, some being what are termed "hot-short," and others "cold-short." We have before quoted a writer on the subject of the manufacture of wrought-iron for ordnance, who has stated that the limit has been reached beyond which forgings cannot be made; assigning reasons for those limits according to his own ideas and experience, the principal one being the assumed difficulty of heating such large masses. Now, if we take strong puddled-iron in place of the "scrap," which has hitherto been the material generally used, we effect, as we have shown, a saving of say about 20 per cent. in the heat required to unite soundly the various slabs or portions of which the "piece" is composed; in other words, by this simple substitution of the material used, we increase, to the extent of about 20 per cent., the suppositious limits of the writer from whom we have quoted, but the accuracy of whose conclusions we challenge.

MANUFACTURE.—But scrap-iron, though, as we have endeavored to show, the worst for our purpose, is the material from which forgings are generally made; and we must say a word or two as to its preparation. It is necessary, in the first place, that the small pieces of scrap-iron should undergo a cleaning process. For this purpose, they are generally placed in a large drum or vessel, which is caused to rotate at a considerable velocity by machinery; and they are thus, to a certain extent, freed from oxide and various other superficial impurities, that would otherwise injure the material for forging purposes. In some works, where large quantities of scrap-iron are consumed for this and other purposes, the scrap is usually carefully selected; and none but blue and clean iron, pure as when it came from the manufacturer's hands, is permitted to be used for forgings, the rusty and dirty iron being set aside for conversion to more common purposes, such as the manufacture of "bar-iron," "grate-bars," etc.

The scrap-iron, having been thus cleaned or selected, is divided into lumps or masses of various descriptions, by being piled in quantities generally varying from 100 to 200 lbs. in weight on a slate or tile. These piles are charged into a reverberating furnace, commonly called a "heating" or "balling" furnace. After remaining about one hour and a quarter, they are sufficiently heated to be forged out into slabs or "blooms." The piling of the iron is an operation requiring considerable skill and experience, for if the pile is not solidly put together, it will fall down in the furnace, and perhaps become attached to others. About ten to eighteen of these piles, according to their size, constitute a charge or "heat;" and a good workman will turn out six charges per day, or about 3 tons 10 cwt. to 4 tons. Larger descriptions of slabs are used for many purposes; and several of those described are again piled together, subjected to the heating process, and hammered to the required shape. In some forges the same workman "shingles" or hammers his iron from the scrap-pile, and heats it in the same furnace in which he heats his forgings; but this is by no means a judicious arrangement. It is much better, especially with large work, that there should be a division of these operations, and that a certain number of men, of inferior skill, and consequently of less value, should heat and "shingle" the iron for the first processes, and deliver it to the more highly-paid and skillful hammerman in a further advanced and more convenient shape. There is another, and by no means inconsiderable advantage to be obtained by this arrangement. A much larger amount of work can be accomplished with the same number of men and tools, than in the case where the two classes of work are completed by one workman. These slabs vary in shape and size, according to the nature of the work for which they are intended; and are delivered to the hammerman accordingly.

In large forgings, each particular piece requires different treatment, according to the shape and use for which it is intended. On this depends the question of the best manner of making it. For instance, a screw-shaft, which is subject to torsion, requires that the iron should be put together in a manner very different from the mode in which a crank or cross-head is prepared. We will take the case of shafts. The most ancient method of forging them was to take a certain number of slabs or plates of iron, made into a pile thus, (Fig. 75), and after heating them, to hammer them into the round shape required. As it soon became necessary to make larger shafts, however, and as this pile could not conveniently be increased, an improvement was introduced, which consisted in taking a pile of slabs as before, and drawing a portion only of the mass into the shape required (see Fig. 76), leaving a lump on the end on which to place more slabs as needed; then drawing a little more at A to the required shape, adding more and more slabs as occasion required. This method is still practised at many works, and with considerable success; but it requires the utmost care and circumspection, both in regard to workmanship and materials. This is the method by which shafts are generally made in the north of England and Scotland, and in America.

Fig. 75. End View,

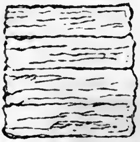


Fig. 75. Front View.

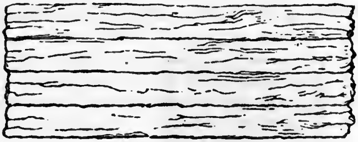
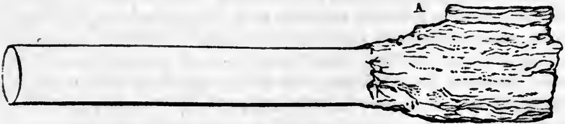


Fig. 76. Front View.



Another plan is to lay up a faggot of square bars sufficient to make the required shaft (Fig. 77). This is a considerable improvement upon the slab-plan, there being much less risk of false weldings and careless workmanship; and for this reason, when slabs are used, if the heat has not been sufficient to give a perfect weld to the iron, or if any oxide or dirt should intrude, the flaw or defect would run more across the shaft than in the faggot, where indeed any flaw from such causes would run longitudinally with the shaft, and consequently would not interfere in any thing like the same degree with its strength. But this method also requires great care and attention; for if the faggot of square bars be made too large at one heat, the interior of the mass cannot be sufficiently heated to allow of the iron being welded at the centre. I have often seen a broken steamboat shaft which has never been united at all at the heart, the bars from which it was made being in the same shape and state as when they were placed in the faggot. To avoid this great evil it is necessary to be especially careful not to pack faggots too large at once, but to make, in the first instance, a moderate-sized one, which, after being worked perfectly sound, has another layer of bars packed round it, and so on with further layers, until the necessary size is attained with perfect soundness. Thus Fig. 78, A being the original faggot after it has been made sound and solid, has the bars, as shown, packed round it; it is then again heated and hammered into the required shape.

Fig. 77. Front view.

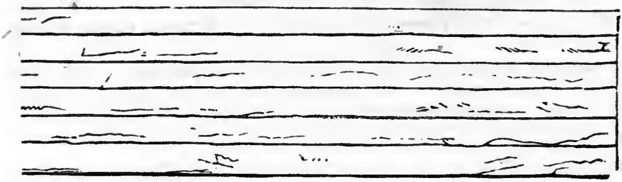


Fig. 77. End view.

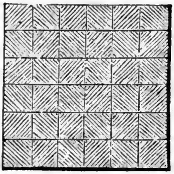


Fig. 78. End view.

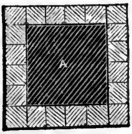
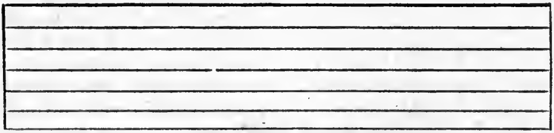
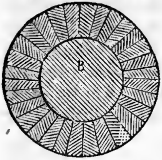


Fig. 78. Front view.



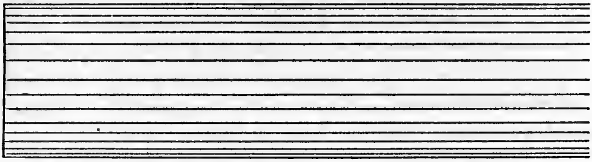
The third method of manufacturing large shafts is commenced by making a round core or heart, B, and taking bars of a V form to pack round it (Fig. 79). This is a method of forging railway axles which is frequently adopted. It was also the method adopted, with some variations, in forging the monster gun at the Mersey Iron Works. In a previous page we have given the tensile strength of the iron before it was forged into the gun, and its condition after undergoing that process; and it may be satisfactory if we give some details of the manner in which this large forging was worked.

Fig. 79. End view.



We have already stated that it was built up in seven distinct layers or slabs, and that the forging occupied seven weeks. Nor will this time seem unreasonable when its dimensions and weight are remembered. The chief points to be considered by the designer of the gun were, to obtain sound weldings; to place the iron, with its fibres, in the proper direction for resisting the most severe strains to which it could be exposed; and to take care that, while working one part of the forging, other portions were not wasted under the action of the furnace by burning or crystallization. The first operation was to prepare a core of suitable dimensions, and nearly the whole length of the gun. This was done by taking a number of rolled bars, about six feet in length, welding them together, and drawing them out until the proper length was obtained. A series of V-shaped bars were now packed round the core, the whole mass heated in a reverberatory furnace, and forged under the largest belly-helve hammer. Another series of bars were now packed on, and the mass was heated again, and worked perfectly sound. Another longitudinal series of bars were still required over the whole length of the forging, which were added; and the mass now presented a forging about fifteen feet in length and thirty-two inches in diameter, but requiring to be augmented to forty-four inches at the breach, tapering down to twenty-seven inches at the muzzle. This was accomplished by two layers of iron, placed in such a manner as to resemble hoops, laid at right angles to the axis of the mass; and, after two more heatings and careful welding, the forging of the gun was completed. After each important addition, a "securing" heat was given to prevent flaws. It would be foreign to our purpose here to deal with this implement otherwise than as a mass of forged iron. Its di-

Fig. 79. Front view.



mensions, as given by Captain Vandaleur, in his report, are as follow:

	Ft.	Ins.
Length	15	10
Diameter at base	3	7½
Diameter at muzzle	2	3½
Diameter at trunnions	3	3½
Length of bore	13	4
Diameter of bore	0	13·05

Its present weight is 21 tons 17 cwt. 1 qr. 14 lbs. The original weight, before boring, was 25 tons. The furnace employed was a reverberatory one; and the hammer, as we have seen, was the great belly-helve tilt-hammer, weighing 10 tons. As already intimated, the iron bored out of the gun was tough, sound, and perfectly homogeneous, some of the borings being curled like a watch-spring seven times round; and, when worked up again, it bore the test applied to prove its strength, as reported at page 117; and Messrs. Horsfall have the satisfaction of having produced a forging which the scientific world had hitherto deemed impracticable.

Shafts have sometimes been made after another method, which we consider very injudicious. Many specimens of this mode of manufacture have come under the notice of the writer in the shape of broken shafts, where the unsoundness, arising from the method of working adopted, has been so great as to make it a matter of surprise that the shaft had done any duty at all.

The method in question was to forge four large square bars, proportioned, of course, to the size of the shaft required; packing them together (Fig. 80). This faggot was of such immense size, that the furnace and hammer employed were altogether insufficient to produce sound work. As a necessary consequence, when the shafts so made were broken, the fracture had an appearance similar to Fig. 81, being only welded on the circumference; while the four fissures at the centre were sufficient, in many cases, to receive a man's hand, while a rod of iron could be inserted from one end to the other.

Fig. 80. Front view.

Fig. 80. End view.

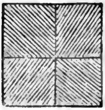
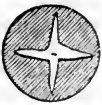


Fig. 81.



CRYSTALLIZATION.—A great deal has been said and written with reference to a supposed deterioration, or, as it has been called, "crystallization" of iron, when rolled in large masses, from long-continued and frequent heatings. It has also been asserted that the iron, while lying in the furnace, is continually attracting carbon from the grate, until, in course of time, it becomes carburetted,—that is, reconverted into pig-iron. When this theory was first propounded, the writer determined to test its accuracy; and that in the presence of the gentlemen by whom it had been promulgated. A small knob, or corner, was accordingly detached from a large forging which had been over-heated or burnt. It broke off with a large flaky appearance very similar to some descriptions of lead ore. This was pronounced to be very similar in its nature to cast-iron, and in the so-called crystallized state. Proceeding to the smiths' department, the iron was heated in the fire, and drawn down to about three times its original length. It worked well under the hammer; and when broken again in the usual way, was as beautifully fibrous as the iron from which it was originally made. This experiment led to the conclusion that the iron acted upon was very different in its nature from cast-iron, and certainly failed in sustaining the crystallization theory.

It may be well, however, in the first place, to consider what is the meaning attached to this term "crystallization." It has been generally used to signify that the structure or composition of the iron has entirely changed its character and assumed a new form. Mr. Mallet, in page 110 of his work before quoted, thus describes this change:

"With the same iron and the same volume of forging, however, the size of the crystals appears to be large and more developed in proportion to the time that the mass is maintained *hot* and in process of forging. This time is necessarily greater as the mass is so; and as the operation of reducing it to the required form is more complex or laborious. In fact, as in cast-iron, we saw that the crystals were larger the longer the mass required to cool; so in wrought-iron, they are larger the longer the mass is kept hot: and thus it happens that in very large and massive forgings, requiring often to be maintained perhaps for weeks, at temperatures varying from welding-heat down to dull redness, crystals are developed within the mass of a size tending materially to diminish, in some places, the average cohesion of the iron, where their planes of cleavage produce partial planes of weakness. The size of these crystals is occasionally surprising; the broadest and flattest planes of cleavage frequently running in the direction in which surfaces of the integrant slabs, or portions of iron of which the mass has been formed, have been welded together. The author has observed crystals to deposit flat planes as large as the surface of a half-crown piece in forgings under seven tons weight."

We have little doubt that in many instances this statement is perfectly correct; we, however, at the same time declare our belief that cases are referred to where the greatest carelessness and inattention on the part of the workmen have been exhibited. We think, moreover, that some experiments which have taken place, and others which are still making, under the direction of Mr. Mallet, will induce him to alter his opinion on this point. To one of these we may here allude in support of this view: a sample bar has been planed out of the body of a large wrought-iron mortar piece made for him, and the sample shows a highly fibrous development, very different in appearance from the specimens described by Mr. Mallet in the above extract—a description, be it observed, which may be at any time observed in a forge on examining a piece of *burnt* iron or in an exposed corner which has been subjected to very great but not necessarily continued heat.

It seems to us that all wrought-iron is, more or less, crystalline in its structure; and that the difference between what we call fibrous and crystallized iron only consists in the degree of fineness in the crystals, and perhaps in the manner in which they are laid together; the presence, also, of foreign matters, such as silicon, in some form, may also have its influence. Whatever the cause may be, however, it is known that a piece of good fibrous iron will break, under the smith's hammer, with a long silky appearance; if suddenly fractured by an irresistible blow, the same piece of iron will break crystalline, but the crystals will be very fine and close, and of a good color.

In some experiments made at Woolwich, in the year 1842, to test the effect of shot against wrought-iron plates, and determine whether wrought-iron was a suitable material for ships of war, it was found that the toughest and most fibrous plate-iron, when struck by shot, was instantaneously crystallized; while the pieces struck out were so hot, that the fragments, even after passing a considerable distance through the air, could not be handled with the naked hand; in many cases the fracture had that blue appearance, which is indicative of considerable heat.

A 68-pounder wrought-iron gun burst with the first charge at Woolwich, on the 12th of July, 1855; on examination, the iron was pronounced to be crystallized, and its nature changed, by long exposure to great heat. This crystalline appearance was, most probably, the result of the very sudden disruption, as in the experiments with the iron plates; and, according to our view of the case, is traceable to bad workmanship. A considerable portion of the bars of which the forging was composed had never been welded at all; and no doubt the fracture commenced with these false weldings. The crystalline appearance, where the iron was torn from the solid mass, arose, at any rate, to a great extent, from the sudden fracture. Other causes, no doubt, assisted; among which the selection of iron too highly-refined may be included. From this crystalline appearance, the authorities of the Ordnance Department arrived at the conclusion, that large masses of iron, from long-continued heating, have a tendency to crystallize, and lose the properties peculiar to wrought-iron. Acting on this hypothesis, they put a stop to what were called "Nasmyth's experiments" at Patricroft, pronouncing the manufacture of a wrought-iron gun of large size impossible—a theory which the successful manufacture of a much larger piece has since practically shown to be incorrect. As we have before shown, a bar of iron, planed transversely from a piece cut off the end of the gun, broke with a fibrous texture, and with a very slight tendency to crystallization; and that crystal by no means of a large character. This sample had never been treated or altered in the slightest degree since it was cut off the gun, and it would be pronounced "excellent best iron." A portion of this was afterwards rolled down to three-eighths of an inch round bar-iron, and it was bent cold in all ways without giving way in the slightest degree.

Having thus endeavored to explain the meaning of the term "crystallization," let us now endeavor to trace the causes which produce this result.

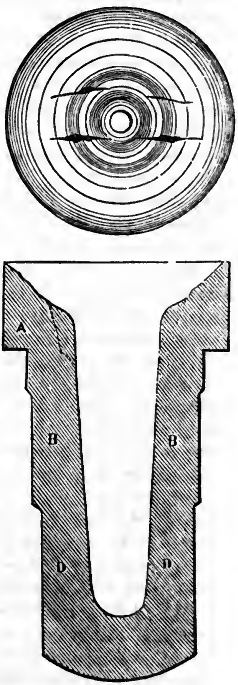
The change in the structure of the mass of iron, when it occurs during the process of heating, is usually produced from the furnace being urged to a much greater heat than is necessary for welding the iron; in fact, the outside first, and, if the heat be not checked, the whole of the mass, is reduced to a pasty or partially fluid condition. The structure of the iron is thus entirely changed; and in the process of cooling the mass, crystallization takes place in the same manner as with other substances which crystallize in passing from the fluid to the solid state. Under these circumstances, the iron may be injured—in other words, it may be burned: but we are not to suppose that such a result is either inevitable or by any means common; on the contrary, the heat necessary to produce the evil is with difficulty obtained in our ordinary furnaces, under the most favorable circumstances.

Some years ago the experiment was tried at the Mersey Steel Works of fusing wrought-iron, with the idea of casting it into such shapes as "cranks," "cross-heads," and other forms required by engineers. They succeeded perfectly in obtaining excellent castings: but it was found that the deterioration of the structure of the iron in passing from the fluid to the solid state was such, that the work produced had little more strength than ordinary cast-iron. Of course, the manufacture was at once given up. But in the appearance of the fracture of the ingots resulting from Mr. Bessemer's experiments at Baxter-house, there was a great similarity between it and the results obtained in melting scrap wrought-iron.

Mr. Mallet, in his work (Note R, page 251), says:—"Late experience has shown me that in very large cylindrical masses of forged wrought-iron (*i. e.* of three feet diameter and upwards), amongst the other abnormal circumstances involved in their production, is that of their frequently rending or tearing internally in planes nearly parallel with, and about the axis, though not always in it, presenting a character similar to those described in section 217; the cause appears to be, that in the progress of cooling such a mass the exterior cools first and becomes rigid, while the internal portions are still red-hot and soft. The external parts contract as they cool, but they already grasp, in perfect contact, the still hot interior; the exterior therefore cannot contract fully, but becomes solid under constraint circumferentially, partly itself extended in virtue of its compressing the still hot and soft interior. The latter at length also becomes cold and rigid; but its contraction is now resisted by the rigid arch of the exterior with which it is surrounded. The contraction of the interior, therefore, is limited to taking place radially outwards from the centre; and thus the mass rends itself asunder in some one or more planes parallel to the axis of the cylinder.

"In a cylindric mass of forged iron, varying from 24 to 36 inches in diameter, rents of 18 inches in width across a diameter were found, with jagged counterpart surfaces clearly torn asunder, and about ¾ths of an inch apart at the widest or central part; the fact is most instructive as to the enormous internal strains that must exist from like causes in cast-iron guns and mortars of large size."

Fig. 82.



We give a sketch (Fig. 82) of the form of this forging, showing the faults or "fissures" that were found in it, and which no doubt took place from contraction after the piece had left the hammerman's hands perfectly sound.

When the forging was cooling, the part D would of course cool first; and as there was no great differential diameter between D and B, the differential contraction was not greater than the elasticity of the materials permitted: but the sudden and great difference in the diameters B and A caused the forging at B to be comparatively cool; whilst the forging at A had very considerable heat, the parts of the forging at B and D, being nearly cold, became rigid and unalterable, constituting a very strong arch, which prevented the forging from contracting in a regular manner.

If this forging had been of one uniform cylindrical shape, these fissures would not have taken place, as the contraction would have been uniform throughout, at the same time the conducting power of iron is sufficient to allow of the heat passing from the interior to the outside with sufficient rapidity to prevent any fissure or unsoundness taking place in the forging.

Mr. Mallet proceeds to say—"It is probably from this cause that more or less hollowness is found in the centre of almost every large forging, greater in proportion as the forging is larger. The difficulty is one not easily overcome. Very slow, and, as far as possible, uniform cooling of the whole mass in an annealing oven, suggests itself as one remedy; but this has disadvantages in enlarging the crystalline development of the metal, or providing a central cylindrical opening, so as to cool the circumference and the centre together."

Here, at last, we come to a tangible danger to be feared in the manufacture of large forgings, provided that due care and attention be not paid to its proper manipulation. But this danger is also common to castings, being created not by equal, but by differential contraction. There is nothing more to be dreaded in casting metals of any sort, but more especially those in which the contraction is great, than that any part of the casting should be suddenly reduced or increased in size. When this is the case, what the founders call "a draw" evidently takes place; and the same result is observed in large forgings, from the cooling of the smaller portions before the larger. In such a case as this, let us follow the practice of the engineer and founder, who, from experience and long practice, discourage such shapes as are found impracticable, and make such modifications in their plans as shall do away with these differential results.

Whilst Mr. Mallet's work was passing through the press, and without any communication from him, the maker of the forgings he mentions, after three failures, overcame the difficulty in the manner proposed: viz., by making a cylindrical opening in the centre, which allowed the interior of the forgings to cool as rapidly as the external ring, and which permitted the necessary contraction without producing fissures. To endeavor to overcome the difficulties incident to an important manufacture, which is still in its infancy, appears to be much preferable to the theory and maxims of the "How-not-to-do-it" school, who would sit quietly down under a difficulty without attempting to remove it.

In the Report, made by a Committee of the Franklin Institute, on the bursting of the wrought-iron gun on board the United States steam-frigate "Princeton," the following facts were elicited:

"1. The iron of which the gun was principally made was capable of being rendered of a good quality by sufficient working.

"2. From the state in which the iron was put into the gun, it was not in a proper condition for the purpose to which it was applied.

"3. The metal, as it existed in the gun, was decidedly bad.

"4. As to the manufacture of the gun, the welding was imperfect.

"These facts relate exclusively to the gun submitted to the examination of the committee, and they are derived from immediate experiments and observation. But besides giving these to the public, the committee felt themselves bound to express the opinion, that in the present state of the arts the use of wrought-iron guns of large calibre, made on the same plan as the gun now under examination, ought to be abandoned for the following reasons:

"1. The practical difficulty, if not impossibility, of welding such a large mass of iron, so as to insure perfect soundness and uniformity throughout.

"2. The uncertainty that will always prevail in regard to imperfections in the welding. And,

"3. From the fact that iron decreases in strength from long exposure to the intense heat necessary in making a gun of this size, without a possibility of restoring the fibre by hammering with the hammer at present in use in this country. At the same time the committee would not wish to be understood as expressing any opinion whether the construction of a safe wrought-iron gun upon some other plan is practicable or otherwise, in the present state of the arts, inasmuch as this subject has not been referred to them by the Department."

We are sorry that Mr. Mallet thinks it necessary to add to this Report, which he quotes at length in his valuable work on the "Construction of Artillery," the following remarks:

"Nothing can more strikingly show the deteriorating effects of forging in large masses (however done) upon the tenacity of wrought-iron, than the fact of the preceding Report, nor the uncertainty of the process as respects welding. That the latter difficulty may be greatly mitigated (though it cannot be removed) by pre-eminent skill on the part of the hammerman, is proved by the success of the Mersey Steel Company in the duplicate perfected by them of the gun which failed for the 'Princeton,' and still more in the stupendous and apparently perfect forging they have now almost finished into a gun for the Government, no doubt by far the largest ever made in one piece, being 13½ feet length of chase, 13 inches calibre, 14 or 15 inches thick at the charge, and about 9 inches at the muzzle, a solid shot of which will weigh 300 lbs." Mr. Mallet thus gives the weight of his authority (for which we entertain the greatest respect) to sentiments which, in our opinion, hardly need any further refutation than the facts which he himself mentions.

The several failures in the manufacture of wrought-iron guns should not be a matter of surprise; for it is hardly reasonable to expect immediate success in any new fabrication. How many failures, it might be asked, occurred before cast-iron guns were brought to the comparative perfection they have now reached? When we consider that an attempt has been successfully made to construct two of the largest guns ever attempted of wrought-iron, without having had any failure to record, we think it hardly probable that failure should occur where sufficient skill in workmanship is used, and with it added experience. It would, indeed, be somewhat strange, if, with additional experience, less successful results were to be obtained than in the first comparatively novel experiments.

One of the most common forms of real crystallization results from what is technically called "hammer-hardening." In the year

1854, at the meeting of the British Association in Liverpool, a paper was read by the writer of this article on the subject of crystallization of iron under certain circumstances. He selected a piece of good, tough, fibrous bar-iron, which he tested by treating in the usual manner. He then heated it to a full red heat, and hammered it by light, rapid, tapping blows, until it was what is called "black-cold." After it was allowed to cool, he again broke it, and found that the structure of the iron was entirely changed; and that, instead of bending nearly double without fracture, and, when the fracture did occur, breaking with a fine, silky fibre, an entire alteration had taken place, and the bar was of a rigid, brittle, sonorous character, incapable of bending in the slightest degree, but breaking with a glassy, crystallized appearance. By simply heating the bar to the same red-heat again, the fibre was restored exactly as before. This change in the structure of iron has been observed in railway axles and chains; and we believe that it is now customary, in some manufactories, to anneal such articles as are exposed to any jar or percussion, at regular periods, and with a beneficial result. Now this crystallization is particularly to be dreaded in forgings, for, unless great care is used, this error of "hammer-hardening" will often take place—sometimes from the vanity of the forge-man, who is naturally desirous to turn out a pretty well-finished forging; at other times, as is more generally the case, from the requisition of the engineer, who, without thinking of the result, wishes to have his forging delivered to him as nearly as possible to the finished size; and when, as is often the case, a very small allowance or margin is given between the forged and finished dimensions, the forge-man is under the necessity of working his iron much colder than is consistent with a due regard to strength. It is very true that some forge-men will work much nearer to the sizes given them than others, and still avoid the dangerous error of cold-hammering; but when certain dimensions are a *sine qua non*, inferior workmen, to keep anywhere near the mark, must "cold-hammer" their work; for none but a first-rate workman, and one who has every confidence in his own powers, dare bring his iron down to the required size at full heat.

Some engineers, and we have known instances among the most eminent, in ordering their forgings, have made the remark—"Pray take care not to finish the work too cold, for we do not care for a fine polish to our forgings;" and this language we would urge all engineers to use. Such an instruction shows a true appreciation of the danger of cold-hammering, and a knowledge of his craft, which it is the object of this work to convey to all. But while we have a very strong objection to cold-hammered forgings, we should be sorry to be understood as encouraging that slovenly description of forging, which leaves the pieces so clumsy and unsightly as to require more than a necessary amount of cutting or turning. This is an error that ought also to be avoided. If proper care and attention were paid to the quality of the material used, as well as to the workmanship, we should have fewer break-downs in our sea-going steamers, and might, with perfect safety and great advantage, reduce the weight of those parts that are made of wrought-iron. In the selection of forgings, the cheapest are generally a long way from being the least costly; for the extra weight of material used, often brings the actual cost up to a level with the dearer, but better-finished and lighter forgings. Where cheapness of first cost is the rule, though accepted as the cheapest, it will, in all probability, be the dearest in the end.

In concluding this chapter, we would observe, that the opinions and facts here developed (although the result of long practical experience) have been put together at a short notice, during the pressure of onerous business engagements, which permitted but little time to be devoted to the subject. The author does not for a moment pretend to treat this important subject in the scientific manner that it deserves; but, when requested, he gave his humble assistance to further, though in a slight degree, the development of knowledge on a subject which has hardly ever received the attention of those practically competent to write upon it; but which, he is convinced, is of great and growing importance to the country, as a national manufacture in which it stands proudly pre-eminent.

Should, however, the few remarks which we have put together awaken more inquiry, and further investigation of the subject, by those who have leisure and ability to pursue it, the author will rejoice that his humble endeavors have not been altogether in vain.

CHAPTER VIII.

GENERAL EXAMPLES OF WELDING.

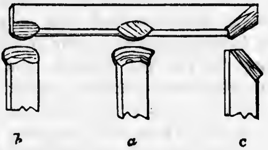
THE former illustrations of forging have been to some extent descriptive of such works as could be made from a single bar of iron, on purpose that the examples to be advanced in welding or joining together two pieces of iron by heat, technically called "*shutting together*," or "*shutting-up*," might be collected at one place.

There are several ways of accomplishing this operation, and which bear some little analogy to the joints employed in carpentry; more particularly that called scarfing, used in the construction of long beams and girders by joining two shorter pieces together endways, with sloping joints, which in carpentry are interlaced or mortised together in various ways, and then secured by iron straps or bolts. In smith's work, likewise, the joinings are called *scarfs*, but from the adhesive nature of the iron when at a suitable temperature, the accessories called for in carpentry, such as glue, bolts, straps and pins, are no longer wanted.

The example, Fig. 58, was left unfinished, but we will proceed to show the mode of joining the two cylindrical ends of the work. The scarfs required for the "*shut,*" are made by first upsetting or thickening the iron by blows upon its extremity, to prepare it for the loss it will sustain from scaling off, both in the fire and upon the anvil, and also in the subsequent working upon the joint. It is next rudely tapered off to the form of a flight of steps, as shown in Figs. 83 and 84, and the sides are slightly beveled or pointed, as in Fig. 84, the proportions being somewhat exceeded to render the forms more apparent.

Figs. 83

84



87

85

86

The two extremities are next heated to the point of ignition; and when this is approached, a little sand is strewed upon each part, which fuses and spreads something like a varnish, and partially defends them from the air; the heat is proper when, notwithstanding the sand, the iron begins to burn away with vivid sparks. The two men then take each one piece, strike them forcibly across the anvil to remove any loose cinders, place them in their true positions, exactly as in Fig. 83, and two or three blows of the small hammer of the principal or fireman stick them together; the assistant then quickly joins in with the sledge-hammer, and the smoothing off and completion of the work are soon accomplished.

It is of course necessary to perform the work with rapidity, and literally "to strike whilst the iron is hot;" the smith afterwards jumps the end of the rod upon the anvil, or strikes it endways with the hammer; this proves the soundness of the joint, but it is mostly done to enlarge the part, should it during the process have become accidentally reduced below the general size. The sand appears to be quite essential to the process of welding, as although the heat might be arrived at without its agency, the surface of the metal would become foul and covered with oxide when unprotected from the air—at all events common experience shows that it is always required. The scarf joint, shown in Figs. 83 and 84, is commonly used for all straight bars, whether flat, square or round, when of medium size.

In very heavy works the welding is principally accomplished within the fire: the two parts are previously prepared either to the form of the *tongue* or *split* joint, Fig. 85, or to that of the *butt* joint, Fig. 86, and placed in their relative positions in a large hollow fire. When the two parts are at the proper heat, they are jumped together endways, which is greatly facilitated by their suspension from the crane, and they are afterwards struck on the ends with sledge-hammers, a heavy mass being in some cases held against the opposite extremity to sustain the blows; the heat is kept up, and the work is ultimately withdrawn from the fire, and finished upon the anvil.

The butt joint, Fig. 86, is materially strengthened, when, as it is usually the case for the paddle shafts of steam vessels and similar works, the joint whilst still large is notched in on three or four sides, and pieces called *stick-in* pieces, *dowels*, or *charlins*, one of which is represented by the dotted lines, are prepared by another fire, and laid in the notches; the whole, when raised to the welding heat, is well worked together and reduced to the intended size; this mingles all the parts in a very substantial manner. For the majority of works, however, the scarf joint, Fig. 83, is used, but the stick-in pieces are also occasionally employed, especially when any accidental deficiency of iron is to be feared.

When two bars are required to form a **T** joint, the transverse piece is *thinned down* as at *a*, in Fig. 87; for an angle or corner the form of *b* may be adopted; but *c*, in which each part is cut off obliquely, is to be preferred. The pieces *a*, *b*, *c*, are represented upside down, in order that the ridges set down on their lower surfaces may be seen. In most cases when two separate bars are to be joined, whatever the nature of the joint, the metal should be first upset, and then set down in ridges on the edge of the anvil, or with a set hammer, as the plain chamfered or sloping surfaces are apt to slide asunder when struck with the hammer, and prevent the union. When a **T** joint is made of square or thick iron, the one piece is upset, and moulded with the fuller much in the form of the letter; it is then welded against the flat side of the bar: such works are sometimes welded with dowel or tenon joints, but all the varieties of method cannot be noticed.

There are many works in which the opposite edges, or the ends of the same piece, require to be welded. In these the risk of the two parts sliding asunder scarcely exists, and the scarfs are made with a plain chamfer, or simply to overlap or fold together without any particular preparation.

Of the last kind Fig. 63 may be taken as an example, in which the parts have no disposition to separate. In this and similar cases the smith often leaves the parts slightly open, in order that the very last process before welding may be the striking the whole edgeways upon the anvil, to drive out any loose scales, cinders or sand, situated between the joints: which if allowed to remain would be either inclosed amidst the sound parts of the work, or would partially prevent the union.

In works that have accidentally broken in the welded part, the fracture will be frequently seen to have arisen from some dirty matter having been allowed to remain between them, on which account, *shuts* or welded joints extending over a large surface are often less secure than those of smaller area, from the greater risk of their becoming foul. In fact, throwing a little small coal between the contiguous surfaces of work not intended to be united, is a common and sometimes a highly essential precaution to prevent them from becoming welded.

The conical sockets of socket chisels, garden spuds, and a variety of agricultural implements, are formed out of a bar of flat iron, which is spread out sideways or to an angle, with the pane of the hammer, and then bent within a semi-circular bottom tool also, by the pane of the hammer, to the form of Fig. 88; after which the sockets are still more curled up by blows on the edges, and are perfected upon a taper-pointed mandrel, so that the two edges slightly overlap at the mouth of the socket, and meet pretty uniformly elsewhere, as in Fig. 89, and lastly, about an inch or more at the end is welded. Sometimes the welding is continued throughout the length, but more commonly only a small portion of the extremity is thus joined, and the remainder of the edges are drawn together with the pane of the hammer.

Figs. 88

89.

In making wrought-iron hinges, two short slits are cut lengthways and nearly through the bar, towards its extremity. The iron is then folded round a mandrel, set down close in the corner, and the two ends are welded together. To complete the hinge, it only remains to cut away transversely, either the central piece or the two external pieces to form the knuckles, and the addition of the pin or pivot finishes the work.

Musket barrels, when made entirely by hand, were forged in the form of long strips about a yard long and four inches wide, but taper both in length and width, which were bent round a cylindrical mandrel until their edges slightly overlapped. They were then welded at three or four heats by introducing the mandrel within them instantly on their removal from the fire at the proper heat, in order to prevent the sides of the tube from being pressed together by the blows of the hammer.

They have been subsequently and are now universally welded by machinery, at one heat; and whilst of the length of only one foot, as on removal from the fire the mandrel is quickly introduced, and the two are passed through a pair of grooved rollers. They are afterwards extended to the full length by similar means, but at a lower temperature, so that the iron is not so much injured as when thrice heated to the welding point.

The twisted barrels are made out of long ribands of iron wound spirally around a mandrel, and welded on their edges by jumping them upon the ground, or rather on an anvil embedded therein. The plain stub barrels are made in this manner, from iron manufactured from a bundle of stub-nails, welded together and drawn out into ribands, to insure the possession of a material most thoroughly and intimately worked. The Damascus barrels are made from a mixture of stub-nails and clippings of steel in given proportions, puddled together, made into a bloom, and subsequently passed through all the stages of the manufacture of iron already explained: to obtain an iron that shall be of unequal quality and hardness, and therefore display different colors and markings when oxidized or browned.

Other twisted barrels are made in the like manner, except that the bars to form the ribands are twisted whilst red-hot like ropes, some to the right, others to the left, and which are sometimes again laminated together for greater diversity. They are subsequently again drawn into the ribands and wound upon the mandrel, and frequently two or three differently-prepared pieces are placed side by side to form the complex and ornamental figures for the barrels of fowling-pieces, described as "*stub-twist, wire-twist, Damascus-twist,*" etc.

A method amongst others of the formation of the Damascus gun-barrels: By arranging twenty-five thin bars of iron and mild steel in alternate layers, welding the whole together, drawing it down small, twisting it like a rope, and again welding three such ropes, for the formation of the riband, which is then spirally twisted to form a barrel, that exhibits, when finished and acted upon by acids, a diversified laminated structure, resembling when properly managed an ostrich feather.

When the illumination by gas was first introduced in the large way, the old musket-barrels, laid by in quiet retirement from the fatigues of war, were employed for the conveyance of gas; and by a curious coincidence, various iron foundries desisted in a great measure from the manufacture of iron ordnance, and took up the peaceful employment of casting pipes for gas and water.

The breech ends of the musket-barrels were broached and tapped, and the muzzles were screwed externally to connect the two without detached sockets. From the rapid increase of gas illumination, the old gun-barrels soon became scarce, and new tubes with detached sockets, made by the old barrel-forgers, were first resorted to. This led to a series of valuable contrivances for the manufacture of the wrought-iron tubes, under which the tubes were first bent up by hand-hammers and swages, to bring the edges near together; and they were welded between semi-circular swages, fixed respectively in the anvil, and the face of a small tilt-hammer worked by machinery, by a series of blows along the tube, either with or without a mandrel. The tube was completed on being passed between rollers with half-round grooves, which forced it over a conical or egg-shaped piece at the end of a long bar, to perfect the interior surface.

Various steps of improvement have been since made. For instance, the skelps were bent at two squeezes, first to the semi-cylindrical and then to the tubular form (preparatory to welding), between a swage-tool five feet long worked by machinery. The whole process was afterwards carried on by rollers, but abandoned on account of the unequal velocity at which the greatest and least diameters of the rollers travelled.

In the present method of manufacturing the patent welded tube, the end of the skelp is bent to the circular form, its entire length is raised to the welding heat in an appropriate furnace, and as it leaves the furnace almost at the point of fusion, it is dragged by the chain of a draw-bench, after the manner of wire, through a pair of tongs with two bell-mouthed jaws. These are opened at the moment of introducing the end of a skelp, which is welded without the agency of a mandrel.

By this ingenious arrangement wrought-iron tubes may be made from the diameter of six inches internally and about one-eighth to three-eighths of an inch thick, to as small as one-quarter of an inch diameter and one-tenth bore; and so admirably is the joining effected in those of the best description, that they will withstand the greatest pressure of gas, steam or water, to which they have been subjected, and they admit of being bent both in the heated and cold state almost with impunity. Sometimes the tubes are made one upon the other when greater thickness is required; but these stout pipes, and those larger than three inches, are comparatively but little used. The wrought-iron tubes of hydrostatic presses, which measure about half an inch internally, and one-fourth to three-eighths of an inch thick in the metal, are frequently subjected to a pressure equal to *four tons* on each square inch.

Various articles, with large apertures, are made not by punching or cutting out the holes, but by folding the metal around the beak iron and finishing them upon a triblet of the appropriate figure. Thus the complete smithy is generally furnished with a series of cones turned in the lathe, for making rings, the ends of which are folded together and welded, such as Fig. 90. The same rings when made of such cast-steel as does not admit of being welded, are first punched with a small hole and gradually thinned out by blows around the margin until they reach the diameter sought. But this, like numerous other works, requires considerable forethought to proportion the quantity of the material to its ultimate form and bulk, so that the work may not in the end become either too slight or too heavy.

Chains may be taken as another familiar example of welding. In these the iron is cut off with a plain chamfer, as from the annular form of the links their extremities cannot slide asunder when struck. Every succeeding link is bent, introduced, and finally welded. In some of these welded chains the links are no more than half an inch long, and the iron wire one-eighth of an inch diameter. Several inches of such chain are required to weigh one pound. These are made with great dexterity by a man and a boy at a small fire. The curbed chains are welded in the ordinary form and twisted afterwards, a few links being made red-hot at a time for the purpose.

The massive cable-chains are made much in the same manner, although partly by aid of machinery. The bar of iron, now one, one and a half, or even two inches in diameter, is heated, and the scarf is made as a plain chamfer by a cutting machine; the link is then formed by inserting the end of the heated bar within a loop in the edge of an oval disk which may be compared to a chuck fixed on the end of a lathe mandrel. The disk is put in gear with the steam-engine; it makes exactly one revolution, and throws itself out of motion; this bends the heated extremity of the iron into an oval figure. Afterwards it is detached from the rod with a chamfered cut by the cutting machine, which at one stroke makes the second scarf of the detached link, and the first of that next to be curled up.

The link is now threaded to the extremity of the chain, closed together, and transferred to the fire, the loose end being carried by a traverse crane. When the link is at the proper heat, it is returned to the anvil, welded, and dressed off between top and bottom tools, after which the cast-iron transverse stay is inserted, and the link having been closed upon the stay, the routine is recommenced. The work commonly requires three men, and the scarf is placed at the side of the oval link, and flatway through the same. In similar chains made by hand it is perhaps more customary to weld the link at the *crown*, or small end.

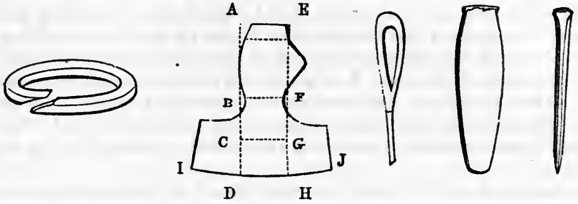
The tires of wrought-iron wheels for locomotive engines and carriages, are in general bent to the circle by somewhat analogous means to those employed in chain-making, as are likewise the skelps for the twisted barrels of guns. The latter only require a mandrel or spindle with a winch-handle at the one extremity, and a loop for the end of the skelp, which is wound in contact with the mandrel by means of a fixed bar placed near the same. Such barrels are coiled up in three lengths, which are joined together after the spirals are welded.

Wheels for railways display many curious examples of smithing; thus some, except the nave, are made entirely by welding; others are partly combined with rivets; in all the nave or boss is a mass of cast-iron usually poured around the ends of the spokes.

The common practice of welding the tires of railway wheels is now as follows: the tires are cut off with ridges in the centre, so as in meeting to form two angular notches, into which two thin iron wedges are subsequently welded radially; the four parts thus united together in the form of a cross, make a very secure joint without the necessity for upsetting the iron, which would distort the form of the tire.

The succeeding illustration of the practice of forging will be that of the formation of a hatchet, Figs. 91 and 92, which like many similar tools is made by doubling the iron around a mandrel, to form the *eye* of the tool; it will also permit the description of some other general proceedings and likewise the introduction of the steel for the cutting edge.

Figs. 90 91 92 93 94



In making the hatchet, a piece of flat iron is selected of the width of A E, and twice the length of A D; it is thinned and extended sideways before it is folded together, to form the projections near B and F, by blows with the pane of the hammer or a round-edged fuller, on the lines A B to E F, but the metal must be preserved of the full thickness at the part A E, to form the poll of the hatchet, although a piece of steel is frequently welded on at that part as a previous step. The work is then bent round a mandrel, Figs. 93 and 94, exactly of the section of the eye as seen in Fig. 92, and the work is welded across the line B F; the mandrel is again introduced, and the eye is perfected.

A slip of shear-steel, equal in length to D H, is next inserted between the two tails of the iron, as yet of their original size, up to the former weld, and all three are welded together between C, G, D, H: the combined iron and steel are now drawn out sideways, by blows of the pane of the hammer on and between C D and G H, to extend them together to I J. The tool is then flattened and smoothed with the face of the hammer, and the edges are pared with straight or circular chisels to the particular pattern, and trimmed with a round-faced hammer, or a top fuller.

In smoothing off the work, the smith pursues his common method of first removing with a file the hard black scales that appear like spots when the work is removed from the fire; he then dips the hammer in the slake trough, and lets fall upon the anvil a few drops of the water it picks up, the explosion of which when the red-hot metal is struck upon it, makes a smart report and detaches the scales that would be otherwise indented in the work. It should be observed that the mandrel, Fig. 93, is purposely made very taper, and is introduced into the hole from both sides, so that the eye may be smaller in the middle; when therefore the handle of the tool is carefully fitted and wedged in, the handle is, as it were, dove-tailed, and the tool can neither fly off nor slip down the handle; the same mode is also adopted for the heads of hammers.

In spades, and many similar implements, the steel is introduced between the two pieces of iron of which the tools are made; in others, as plane irons and socket chisels, it is laid on the outside, and the two are afterwards extended in length or width to the required size. The ordinary chisel for the smith's shop is made by inserting the steel in a cleft, as in Fig. 85, and so is also the *pane* of a hammer; but the flat *face* of the hammer is sometimes stuck on whilst it continues at the extremity of a flat bar of steel; it is then cut off, and the welding is afterwards completed. At other times the face of the hammer is prepared like a nail, with a small spike and a very large head, so as to be driven into the iron to retain its position, until finally secured by the operation of welding.

In putting a piece of steel into the end of an iron rod to serve for a centre, the bar is heated, fixed horizontally in the vice, and punched lengthways with a sharp square punch for the reception of the steel, which is drawn down like a taper tang or thick nail, and driven in; the whole is then returned to the fire, and when at the proper heat united by welding, the blows being first directed as for forming a very obtuse cone, to prevent the piece of steel from dropping out.

For some few purposes the blistered steel is used for welding, either to itself or to iron; it is true the first working under the hammer in a measure changes it to the condition of shear-steel, but less efficiently so than when the ordinary course of manufacture is pursued, as the hammering is found to improve steel in a remarkable and increasing degree.

For the majority of works in which it is necessary to weld steel to iron, or steel to steel, the shear, or double shear, is exceedingly suitable; it is used for welding upon various cutting tools, as the majority of cast-steel will not endure the heat without crumbling under the hammer. Shear-steel is also used for various kinds of springs, and for some cutting tools requiring much elasticity.

It is more usual to reserve the cast-steel for those works in which the process of welding is not required, although of late years mild cast-steel, or welding cast-steel, containing a smaller proportion of carbon has been rather extensively used; but in general the harder the steel the less easily will it admit of welding, and not unfrequently it is altogether inadmissible.

The hard or *harsh* varieties of cast-steel, are somewhat more manageable when fused borax is used as a defence instead of sand, either sprinkled on in powder or rubbed on in a lump: and cast-steel otherwise intractable may be sometimes welded to iron by first heating the iron pretty smartly, then placing the cold steel beside it in the fire, and welding them the moment the steel has acquired its maximum temperature, by which time the iron will be fully up to the welding heat. When both are put into the fire cold alike, the steel is often spoiled before the iron is nearly hot enough, and therefore it is generally usual to heat the iron and steel separately, and only to place them in contact towards the conclusion of the period of getting up the heat. In forging works either of iron or steel, the *uniformity* of the hammering tends greatly to increase and equalize the strength of each material; and in steel, judicious and equal forging greatly lessens also the after-risk in hardening.

When cast-steel has been spoiled by overheating, it may be partially recovered by four or five reheatings and quenchings in water, each carried to an extent a little less and less than the first excess; and lastly, the steel must have a good hammering at the ordinary red heat. Some go so far as to prefer for cutting tools the steel thus recovered, but this seems a most questionable policy, although the change wrought by this treatment is really remarkable; as the fragment broken off from the bar in the spoiled state, and another from the same bar after part restoration and hardening, will exhibit the extreme characters of coarse and fine.

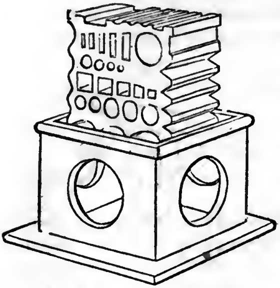
The hammering I suspect to be the principal requisite, and in superior tools it should be continued until the work is nearly cold, to produce the maximum amount of condensation before hardening; but no hammering will restore the loss of tenacity consequent upon the over-heating, or even the too frequent heating, of steel, without excess.

CONCLUDING REMARKS ON FORGING; AND THE APPLICATIONS OF HEADING TOOLS, SWAGE TOOLS, PUNCHES, ETC.—With the utmost care and unlimited space, it would have been quite impossible to have conveyed the instructions called for, in forging the thousand varieties of tools, and parts of mechanism the smith is continually called upon to produce; and all that could be reasonably attempted in this place, was to convey a few of the general features and practices of this most useful and interesting branch of industry. It is hoped, that such combinations of these methods may be readily arrived at as will serve for the majority of ordinary wants.

The smith in all cases selects or prepares that particular form and magnitude of iron, and also adopts that order of proceeding, which experience points out as being the most exact, sound, and economical. In this he is assisted by a large assortment of various tools and moulds for such parts of the work as are often repeated, or that are of a character sufficiently general to warrant the outlay, and to some of which I will advert.

The heading tools, Figs. 53 and 54, are made of all sizes and varieties of form; some with a square recess to produce a square beneath the head, to prevent the bolt from being turned round in the act of tightening its nut; others for countersunk and round-headed bolts, with and without square shoulders: many similar heading tools are used for all those parts of work which at all resemble bolts, in having any sudden enlargement from the stem or shaft. The holes in the swage block, Fig. 95, are used after the manner of heading tools for large objects; the grooves and recesses around its margin, also serve in a variety of works as bottom swages beyond the size of those fitted to the anvil. At the opposite extreme of the heading tools, as to size, may be noticed those constantly employed in producing the smallest kinds of nails, brads and rivets, of various denominations, some of which heading tools divide in two parts like a pair of spring forceps to release the nails after they have been forged.

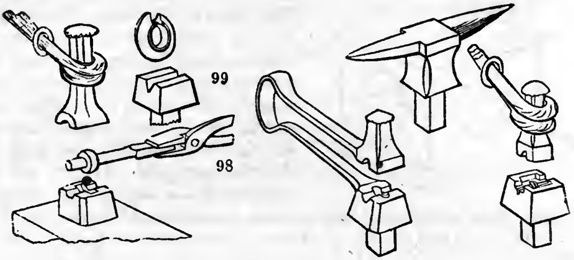
Fig. 95.



The forge used by the nail-makers is built as a circular pedestal with the fire in the centre and the chimney directly over it; the rock-staff of the bellows extends entirely around the forge, so that one of the four or five persons who work at the same fire is continually blowing it, whence the fire is always at a heat proper for welding, and which keeps the nails sound and good. These kinds are called *wrought nails* and brads, in contradistinction to similar nails cut out of sheet-iron by various processes of shearing and punching, which latter kinds are known as *cut brads* and nails, and will be adverted to hereafter.

The top and bottom rounding tools, Fig. 50, are made of all diameters for plain cylindrical works: and when they are used for objects the different parts of which are of various diameters, it requires much care to apply them equally on all parts of the work, that the several circles may be concentric and true one with the other, or possess one axis in common. To insure this condition some of these rounding tools are made of various and specific forms, for the heads of screws, for collars, flanges or enlargements, which are of continual occurrence in machinery; for the ornamental swells or flanges about the iron work of carriages, and other works. Such tools, like the pair represented in Figs. 96 and 97, are called swage or collar tools; they save labor in a most important degree, and are thus made. A solid mould, core or striker, exactly a copy of the work to be produced, is made of steel by hand-forging, and then turned in the lathe to the required form, as shown in Fig. 98.

The top tool is first moulded to the general form in an appropriate aperture in the swage block, Fig. 95, it is faced with steel like a hammer, and the core, Fig. 98, is indented into it; the blows of the sledge-hammer not being given directly upon the core, but upon some hollow tool previously made; otherwise the core must be filed partly flat to present a plane surface to the hammer. The bottom tool, which is fitted to the anvil, is made in a similar manner, and sometimes the two are finished at the same time whilst hot, with the cold striker between them; their edges are carefully rounded with a file so as not to cut the work, and lastly they are hardened, under a stream of water.


Figs. 96 100 103 102 99 98 97 101

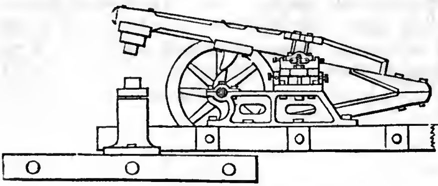
In preparing the work for the collar tools, when the projection is inconsiderable, the work is always drawn down rudely to the form between the top and bottom fullers, as in Fig. 48; but for greater economy, large works in iron are sometimes made by folding a ring around them as in Fig. 56. The metal for a large ring is occasionally moulded in a bottom tool, like Fig. 99, and coiled up to the shape of Fig. 100, after which it is closed upon the central rod between the swages, and then welded within them. The tools are slightly greased, to prevent the work from hanging to them, and from the same motive their surfaces are not made quite flat or perpendicular, but slightly conical, and all the angles are obliterated and rounded.

The spring swage tool, represented in Fig. 101, is used for some small manufacturing purposes; it differs in no respect from the former, except in the steel spring which connects the two parts; it is employed for light single hand-forgings. Other workmen use swage tools, such as Fig. 102, in which there is a square recess in the bottom tool to fit the margin of the top-tool so as to guide it exactly to its true position. In practice the recess in the bottom tool would be deeper, and taper or larger above to guide the tool more easily to its place; but if so drawn the figure would have been less distinct. This kind also may be used for single hand works, and is particularly suited to those which are of rectangular section, as the shoulders of table-knives; these do not admit of being twisted round, which movement furnishes the guide for the position of the top-tool in forging circular works.

The smith has likewise a variety of punches of all shapes and sizes, for making holes of corresponding forms; and also drifts or mandrels, used alone for finishing them, many of which, like the turned cones, are made from a small to a large size to serve for objects of various sizes. Two examples of the very dexterous use of punches, are in the hands of almost every person, namely ordinary scissors and pliers.

The first are made from a small bar of flat steel; the end is flattened and punched with a small round hole, which is gradually opened upon a beak-iron, Fig. 103, attached to the square hole of the anvil; the beak-iron has a shallow groove (accidentally omitted) for rounding the inside of the bows. The remaining parts of the scissors are moulded jointly by the hammer, and bottom swage tools; but the bows are mostly finished by the eye alone.

Figs. 104



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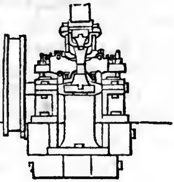
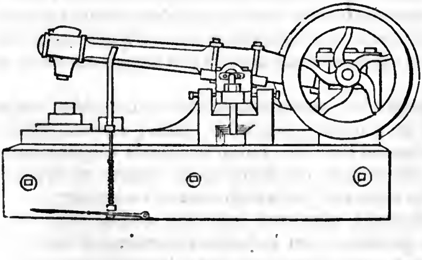


In some pliers, the central half of the joint is first made; the aperture in the other part is then punched through sideways, and sufficiently bulged out to allow the middle joint to be passed through, after which the outsides are closed upon the centre. This proceeding exhibits, in the smallest kinds especially, a surprising degree of dexterity and dispatch, only to be arrived at by very great practice; and which in this and numerous other instances of manufacture could be scarcely attained but for the enormous de-

Figs. 106



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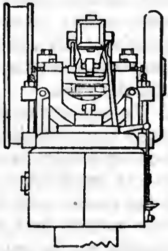

mand, which enables a great subdivision of labor to be successfully applied to their production.

Figs. 104, 105, 106 and 107 represent the ordinary trip and tilt hammer used in this country. The drawings are taken from those manufactured at the Lowell Machine Shop, Lowell, Mass., of which W. A. Burke is the superintendent. The smaller trip-hammers are mounted with iron bed-pieces firmly bolted on large timber, furnished with a cast-iron stake, adapted to drawing and swaging spindles, bolts, and other small work, balance wheels on cam-shaft, and a husk adjustable by bolts and screws; the hammer-head weighing from thirty to one hundred and twenty-five pounds, driven by a belt. The heavy trip-hammer, manufactured in this shop, has a very heavy strong cast-iron frame, adjustable husk, cast-iron stake, driven by belt with balance-wheel on cam-shaft, and suited to a hammer-head weighing from one hundred and twenty-five to four hundred pounds.

CHAPTER IX.

HARDENING AND TEMPERING.

General View of the Subject.—When the malleable metals are hammered or rolled, they generally increase in hardness, in elasticity, and in density or specific gravity; which effects are produced simply from the closer approximation of their particles, and in this respect steel may be perhaps considered to excel, as the process called hammer-hardening, which simply means hammering without heat, is frequently employed as the sole means of hardening some kinds of steel springs, and for which it answers remarkably well.

After a certain degree of compression, the malleable metals assume their closest and most condensed states; and it then becomes necessary to discontinue the compression or elongation, as it would cause the disunion or cracking of the sheet or wire, or else the metal must be softened by the process of annealing.

The metals, lead, tin, and zinc, are by some considered to be perceptibly softened by immersion in boiling water: but such of the metals as will bear it are generally heated to redness, the cohesion of the mass is for the time reduced, and the metal becomes as soft as at first, and the working and annealing may be thus alternately pursued, until the sheet metal, or the wire, reaches its limit of tenuity.

The generality of the metals and alloys suffer no very observable change, whether or not they are suddenly quenched in water from the red heat. Pure hammered iron, like the rest, appears after annealing, to be equally soft whether suddenly or slowly cooled; some of the impure kinds of malleable iron harden by immersion, but only to an extent that is rather hurtful than useful, and which may be considered as an accidental quality.

Steel however receives by sudden cooling that extreme degree of hardness combined with tenacity, which places it so incalculably beyond every other material for the manufacture of cutting tools; especially as it likewise admits of a regular gradation from extreme hardness to its softest state, when subsequently re-heated or *tempered.* Steel therefore assumes a place in the economy of manufacture unapproachable by any other material: consequently we may safely say that without it, it would be impossible to produce nearly all our finished works in metal and other hard substances; for although some of the metallic alloys are remarkable for hardness, and were used for various implements of peaceful industry, and also those of war, before the invention of steel, yet in point of absolute and enduring hardness, and equally so in respect to elasticity and tenacity, they fall exceedingly short of hardened steel.

Hammer hardening renders the steel more fibrous and less crystalline, and reduces it in bulk; on the other hand, fire hardening makes steel more crystalline, and frequently of greater bulk; but the elastic nature of hammer hardened steel will not take so wide nor so efficient a range as that which is fire hardened.

If we attempt to seek the remarkable difference between pure iron and steel in their chemical analyses, it appears to result from a minute portion of carbon; and cast-iron, which possesses a much larger share, presents, as we should expect, somewhat, similar phenomena.

Iron semi-steelified	contains one	150th	of carbon.
Soft cast-steel capable of welding . . .	"	120th	"
Cast-steel for common purposes	"	100th	"
Cast-steel requiring more hardness . . .	"	90th	"
Steel capable of standing a few blows, but quite unfit for drawing		50th	"
First approach to a steely granulated fracture	"	30th to 40th.	
White cast-iron	"	25th	"
Mottled cast-iron	"	20th	"
Carbonated cast-iron	"	15th	"
Super-carbonated crude iron	"	12th	"

For the mode of analysis for ascertaining the quantity of carbon in cast-iron and steel, invented by M. V. Regnault, Mining Engineer, see *Annales de Chimie et de Physique,* for January, 1839; also Journal of the Franklin Institute, vol. xxv. p. 327. It is stated that the analysis is very easy and exact, and may be completed in half an hour.

Moreover, as the hard and soft conditions of steel may be reversed backwards and forwards without any rapid chemical change in its substance, it has been pronounced to result from internal arrangement or crystallization, which may be in a degree illustrated and explained by similar changes observed in glass.

A wine-glass, or other object recently blown, and plunged whilst red hot into cold water, cracks in a thousand places, and even cooled in warm air it is very brittle, and will scarcely endure the slightest violence or sudden change of temperature; and visitors to the glass-house are often shown that a wine-glass, or other article of irregular form, breaks in cooling in the open air from its unequal contraction at different parts. But the objects would have become useful, and less disposed to fracture, if they had been allowed to arrange their particles gradually during their very slow passage through the long annealing oven or *leer* of the glass-house, the end at which they enter being at the red heat, and the opposite extremity almost cold.

To perfect the annealing, it is not unusual with lamp-glasses, tubes for steam-gages, and similar pieces exposed to sudden transitions of heat and cold, to place them in a vessel of cold water, which is slowly raised to the boiling temperature, kept for some hours at that heat and then allowed to cool very slowly: the effect thus produced is far from chimerical. For such pieces of flint glass intended for cutting, as are found to be insufficiently annealed, the boiling is sometimes preferred to a second passage through the leer: lamp-glasses are also much *less* exposed to fracture when they have been once used, as the heat, if not too suddenly applied or checked, completes the annealing.

Steel in like manner when suddenly cooled is disposed to crack in pieces, which is a constant source of anxiety; the danger increases with the thickness in the same way as with glass, and the more especially when the works are unequally thick and thin.

Another ground of analogy between glass and steel appears to exist in the pieces of unannealed glass used for exhibiting the phenomena formerly called double refraction, but now polarization of light; an effect distinctly traced to its peculiar crystalline structure.

In glass it is supposed to arise from the cooling of the external crust more rapidly than the internal mass; the outer crust is therefore in a state of tension, or restraint, from an attempt to squeeze the inner mass into a smaller space than it seems to require; and from the hasty arrangement of the unannealed glass the natural positions of its crystals are in a measure disturbed or dislocated. It has been shown experimentally, that a re-arrangement of the particles of glass occurs in the process of annealing, as, of two pieces of the same tube each 40 inches long, the one sent through the leer contracted one-sixteenth of an inch more than the other, which was cooled as usual in the open air. Tubes for philosophical purposes are not annealed, as their inner surfaces are apt to become soiled with the sulphur of the fuel; they are in consequence very brittle and liable to accident.

The unannealed glass, when cautiously heated and slowly cooled, ceases to present the polarizing effect, and the steel similarly treated ceases to be hard; and may we not therefore indulge in the speculation, that in both cases a peculiar crystalline structure is consequent upon the unannealed or hardened state?

In the process of hardening steel, water is by no means essential, as the sole object is to extract its heat rapidly, and the following are examples, commencing with the condition of extreme hardness, and ending with the reverse condition.

A thin heated blade placed between the cold hammer and anvil, or other good conductors of heat, becomes perfectly hard. Thicker pieces of steel, cooled by exposure to the air upon the anvil, become rather hard, but readily admit of being filed. They become softer when placed on cold cinders, or other bad conductors of heat. Still more soft when placed in hot cinders, or within the fire itself, and cooled by their gradual extinction. When the steel is encased in close boxes with charcoal powder, and it is raised to a red-heat and allowed to cool in the fire or furnace, it assumes its softest state; unless, lastly, we proceed to its partial decomposition. This is done by enclosing the steel with iron turnings or filings, the scales from the smith's anvil, lime, or other matters that will abstract the carbon from its surface; by this mode it is superficially decarbonized, or reduced to the condition of pure soft iron, in the manner practised by Mr. Jacob Perkins, of Massachusetts, in his most ingenious and effective combination of processes, employed for producing in unlimited numbers absolutely identical impressions of bank notes and checks, for the prevention of forgery. These methods of treating steel will be hereafter noticed.

A nearly similar variety of conditions might be referred to as existing in cast-iron in its ordinary state, governed by the magnitude, quality, and management of the castings; independently of which, by one particular method, some cast-iron may be rendered externally as hard as the hardest steel; such are called *chilled iron castings;* and, as the opposite extreme, by a method of annealing combined with partial decomposition, *malleable iron castings* may be obtained, so that cast-iron nails may be clenched.

Again, the purest iron, and most varieties of cast-iron, may, by another proceeding, be superficially converted into steel, and then hardened, the operation being appropriately named *case-hardening.* I therefore propose to illustrate these phenomena collectively, under three divisions: first, the hardening and tempering of steel; secondly, the hardening and annealing of cast-iron; and thirdly, the process of case-hardening.

PRACTICE OF HARDENING AND TEMPERING STEEL.—It may perhaps be truly said, that upon no one subject connected with mechanical art does there exist such a contrariety of opinion, not unmixed with prejudice, as upon that of hardening and tempering steel; which makes it often difficult to reconcile the practices followed by different individuals in order to arrive at exactly similar ends. The real difficulty of the subject occurs in part from the mysteriousness of the change; and from the absence of defined measures, by which either the steps of the process itself, or the value of the results when obtained, may be satisfactorily measured; as each is determined almost alone by the unassisted senses of sight and touch, instead of by those physical means by which numerous other matters may be strictly tested and measured, nearly without reference to the judgment of the individual, which in its very nature is less to be relied upon.

The excellence of cutting-tools, for instance, is pronounced upon their relative degrees of endurance, but many accidental circumstances here interfere to vitiate the strict comparison: and in respect to the measure of simple hardness, nearly the only test is the resistance the objects offer to the file, a mode in two ways defective, as the files differ amongst themselves in hardness; and they only serve to indicate in an imperfect manner to the touch of the individual, a general notion without any distinct measure, so that when the opinion of half a dozen persons may be taken, upon as many pieces of steel differing but slightly in hardness, the want of uniformity in their decisions will show the vague nature of the proof.

Under these circumstances, instead of recommending any particular methods, I have determined to advance a variety of practical examples derived from various sources, which will serve in most cases to confirm, but in some to confute one another; leaving to every individual to follow those examples which may be the most nearly parallel with his own wants. There are, however, some few points upon which it may be said that all are agreed; namely,

The temperature suitable to forging and hardening steel differs in some degree with its quality and its mode of manufacture; the heat that is required diminishes with the increase of carbon:

In every case *the lowest available temperature* should be employed in each process, the hammering should be applied in *the most equal manner throughout*, and for cutting tools it should be continued until they are nearly cold:

Coke or charcoal is much better as a fuel than fresh coal, the sulphur of which is highly injurious:

The scale should be removed from the face of the work to expose it the more uniformly to the effect of the cooling medium:

Hardening a second time without the intervention of hammering is attended with increased risk; and the less frequently steel passes through the fire the better.

In hardening and tempering steel there are three things to be considered; namely, the means of heating the objects to redness, the means of cooling the same, and the means of applying the heat for tempering or letting them down. I will speak of these separately, before giving examples of their application.

The smallest works are heated with the flame of the blowpipe, and are occasionally supported upon charcoal; but as the blowpipe is used to a far greater extent in soldering, its management will be described in the chapter devoted to that process.

For objects that are too large to be heated by the blowpipe, and too small to be conveniently warmed in the naked fire, various protective means are employed. Thus, an iron tube or sheet-iron box inserted in the midst of the ignited fuel is a safe and cleanly way; it resembles the muffle employed in chemical works. The work is then managed with long forceps made of steel or iron wire, bent in the form of the letter U, and flattened or hollowed at the ends. A crucible or an iron pot about four to six inches deep, filled with lead and heated to redness, is likewise excellent, but more particularly for long and thin tools, such as gravers for artists, and other slight instruments; several of these may be inserted at once, although towards the last they should be moved about to equalize the heat; the weight of the lead makes it desirable to use a bridle or trevet for the support of the crucible. Some workmen place on the fire a pan of charcoal dust, and heat it to redness.

Great numbers of tools, both of medium and large size, are heated in the ordinary forge fire, which should consist of cinders rather than fresh coals; coke and also charcoal are used, but far less generally; recourse is also had to hollow fires, the construction of which was explained at page 94; but the bellows should be very sparingly used, except in blowing up the fire before the introduction of the work, *which should be allowed ample time to get hot,* or, as it is called, to "*soak.*"

Which method soever may be resorted to for heating the work, the greatest care should be given to communicate to all the parts requiring to be hardened a *uniform* temperature, and which is only to be arrived at by cautiously moving the work to and fro to expose all parts alike to the fire; the difficulty of accomplishing this of course increases with long objects, for which fires of proportionate length are required.

It is far better to err on the side of deficiency than of excess of heat; the point is rather critical, and not alike in all varieties of steel. Until the quality of the steel is familiarly known, it is a safe precaution to commence rather too low than otherwise, as then the extent of the mischief will be the necessity for a repetition of the process at a higher degree of heat; but the steel, if burned or over-heated, will be covered with scales, and what is far worse, its quality will be permanently injured; a good hammering will, in a degree, restore it; but this in finished works is generally impracticable.

Less than a certain heat fails to produce hardness, and in the opinion of some workmen has quite the opposite effect, and they consequently resort to it as the means of rapid annealing; not, however, by plunging the steel into the water and allowing it to remain until cold, but dipping it quickly, holding it in the steam for a few moments, dipping it again and so on, reducing it to the cold state in a hasty but intermittent manner.

There is another opinion prevalent amongst workmen, that steel which is "*pinny,*" or as if composed of a bundle of hard wires, is rendered uniform in its substance if it is first hardened and then annealed.

Secondly, the choice of the cooling medium has reference mainly to the relative powers of conducting heat they severally possess: the following have been at different times resorted to with various degrees of success: currents of cold air; immersion in water in various states, in oil or wax, and in freezing mixtures; mercury, and flat metallic surfaces have been also used. Plain water, at a temperature of 40° Fahrenheit, has been recommended. On the whole, however, there appears to be an opinion that mercury gives the greatest degree of hardness; then cold salt and water, or water mixed with various "astringent and acidifying matters;" plain water follows; and lastly, oily mixtures.

I find but one person who has commonly used the mercury. Many presume upon the good conducting power of the metal, and the non-formation of steam, which causes a separation betwixt the steel and water, when the latter is employed as the cooling medium. I have failed to learn the *reason* of the advantage of salt and water, unless the fluid have, as well as a greater density, a superior conducting power. The file-makers medicate the water in other ways, but this is one of the questionable mysteries which is never divulged,—although it is supposed that a small quantity of white arsenic is generally added to water saturated with salt. One thing, however, may be noticed, that articles hardened in salt and water are apt to rust, unless they are laid for a time in lime-water, or some neutralizing agent.

With plain water, an opinion very largely exists in favor of that which has been used over and over again, even for years, provided it is not greasy: and when the steel is very harsh, the chill is taken off plain water to lessen the risk of cracking it. Oily mixtures impart to *thin* articles, such as springs, a sufficient and milder degree of hardness, with less danger of cracking, than from water; and in some cases a medium course is pursued by covering the water with a thick film of oil, which is said to be adopted occasionally with scythes, reaping-hooks, and thin edge-tools.

A so-called natural spring is made by a vessel with a true and a false-bottom, the latter perforated with small holes; it is filled with water, and a copious supply is admitted beneath the partition; it ascends through the holes, and pursues the same current as the heated portions, which also escape at the top. This was invented by the late John Oldham, of Dublin, Engineer to the Bank of England, and was used by him in hardening the rollers for transferring the impressions to the steel-plates for bank-notes.

Sometimes when neighboring parts of works are required to be respectively hard and soft, metal tubes or collars are fitted tight upon the work, to protect the parts to be kept soft from the direct action of the water, at any rate for so long a period as they retain the temperature suitable to hardening.

The process of hardening is generally one of anxiety, as the sudden transition from heat to cold often causes the works to become greatly distorted if not cracked. The last accident is much the most likely to occur with thick massive pieces, which are, as it were, hardened in layers,—as although the external crust or shell may be perfectly hard, there is almost a certainty that towards the centre the parts are gradually less hard; and when broken, the inner portions will sometimes admit of being readily filed.

When in the fire the steel becomes altogether expanded, and in the water its outer crust is suddenly arrested, but with a tendency to contract from the loss of heat, which cannot so rapidly occur at the central part; it may be therefore presumed that the inner bulk continues to contract after the outer crust is fixed, and which tends to tear the two asunder, the more especially if there be any defective part in the steel itself. An external flake of greater or less extent not unfrequently shells off in hardening; and it often happens that works remain unbroken for hours after removal from the water, but eventually give way and crack with a loud report, from the rigid unequal tension produced by the violence of the process of hardening.

The contiguity of thick and thin parts is also highly dangerous, as they can neither receive nor yield up heat in the same times. The mischief is sometimes lessened by binding pieces of metal around the thin parts with wire, to save them from the action of the cooling medium. Sharp angular notches are also fertile sources of mischief, and where practicable they should be rejected in favor of curved lines.

As regards both cracks and distortions, it may perhaps be generally said that their avoidance depends principally upon *manipulation, or the successful management of every step:* first, the original manufacture of the steel, its being forged and wrought so that it may be equally condensed on all sides with the hammer, otherwise when the cohesion of the mass is lessened from its becoming red hot, it recovers in part from any unequal state of density in which it may have been placed.

Whilst red hot it is also in its weakest condition. It is therefore prone to injury, either from incautious handling with the tongs, or from meeting the sudden cooling action irregularly, and therefore it is generally best to plunge works vertically, as all parts are then exposed to equal circumstances, and less disturbance is risked than when the objects are immersed obliquely or sideways into the water,—although for swords, and objects of similar form, it is found the best to dip them exactly as in making a vertical downward cut with a sabre, which for this weapon is its strongest direction.

Occasionally objects are clamped between stubborn pieces of metal, as soft iron or copper, during their passage through the fire and water. Such plans can be seldom adopted, and are rarely followed, the success of the process being mostly allowed to depend exclusively upon good general management.

In making the magnets for needles ten inches long, one-fourth of an inch wide, and the two-hundredth part of an inch thick, this precaution entirely failed; and the needles assumed all sorts of distortions when released from between the stiff bars within which they were hardened. The plan was eventually abandoned and the magnets were heated in the ordinary way within an iron tube, and were set straight with the hammer after being let down to a deep orange or brown color. Steel, however, is in the best condition for the formation of good permanent magnets when perfectly hard.

In all cases the thick unequal scale left from the forge should be ground off before hardening, in order to expose a clean metallic surface, otherwise the cooling medium cannot produce its due and equal effect throughout the instrument. The edges also should be left thick, that they may not be burned in the fire; thus it will frequently happen that the extreme end or edge of a tool is inferior in quality to the part within, and that the instrument is much better after it has been a few times ground.

Thirdly, the heat for tempering or letting down. Between the extreme conditions of hard and soft steel there are many intermediate grades, the common index for which is the oxidation of the brightened surface, and it is quite sufficient for practice. These tints, and their respective approximate temperatures, are thus tabulated:

1.	Very pale straw yellow	430 deg.	Tools for metals.
2.	A shade of darker yellow	450 "	
3.	Darker straw yellow	470 "	Tools for wood, and screw taps, etc.
4.	Still darker straw yellow	490 "	
5.	A brown yellow	500 "	Hatchets, chipping chisels, and other percussive tools, saws, etc.
6.	A yellow, tinged slightly with purple	520 "	
7.	Light purple	530 "	
8.	Dark purple	550 "	Springs.
9.	Dark blue	570 "	
10.	Paler blue	590 "	Too soft for the above purposes.
11.	Still paler blue	610 "	
12.	Still paler blue, with a tinge of green	630 "	

The first tint arrives at about 430° F., but it is only seen by comparison with a piece of steel not heated: the tempering colors differ slightly with the various qualities of steel.

The heat for tempering being moderate, it is often supplied by the part of the tool not requiring to be hardened, and which is not therefore cooled in the water. The workman first hastily tries with a file whether the work is hard; he then partially brightens it at a few parts with a piece of grindstone or an emery stick, that he may be enabled to watch for the required color; which attained, the work is usually cooled in any convenient manner, lest the body of the tool should continue to supply heat. But when, on the contrary, the color does not otherwise appear, partial recurrence is had to the mode in which the work is heated, as the flame of the candle, or the surface of the clear fire applied, if possible, a little below the part where the color is to be observed, that it may not be soiled by the smoke.

A very convenient and general manner of tempering small objects is to heat to redness a few inches of the end of a flat bar of iron about two feet long; it is laid across the anvil, or fixed by its cold extremity in the vice; and the work is placed on that part of its surface which is found by trial to be of the suitable temperature, by gradually sliding the work towards the heated extremity. In this manner many tools may be tempered at once, those at the hot part being pushed off into a vessel of water or oil, as they severally show the required color, but it requires dexterity and quickness in thus managing many pieces.

Vessels containing oil or fusible alloys carefully heated to the required temperatures have also been used, and I shall have to describe a method called "*blazing-off*," resorted to for many articles, such as springs and saws, by heating them over the naked fire until the oil, wax, or composition in which they have been hardened ignites; this can only occur when they respectively reach their boiling temperatures and are also evaporated in the gaseous form.

The period of letting down the works is also commonly chosen for correcting, by means of the hammer, those distortions which so commonly occur in hardening; this is done upon the anvil, either with the thin pane of an ordinary hammer, or else with a *hack-hammer*, a tool terminating at each end in an obtuse chisel edge which requires continual repair on the grindstone.

The blows are given on the hollow side of the work, and at right angles to the length of the curve; they elongate the concave side, and gradually restore it to a plane surface, when the blows are distributed consistently with the position of the erroneous parts. The hack-hammer unavoidably injures the surface of the work, but the blows should not be too violent, as they are then also more prone to break the work, the liability to which is materially lessened when it is kept at or near the tempering heat, and the edge of the hack-hammer is slightly rounded.

COMMON EXAMPLES OF HARDENING AND TEMPERING STEEL.—Watchmakers' drills of the smallest kinds are heated in the blue part of the flame of the candle; larger drills are heated with the blowpipe flame, applied very obliquely, and a little below the point; when very thin they may be whisked in the air to cool them, but they are more generally thrust into the tallow of the candle or the oil of a lamp; they are tempered either by their own heat, or by immersion in the flame below the point of the tool.

For tools between those suited to the action of the blowpipe and those proper for the open fire, there are many which require either the iron tube, or the bath of lead or charcoal described at page 149, but the greater number of works are hardened in the ordinary smith's fire, without such defences.

Tools of moderate size, such as the majority of turning tools, carpenters' chisels, and gouges, and so forth, are generally heated in the open fire; they require to be continually drawn backwards and forwards through the fire, to equalize the temperature applied, they are plunged vertically into the water, and then moved about sideways to expose them to the cooler portions of the fluid. If needful, they are only dipped to a certain depth, the remainder being left soft.

Some persons use a shallow vessel filled only to the height of the portion to be hardened, and plunge the tools to the bottom; but this strict line of demarkation is sometimes dangerous, as the tools are apt to become cracked at the part, and therefore a small vertical movement is also generally given, that the transition from the hard to the soft part may occupy more length.

Razors and penknives are too frequently hardened without the removal of the scale arising from the forging; *this practice, which is not done with the best works, cannot be too much deprecated.* The blades are heated in a coke or charcoal fire, and dipped into the water obliquely. In tempering razors, they are laid on their backs upon a clear fire, about half-a-dozen together, and they are removed one at a time, when the edges, which are as yet thick, come down to a pale straw color. Should the backs accidentally get heated beyond the straw color, the blades are cooled in water, but not otherwise. Penknife blades are tempered, a dozen or two at a time, on a plate of iron or copper about twelve inches long, three or four wide, and about a quarter of an inch thick; the blades are arranged close together on their backs, and lean at an angle against each other. As they come down to the temper, they are picked out with small pliers and thrown into water if necessary; other blades are then thrust forward from the cooler parts of the plate to take their place.

Hatchets, adzes, cold chisels, and numbers of similar tools, in which the total bulk is considerable compared with the part to be hardened, are only partially dipped; they are afterwards let down by the heat of the remainder of the tool, and when the color indicative of the temper is attained, they are entirely quenched. With the view of removing the loose scales, or the oxidation acquired in the fire, some workmen rub the objects hastily in dry salt before plunging them in the water, in order to give them a cleaner and whiter face.

In hardening large dies, anvils, and other pieces of considerable size, by direct immersion, the rapid formation of steam at the sides of the metal prevents the free access of the water for the removal of the heat with the required expedition; in these cases, a copious stream of water from a reservoir above is allowed to fall on the surface to be hardened. This contrivance is frequently called a "float," and although the derivation of the name is not very clear, the practice is excellent, as it supplies an abundance of cold water; and which, as it falls directly on the centre of the anvil, is sure to render that part hard. It is, however, rather dangerous to stand near such works at the time, as when the anvil face is not perfectly welded, it sometimes in part flies off with great violence and a loud report.

Occasionally the object is partly immersed in a tank beneath the fall of water, by means of a crane and slings; it is ultimately tempered with its own heat, and dropped in the water to become entirely cold.

Oil, or various mixtures of oil, tallow, wax, and resin, are used for many thin and elastic objects, such as needles, fish-hooks, steel pens and springs, which require a milder degree of hardness than is given by water.

For example, steel pens are heated in large quantities in iron trays within a furnace, and are then hardened in an oily mixture; generally they are likewise tempered in oil, or a composition the boiling point of which is the same as the temperature suited to letting them down. This mode is particularly expeditious, as the temper cannot fall below the assigned degree. The dry heat of an oven is also used, and both the oil and oven may be made to serve for tempers harder than that given by boiling oil; but more care and observation are required for these lower temperatures.

Saws and springs are generally hardened in various compositions of oil, suet, wax and other ingredients, which, however, lose their hardening property after a few weeks' constant use: the saws are heated in long furnaces, and then immersed horizontally and edge-ways in a long trough containing the composition; two troughs are commonly used, the one until it gets too warm, then the other for a period, and so on alternately. Part of the composition is wiped off the saws with a piece of leather, when they are removed from the trough, and they are heated one by one over a clear coke fire, until the grease inflames; this is called "*blazing off*."

The composition used by an experienced saw-maker is two pounds of suet and a quarter of a pound of bees-wax to every gallon of whale-oil; these are boiled together, and will serve for thin works and most kinds of steel. The addition of black resin, to the extent of about one pound to the gallon, makes it serve for thicker pieces and for those it refused to harden before; but the resin should be added with judgment, or the works will become too hard and brittle. The composition is useless when it has been constantly employed for about a month; the period depends, however, on the extent to which it is used, and the trough should be thoroughly cleansed out before new mixture is placed in it.

The following recipe is recommended:

Twenty gallons of spermaceti oil;
Twenty pounds of beef suet rendered;
One gallon of neat's-foot oil;
One pound of pitch;
Three pounds of black resin.

These last two articles must be previously melted together, and then added to the other ingredients; when the whole must be heated in a proper iron vessel, with a close cover fitted to it, until the moisture is entirely evaporated, and the composition will take fire on a flaming body being presented to its surface, but which must be instantly extinguished again by putting on the cover of the vessel.

When the saws are wanted to be rather hard, but little of the grease is burned off; when milder, a larger portion; and for a spring temper, the whole is allowed to burn away. When the work is thick, or irregularly thick and thin, as in some springs, a second and third dose is burned off, to insure equality of temper at all parts alike.

Gun-lock springs are sometimes literally *fried in oil* for a considerable time over a fire in an iron tray; the thick parts are then sure to be sufficiently reduced, and the thin parts do not become the more softened from the continuance of the blazing heat.

Springs and saws appear to lose their elasticity, after hardening and tempering, from the reduction and friction they undergo in grinding and polishing. Towards the conclusion of the manufacture, the elasticity of the saw is restored principally by hammering, and partly by heating it over a clear coke fire to a straw color: the tint is removed by very diluted muriatic acid, after which the saws are well washed in plain water and dried.

Watch springs are hammered out of round steel wire, of suitable diameter, until they fill the gage for width, which at the same time insures equality of thickness; the holes are punched in their extremities, and they are trimmed on the edge with a smooth file; the springs are then tied up with binding-wire, in a loose *open* coil, and heated over a charcoal fire upon a perforated revolving plate, they are hardened in oil, and blazed off.

The spring is now distended in a long metal frame, similar to that used for a saw blade, and ground and polished with emery and oil, between lead blocks; by this time its elasticity appears quite lost, and it may be bent in any direction; its elasticity is, however, entirely restored by a subsequent hammering on a very bright anvil, which "*puts the nature into the spring.*"

The coloring is done over a flat plate of iron, or hood, under which a little spirit-lamp is kept burning; the spring is continually drawn backwards and forwards, about two or three inches at a time, until it assumes the orange or deep blue tint throughout, according to the taste of the purchaser; by many the coloring is considered to be a matter of ornament, and not essential. The last process is to coil the spring into the spiral form, that it may enter the barrel in which it is to be contained; this is done by a tool with a small axis and winch handle, and does not require heat.

The balance-springs of marine chronometers, which are in the form of a screw, are wound into the square thread of a screw of the appropriate diameter and coarseness; the two ends of the spring are retained by side screws, and the whole is carefully enveloped in platinum-foil, and tightly bound with wire. The mass is next heated in a piece of gun barrel closed at the one end, and plunged into oil, which hardens the spring almost without discoloring it, owing to the exclusion of the air by the close platinum covering, which is now removed, and the spring is let down to the blue, before removal from the screwed block.

The balance or hair-springs of common watches are frequently left soft; those of the best watches are hardened in the coil upon a plain cylinder, and are then curled into the spiral form between the edge of a blunt-knife and the thumb, the same as in curling up a narrow ribbon of paper, or the filaments of an ostrich feather.

Thirty-two hundred balance springs weigh about an ounce. The soft springs are worth 60 cents each; the hardened and tempered springs, $1.26 each. This raises the value of the steel, originally less than four cents, to $2000 and $8000 respectively. But springs also include the heaviest examples of hardened steel works uncombined with iron: for example, bow-springs for all kind of vehicles, some intended for railway use, measure 3½ feet long, and weigh 50 pounds each piece; two of these are used in combination; other single springs are 6 feet long, and weigh seventy pounds. The principle of these bow-springs will be immediately seen, by conceiving the common archery bow fixed horizontally with its cord upwards; the body of the carriage being attached to the cord sways both perpendicularly and sideways with perfect freedom.

In hardening them they are heated by being drawn backwards and forwards through an ordinary forge fire, built hollow, and they are immersed in a trough of plain water: in tempering them they are heated until the black red is just visible at night; by daylight the heat is denoted by its making a piece of wood sparkle when rubbed on the spring, which is then allowed to cool in the air. The metal is nine-sixteenths of an inch thick, and some consider five-eighths the limits to which steel will harden properly, that is sufficiently alike to serve as a spring; their elasticity is tested far beyond their intended range.

Great diversity of opinion exists respecting the cause of elasticity in springs; by some it is referred to different states of electricity; by others the elasticity is considered to reside in the thin blue, oxidized surface, the removal of which is thought to destroy the elasticity, much in the same manner that the elasticity of a cane is greatly lost by stripping off its silicious rind. The elasticity of a thick spring is certainly much impaired by grinding off a small quantity of its exterior metal, which is harder than the inner portion; and perhaps thin springs sustain in the polishing a proportional loss, which is to them equally fatal.

It has been stated that the bare removal of the blue tint from a pendulum spring, by its immersion in weak acid, caused the chronometer to lose nearly one minute each hour; a second and equal immersion scarcely caused any further loss. It is supposed springs get stronger, in a minute degree, during the first two or three years they are in use, from some atmospheric change; when the springs are coated with gold by the electrotype process, no such change is observable, and the covering, although perfect, may be so thin as not to compensate for the loss of the blue oxidized surface.

LESS COMMON EXAMPLES OF HARDENING, AND PRECAUTIONARY MEASURES.—English writers are famous all over the world for distributing between themselves and their friends the inventions and discoveries of the rest of mankind. One of the leading points of Jacob Perkins's discovery is disposed of in an original manner in the following paragraph. I thought I was up to every mode in which they drag in their friends; but this mode is new to me.

One of the most serious evils in hardening steel, especially in thick blocks, or those which are unequally thick and thin, is their liability to crack, from the sudden transition; and in reference to hardening razors, a case in point: Mr. —— mentions it as the observation and practice of one of his workmen, "that the charcoal fire should be made up with shavings of leather;" and upon being asked what good he supposed the leather could do, this workman replied, "that he could take upon him to say that he never had a razor crack in the hardening since he had used this method, though it was a frequent occurrence before."

When brittle substances crack in cooling, it always happens from the outside contracting and becoming too small to contain the interior parts. But it is known that hard steel occupies more space than when soft; and it may easily be inferred that the nearer the steel approaches to the state of iron, the less will be this increase of dimensions. If, then, we suppose a razor or any other piece of steel to be heated in an open fire with a current of air passing through it, the external part will, by the loss of carbon, become less steely than before; and when the whole piece comes to be hardened, the inside will be too large for the external part, which will probably crack. But if the piece of steel be wrapped up in the cementing mixture, or if the fire itself contain animal coal, and is put together so as to operate in the manner of that mixture, the external part, instead of being degraded by this heat, will be more carbonated than the internal part, in consequence of which it will be so far from splitting or bursting during its cooling that it will be acted upon in a contrary direction, tending to render it more dense and solid.

The cracking which so often occurs on the immersion of steel articles in water, does not appear to arise so much from any decarbonization of the surface merely, as from the sudden condensation and contraction of a superficial portion of the metal, while the mass inside remains swelled with the heat, and probably expands for a moment, on the outside coming in contact with the water.

The file-makers, to save their works from *clinking* or cracking partly through in hardening, draw the files through yeast, beer-grounds, or any sticky material, and then through a mixture of common salt and animal hoof roasted and pounded. This is corroborative of the above, as in the like manner it supplies a little carbon to the outside, and also renders the steel somewhat harder and less disposed to crack; the composition also renders the more important service of protecting the fine points of the teeth from being injured by the fire.

An analogous method is now practised in hardening Murphy's axletrees, which are of wrought-iron, with two pieces of steel welded into the lower side, where they rest upon the wheels and sustain the load. The work is heated in an open forge fire, quite in the ordinary way, and when it is removed, a mixture, principally the prussiate of potash, is laid upon the steel; the axletree is then immediately immersed in water, and additional water is allowed to fall upon it from a cistern. The steel is considered to become very materially harder for the treatment, and the iron around the same is also partially hardened.

These are, in fact, applications of the case-hardening process which is usually applied to wrought-iron for giving it a steely exterior, as the name very properly implies. Occasionally, steel which hardens but imperfectly, either from an original defect in the material, or from its having become deteriorated by bad treatment, or too frequent passage through the fire, is submitted to the case-hardening process in the ordinary way, by inclosing the objects in iron boxes, as will be explained.

Jacob Perkins's admirable process of transfer engraving may be thus explained. A soft steel plate was first engraved with the required subject in the most finished style of art, either by hand or mechanically, or the two combined, and the plate was then hardened. A decarbonized steel cylinder was next rolled over the hardened plate by powerful machinery until the engraved impression appeared in relief, the hollow lines of the original becoming ridges upon the cylinder. The roller was reconverted to the condition of ordinary steel and hardened, after which it served for returning the impression to any number of decarbonized plates, every one of which became absolutely a *counterpart* of the original; and every plate, when hardened, would yield the enormous number of 150,000 impressions without any perceptible difference between the first and the last.

In the event of any accident occurring to the transfer roller, the original plate still existed, from which another or any required number of rollers could be made, and from these rollers any number of new plates, all capable of producing as many impressions as above cited.

The present practice at the Bank of England, introduced by the late Mr. John Oldham, and now under the superintendence of his son, Mr. Thomas Oldham, is to anneal at one time four cast-iron boxes, each containing from three to six steel plates, surrounded on all sides with fine charcoal mixed with an equal quantity of chalk and driven in hard.

The reverberatory furnace employed has a circular cast-iron plate or bed upon which the four boxes are fastened by wedges, and as the plate revolves very slowly and continually by the steam-engine employed in working the printing-presses and other machinery, the plates are exposed in the most equal manner to the heat, and when the proper temperature is attained all the apertures are carefully closed and luted, to extend the cooling over a space of at least forty-eight hours.

The surfaces of the cylinders and plates are thus rendered exceedingly soft, to the depth of about the 32d of an inch, "so as to become more like lead than any thing else," and thus much of their surfaces must be turned or planed off; the device is raised in the transfer-press upon the natural soft steel of the rollers, under a pressure of some tons, and these are hardened without any intentional application of the case-hardening process, as the simple steel is undoubtedly very superior in all respects to that which has been decarbonized and reconverted.

The plates themselves are used in the soft state, as they then admit of reparation by the transfer rollers; and the process is found to be more economical, as the risk of warping is avoided, and they may be easily repaired. The dates and numbers are at present printed as a second process by letter-press printing, with the machines invented by the late Mr. Bramah, and which have been engraved and described in different books.

In hardening engraved plates, rollers, dies, and similar works, it is of the greatest importance to preserve the surface unimpaired, and as steel is very liable to oxidation at the red heat if exposed to the air for even a few seconds, and which oxidized scale will in some cases nearly remove, or at any rate injure, the subject produced upon its surface, it is of great importance to conduct the heating and cooling with the most complete exclusion of the air.

Mr. Thomas Oldham has, more recently, introduced a mode of proceeding which appears as near to perfection as possible, and by it, instead of the works acquiring the ordinary black and gray tints, and a minute roughness, like the surface of the finest emery paper, the steel comes out of the water as smooth to the touch as at first, and mottled with all the beautiful tints seen on case-hardened gun-locks. The method is simply as follows:

The work to be hardened is inclosed in a wrought-iron box with a loose cover, a false bottom, and with three ears projecting from its surface about midway; the steel is surrounded on all sides with carbon from leather, driven in hard, and the cover and bottom are carefully luted with moist clay. Thus prepared, the case is placed in the vertical position, in a bridle fixed across a great tub, which is then filled with water almost to touch the false bottom of the case. The latter is now heated in the furnace as quickly as will allow the uniform penetration of the heat.

When sufficiently hot, it is removed to its place in the hardening tub, the cover of the iron box is removed, and the neck or gudgeon of the cylinder is grasped, *beneath the surface of the carbon*, with a long pair of tongs, upon which a coupler is dropped to secure the grasp. It only remains for the individual to hold the tongs with a glove whilst a smart tap of a hammer is given on their extremity; this knocks out the false bottom of the case, and the cylinder and tongs are instantly immersed in the water; the tongs prevent the cylinder from falling on its side, and thus injuring its delicate but still hot surface. For square plates, a suitable frame is attached by four slight claws, and it is the frame which is seized by the tongs: the latter are sometimes held by a chain, which removes the risk of accident to the individual. In some cases, the work assumes a striated and mackled appearance, evident to the touch as well as the sight, and which is to be attributed to an imperfect manufacture of the steel.

Mr. Oldham informs me that in the Paris Mint, the dies are inclosed in the soot of burnt wood; and that in the Royal mint the dies are hardened by a powerful jet of water. He also adds, that his workpeople have the impression that steel is reduced to its softest state by enclosure with lime and ox-gall.

Various methods have been likewise attempted to prevent the distortions to which work is liable in the operation of hardening, but without any very advantageous results; for instance, it has been recommended to harden small cylindrical wires, by rolling them when heated between cold metallic surfaces to retain them perfectly straight. This might probably answer, but unfortunately cylindrical steel wires supply but a very insignificant portion of our wants.

Another mode tried by Dr. Wollaston was to inclose the piece of steel in a tube filled with Newton's fusible alloy, the whole to be heated to redness and plunged in cold water: the object was released by immersion in boiling water, which melted the alloy, and the piece came out perfectly unaltered in form, and quite hard. This mode is too circuitous for common practice, and the reason why it is to be always successful is not very apparent.

Is not this a base attempt to drag in Newton and Wollaston? To these men the English attribute every thing. Jacob Perkins was an American to whom all the credit is due. The two Oldhams were Irishmen, Brunel was a Frenchman, and Bramah was a German.

Mr. Perkins resorted to a very simple practice with the view of lessening the distortion of his engraved steel plates by boiling the water in which they were to be hardened to drive off the air, and plunging them vertically; and as the plates were required to be tempered to a straw color, instead of allowing them to remain in the water until entirely cold, he removed them whilst the inside was still hot, and placed them on the top of a clear fire until the tallow with which they were rubbed, smoked; the plate was then returned to the water for a few moments, and so on alternately until they were quite cold, the surface never being allowed to exceed the tempering heat.

From various observations, it appears on the whole to be the best in thick works thus to combine the hardening and tempering processes, instead of allowing the objects to become entirely cold, and then to reheat them for tempering. To ascertain the time when the plate should be first removed from the water, Mr. Perkins heated a piece of steel to the straw color, and dipped it into water to learn the sound it made; and when the hardened plate caused the *same* sound, it was considered to be cooled to the right degree, and was immediately withdrawn.

I will conclude these numerous examples and remarks by one of a very curious, massive, and perfect kind, in which the hardening is sure to occur without loss of figure, unless the work break under the process. I refer to the locomotive wheels with hardened steel tires, which may be viewed as the most ponderous example of hardening, as the tires of the eight-foot wheels weigh about 10 cwt., and consist of about one-third steel, and there seems no reason why this diameter might not be greatly exceeded.

The materials for the tires are first swaged separately, and then welded together under the heavy hammer at the steel-works, after which they are bent to the circle, welded, and turned to certain gages. The tire is now heated to redness in a circular furnace: during the time it is getting hot, the iron wheel, previously turned to the right diameter, is bolted down upon a face-plate; the tire expands with the heat, and when at a cherry-red, it is dropped over the wheel, for which it was previously too small, and is also hastily bolted down to the surface plate, the whole load is quickly immersed by a swing crane into a tank of water about five feet deep, and hauled up and down until nearly cold; the steel tires are not afterwards tempered.

The spokes are forged out of flat bars with T formed heads; these are arranged radially in the founder's mould, whilst the cast-iron centre is poured around them: the ends of the T heads are then welded together to constitute the periphery of the wheel or inner tire, and little wedge-form pieces are inserted where there is any deficiency of iron.

The wheel is then chucked on a lathe, bored, and turned on the edge, not cylindrically, but like the meeting of two cones, and about one quarter of an inch higher in the middle than on the two edges. The compound tire is turned to the corresponding form, and consequently larger within or under-cut, so that the shrinking secures the tire without the possibility of obliquity or derangement, and no rivets are required. It sometimes happens that the tire breaks in shrinking when by mismanagement the diameter of the wheel is in excess.

CHAPTER X.

HARDENING CAST AND WROUGHT-IRON.

THE similitude of chemical constitution between steel, which usually contains about one per cent. of carbon, and cast-iron that has from three to six or seven per cent., naturally leads to the expectation of some correspondence in their characters, and which is found to exist. Thus some kinds of cast-iron will harden almost like steel, but they generally require a higher temperature; and the majority of cast-iron, also like steel, assumes different degrees of hardness, according to the rapidity with which the pieces are allowed to cool.

The casting left undisturbed in the mould, is softer than a similar one exposed to the air soon after it has been poured. Large castings cannot cool very hastily, and are seldom so hard as the small pieces, some of which are hardened like steel by the moisture combined with the moulding sand, and cannot be filed until they have been annealed after the manner of steel, which renders them soft and easy to be worked.

Chilled iron-castings present as difficult a problem as the hardening and tempering of steel; the fact is simply this, that iron castings, made in iron moulds under particular circumstances, become on their outer surfaces perfectly hard, and resist the file almost like hardened steel; the effect is however superficial, as the chilled exterior shows a distinct line of demarkation when the objects are broken.

The production of chilled castings is always a matter of some uncertainty, and depends upon the united effect of several causes; the quality of the iron, the thickness of the casting, the temperature of the iron at the time of pouring, and the condition or temperature of the iron mould, which has a greater effect in "striking in" when the mould is *heated* than if quite cold: a very thin stratum of earthy matter will almost entirely obviate the chilling effect. A cold mould does not generally chill so readily as one heated nearly to the extent called "black-hot:" but the reverse conditions occur with some cast-iron. The hard portion varies from less than one-sixteenth to more than one-fourth of an inch in thickness.

There is this remarkable difference between cast-iron thus hardened, and steel hardened by plunging whilst hot into water; that whereas the latter is softened again by a dull red-heat, the chilled castings on the contrary are turned out of the moulds as soon as the metal is set, and are allowed to cool in the air; yet although the whole is at a bright red heat, no softening of the chilled part takes place. This material has been employed for punches for red-hot iron; the punches were fixed in cast-iron sockets, from which they only projected sufficiently to perforate the wheel tires in the formation of which they were used, and from retaining their hardness they were more efficient than those punches made of steel.

Chilled castings are also commonly employed for axletree boxes, and naves of wheels, which are finished by grinding only; also for cylinders for rolling metal, for the heavy hammers and anvils or stithies for iron works, the stamp-heads for pounding metallic ores, etc. Cannon balls, as well as ploughshares, are examples of chilled castings; with balls the chilling is unimportant, and occurs alone from the method essential to giving the balls the required perfection of form and size.

Malleable iron-castings are at the opposite extreme of the scale, and are rendered externally *soft* by the abstraction of their carbon. whereby they are nearly reduced to the condition of pure malleable iron, but without the fibre which is due to the hammering and rolling employed at the forge.

The malleable iron-castings are made from the rich iron, and are at first as brittle as glass or hardened steel; they are enclosed in iron boxes of suitable size, and surrounded with pounded ironstone, or some of the metallic oxides, as the scales from the iron forge, or with common lime, and various other absorbents of carbon, used either together or separately. The cases, which are sometimes as large as barrels, are luted, rolled into the ovens or furnaces, and submitted to a good heat for about five days, and are then allowed to cool very gradually within the furnaces.

The time and other circumstances determine the depth of the effect; thin pieces become malleable entirely through; they are then readily bent, and may be slightly forged; cast-iron nails and tacks thus treated admit of being clenched, thicker pieces retain a central portion of cast-iron, but in a softened state, and not brittle as at first; on sawing them through, the skin or coat of soft iron is perfectly distinct from the remainder.

This mode is particularly useful for thin articles that can be more economically and correctly cast, than wrought at the forge, as bridle-bits, snuffers, parts of locks, culinary and other vessels, pokers and tongs, many of which are subsequently case-hardened and polished, as will be explained, but malleable cast-iron should never be used for cutting-tools.

CASE-HARDENING WROUGHT AND CAST-IRON.—The property of hardening is not possessed by pure malleable iron; but I have now to explain a rapid and partial process of cementation, by which wrought-iron is first converted exteriorly into steel, and is subsequently hardened to that particular depth; leaving the central parts in their original condition of soft fibrous iron. The process is very consistently called *case-hardening*, and is of great importance in the mechanical arts, as the pieces combine the economy, strength, and internal flexibility of iron, with a thin casting of steel; which, although admirable as an armor of defence from wear or deterioration as regards the surface, is unfit for the formation of cutting edges or tools, owing to the entire absence of hammering, subsequent to the cementation with the carbon. Cast-iron obtains in like manner a coating of steel, which surrounds the peculiar shape the metal may have assumed in the iron-foundry and workshop.

The principal agents used for case-hardening are animal matters, as the hoofs, horns, bones, and skins of animals; these are nearly alike in chemical constitution; they are mostly charred and coarsely pounded; some persons also mix a little common salt with some of the above. The work should be surrounded on all sides with a layer from half an inch to one inch thick.

The methods pursued by different individuals do not greatly differ; for example, the gunsmith inserts the iron work of the gun-lock, in a sheet-iron case in the midst of bone-dust (often not burned), the lid of the box is tied on with iron wire, and the joint is luted wth clay; it is then heated to redness as quickly as possible, and retained at that heat from half an hour to an hour, and the contents are quickly immersed in cold water. The objects sought are a steely exterior, and a clean surface covered with the pretty mottled tints, apparently caused by oxidation from the partial admission of air.

Some of the malleable iron castings, such as snuffers, are case-hardened to admit of a better polish; it is usually done with burnt bone-dust, and at a dull red heat; they remain in the fire about two or three hours, and should be immersed in oil, as it does not render them quite so brittle as when plunged into water. It must be remembered they are sometimes changed throughout their substance into an inferior kind of steel, by a process that should in such instances be called cementation, and not *case*-hardening, consequently they will not endure violence.

The mechanician and engineer use horns, hoofs, bone-dust, and leather, and allow the period to extend from two to eight hours, most generally four or five; sometimes for its greater penetration, the process is repeated a second time with new carbonaceous materials. Some open the box and immerse the work in water, direct from the furnace; others, with the view to preserve a better surface, allow the box to cool without being opened, and harden the pieces with the open fire as a subsequent operation; the carbon once added, the work may be annealed and hardened much the same as ordinary steel.

When the case-hardening is required to terminate at any particular part, as a shoulder, the object is left with a band or projection, the work is allowed to cool without being immersed in water the band is turned off, and the work when hardened in the open fire is only affected so far as the original cemented surface remains.

A new substance for the case-hardening process, but containing the same elements as those more commonly employed, has of late years been added, namely, the prussiate of potash (a salt consisting of two atoms of carbon and one of nitrogen), which is made from a variety of animal matters.

It is a new application without any change of principle; the time occupied in this steelifying process is sometimes only minutes instead of hours and days, as for example when iron is heated in the open fire to a dull red, and the prussiate is either sprinkled upon it or rubbed on in the lump, it is returned to the fire for a few minutes and immersed in water; but the process is then exceedingly superficial, and it may if needful be limited to any particular part upon which alone the prussiate is applied. The effect by many is thought to be partial or in spots, as if the salt refused to act uniformly; in the same manner that water only moistens a greasy surface in places.

The prussiate of potash has been used for case-hardening the bearings of wrought-iron shafts, but this seems scarcely worth the doing.

In the general way, the conversion of the iron into steel, by case-hardening, is quite superficial, and does not exceed the sixteenth of an inch; if made to extend to one-quarter or three-eighths of an inch in depth, to say the least it would be generally useless, as the object is to obtain durability of surface, with strength of interior, and this would disproportionately encroach on the strong iron within. The steel obtained in this adventitious manner is not equal in strength to that converted and hammered in the usual way, and if sent in so deeply, the provision for wear would far exceed that which is required.

Let us compare the case-hardening process with the usual conversion of steel. The latter requires a period of about seven days, and a very pure carbon, namely, wood charcoal, of which a minute portion only is absorbed; and it being a simple body, when the access of air is prevented by the proper security of the troughs, the bulk of the charcoal remains unconsumed, and is reserved for future use, as it has undergone no change. The hasty and partial process of cementation is produced in a period commonly less than as many hours with the animal charcoal, or than as many minutes with the prussiate of potash; but all these are compound bodies (which contain cyanogen, a body consisting of carbon and nitrogen), and are never used a second time, but on the contrary the process is often repeated with another dose. It would be, therefore, an interesting inquiry for the chemist, as to whether the cyanogen is absorbed after the same manner as carbon in ordinary steel, or whether the nitrogen assists in any way in hastening the admission of the carbon, by some as yet untraced affinity or decomposition. It may happen that the carbon is not essential, as the Indian steel or wootz is stated to contain alumina, silex, and manganese.

This hasty supposition will apply less easily to cast-iron, which contains from three to seven times as much carbon as steel, and although not always hardened by simple immersion, is constantly under the influence of the case-hardening process; unless we adopt the supposition, that the carbon in cast-iron which is mixed with the metal in the shape of cinder in the blast furnace, when all is in a fluid state, is in a less refined union than that instilled in a more aeriform condition in the acts of cementation and case-hardening.

CHAPTER XI.

ON THE APPLICATION OF IRON TO SHIP-BUILDING.

THERE is probably no branch of industry in which the use of iron is more important than that of ship-building. The strength, ductility, and comparative lightness of this material are all in its favor; and, although much has been done in the application of iron to this important purpose, a great deal more remains to be accomplished.

Vessels composed of iron plates have been employed for more than fifty years in the navigation of canals; but it is not more than twenty-five or twenty-six since they were first introduced as sea-going vessels. It is true that the late Mr. Aaron Manby projected an iron vessel in 1820, which was built in the ensuing year, and early in 1822 was navigated by Captain (since Admiral Sir Charles) Napier from London to Havre, and on to Paris; this, however, was not a sea-going vessel, but an iron steamer constructed for the Seine, and which for many years navigated that river between Paris and Rouen.

From this period little appears to have been done in furtherance of the application of iron to the construction of ships till 1829–30, when the introduction of a new system of traction at high velocities on canals led to new developments; and from this time to the present, iron, as a material for ship-building, has been extensively used, and is increasingly in demand. From 1829 to 1832, iron ship-building may be considered to have been experimental; and the trials conducted by Mr. Fairbairn on the Forth and Clyde Canal,* simultaneously with those of Mr. John and Mr. McGregor Laird at Liverpool, led to a new era in the history of ship-building.

Among the first iron vessels for sea-going purposes was one of small tonnage, built at Manchester for the Forth and Clyde Canal Company. She was built with paddle-wheels on the quarter near the stern, and propelled by two high-pressure engines of, collectively, 30 horse-power. This vessel attained great speed, considering the date at which she was built; and for many years traded between Grangemouth and the coast of Fife, round to Dundee.

Previously to the building of the "Manchester," another small vessel, called the "Lord Dundas," was constructed for the same

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* Vide "Remarks on Canal Navigation," by W. Fairbairn. Longman, 1831.

company. She was strictly experimental, and was propelled by a locomotive engine of 16 horse-power, with 8-inch cylinders. Such was the lightness of her construction, that the plates were only 1-14th of an inch thick, riveted to light T iron, which formed the ribs of the hull. This vessel had stern paddles, and was of the following dimensions:—

Length, 68 feet.
Breadth on beam, 11 feet 6 inches.
Depth, 4 feet 6 inches.
Diameter of paddle-wheel, 9 feet.
Whole weight, including engine, paddle-wheel, etc., 7 tons 16 cwt.
Draught of water with cargo on board, 16 inches.

The "Lord Dundas" was built in 1830, conveyed through the streets of Manchester on trucks, and launched into the Irwell, where numerous trials took place in regard to her speed in narrow channels, such as canals; including such other direct experiments as were likely to result from vessels of this kind propelled by steam. Subsequently to these trials she was navigated to Liverpool, and from thence to Glasgow *via* the Isle of Man. As this voyage was rather a perilous one, when the slightness of the vessel's build and the thinness of her sheathing-plates are considered, and as it was among the first—if, indeed, it were not the very first—which indicated the necessity of adjusting the compass in order to neutralize the local attraction of the material by which it was surrounded, we may probably be permitted to give a brief narrative of the circumstances as they occurred during the voyage. The "Lord Dundas" sailed from Liverpool at four A.M. on a fine morning in June, 1831, and steered direct for the floating-light. She made the light in good time, notwithstanding a thick haze in the atmosphere, which, during the forenoon, thickened into a dense fog. Towards one o'clock land was descried upon the starboard bow, showing apparently that she had made considerable deviation in a westerly direction. A dispute arose as to what land it was—one party contending that it was the western side of the Isle of Man; the other, better acquainted with that side of the island, that it was not. After a considerable contest and examination of the charts, it was at last discovered that the little vessel was on the north of Morecambe Bay, approaching the coast of Cumberland. On the discovery of this error, and in consequence of the frail bark showing symptoms of weakness, from the effects of the swell which was rolling in from the west, it was considered desirable to look out for shelter; and consequently her course was altered in the direction of the Island of Peel Foundry, where she was sheltered for the night. On the following morning she crossed to Ramsey, where the question of the variation of the compass was investigated, and rectified by the simple process of nailing a block of iron to the deck, in the immediate vicinity of the compass—by this means neutralizing the local attraction of the iron by which it was surrounded. After this, the remainder of the voyage from Ramsey to Greenock was effected in a direct course with perfect safety.

We have noticed these circumstances as illustrating the imperfect state of our knowledge, as respects the influence of large masses of iron upon the ship's compass. It has been ascertained that the angle-iron and T iron ribs, when carried above the deck so as to form part of the bulwarks, had a remarkable effect upon the compass, each of them forming, as it were, a separate magnet, whose influence, unless neutralized by some greater magnetic power, caused a considerable deviation of the needle, so that it indicated a point wide of the magnetic north; and as this deviation altered with every change of the position of the vessel, no reliance could be placed upon it. Captain Johnson and Professor Airey, by an interesting series of experiments, ultimately settled this question, and provided a remedy in the adjustment and correction of the compass on board iron ships.

The object contemplated by this light vessel and light machinery was, to ascertain how far quick speeds could be attained upon canals by steam-power. As much as fourteen miles an hour had been accomplished by horses, with a tractive power of 352 lbs. by dynamometer, and that without the least appearance of surge;* but the experiments made with the "Lord Dundas" steamer indicated a very different law, and, under the most favorable circumstances, never exceeded more than eight to eight and a half miles an hour, and that with an enormous swell washing over the banks of the canal in every direction. In fact, the object for which the boat was built was never attained, and it was found impossible to effect by steam what was done by horses. It nevertheless led to a more important and a greatly-enlarged branch of industry—namely, the construction of iron vessels upon a large scale for ocean traffic.

These experimental vessels, the "Lord Dundas" and the "Manchester," already mentioned, in conjunction with the "Alburka," and some other vessels, by Messrs. J. Laird and Co., of Liverpool, may be considered as the first successful attempts in iron shipbuilding. Shortly after the completion of these vessels, several large establishments were founded for this branch of construction, amongst whom may be enumerated Messrs. W. Fairbairn and Co., Millwall, and Messrs. Ditchburn and Mare, Blackwall, London; Messrs. Laird and Co., Liverpool; Messrs. Tod and McGregor, Glasgow; and several others, all of whom were engaged for many years in the construction of iron ships.

In this chapter we shall be unable to go much into detail, and must confine ourselves to a few general observations in connection with the more important application of iron as a material of construction for ocean steamers and sailing vessels, exposed to all the changes and vicissitudes of wind and tides in the open sea.

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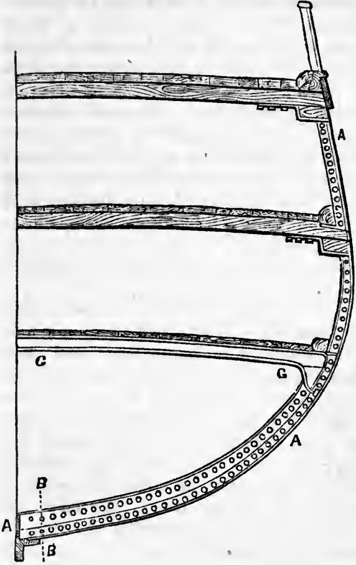
* "Remarks on Canal Navigation," page 57.

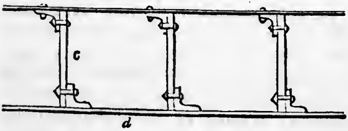
Fig. 108 exhibits a half cross section of one of Her Majesty's frigates of the second class, and will, to a certain extent, illustrate the principles of construction. It will be seen that the iron-ship is composed of a series of frames or ribs, placed at various distances apart; these are connected together in the interior of the vessel by transverse beams, mostly of iron, but sometimes of wood, which support the decks. Over the exterior of the ribs the iron sheathing-plates are riveted, so as to form a continuous water-tight covering over the entire exterior of the vessel.

Fig. 108.



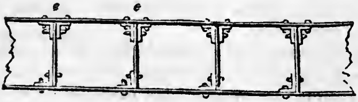
Ribs.—One of the ribs is shown at *a a a*, Fig. 108; and its section will be seen in Fig. 109, which is a longitudinal section through the line *b b*; it consists of a vertical plate *c*, to which two angle-irons are riveted, one at the top and the other at the bottom. On the lower angle-iron the sheathing plates *d* are riveted; and on the upper, interior plates, some of which in large vessels are riveted diagonally, so as to form stringers and braces from the keelsons round the bilge to the upper decks. These ribs are placed at distances of about fifteen inches to eighteen inches apart, according to their position in the direction of the length of the ship.

Fig. 109.



Other kinds of frames might be used with double angle-iron, as shown at *e e*, in the annexed sketch (Fig. 110), but they are more expensive; and from the increased complexity of construction, the extra strength obtained does not compensate for the difference of cost. Although the frames shown

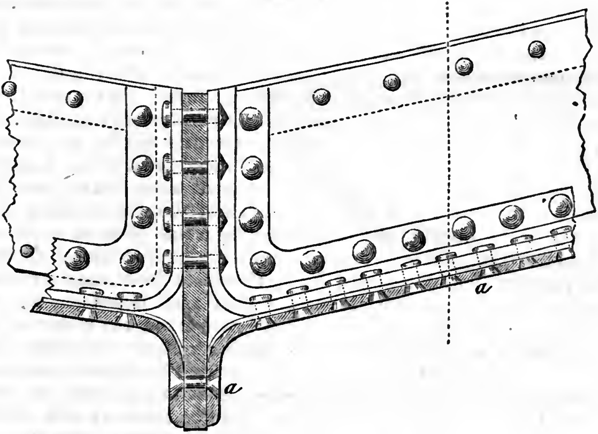
Fig. 110.



in Fig. 109 have come into general use as the most effective and easy of construction.

Keels.—This part of the vessel requires to be made exceedingly strong to resist the pressure or violent shocks to which it is subjected, when a vessel grounds. It is made in various ways, generally with a false keel, which is riveted on below the ribs by two angle-irons. The false keel is intended to receive the first shock in grounding; and is so arranged that it may even be carried away without material injury to the true keel. Fig. 111 shows a method in which it will be seen that the sheathing-plates *a a* are bent downwards so as to grasp the side of the keel, which consists of a massive plate of iron; whilst the angle-iron of the ribs is bent upwards at right angles, and is firmly riveted to the vertical keel plate.

Fig. 111.



Decks.—The floorings are supported upon beams extending from one side of the vessel to the other, and attached at either end to the ribs or side frames. In the section, Fig. 108, the two upper decks are supported upon wooden beams, as in an ordinary wooden vessel; but wrought-iron beams may be substituted for these with great advantage, as shown at *g g*.

Fig. 112.

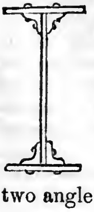


Fig 113.

These deck-beams have been made of various forms, the best of which for large vessels is probably that shown in Fig. 112, which consists of angle irons riveted to the top and to the bottom of a thin vertical plate. In some cases a vertical plate, with two angle-irons at the top and one at the bottom, is used, and has the advantage of greater simplicity, though the material is not so well distributed. The box beam (Fig. 113) is employed for supporting the shafts and paddle-boxes of steamers, etc.

RIVETING OF THE PLATES.—In all wrought-iron constructions, the mode of joining two plates together is the same. When the article can neither be produced at once from the rolling-mill nor the steam-hammer, and except in the comparatively few cases where parts are *welded* together, they are universally united by *rivets.* A series of holes being made through both pieces, a small bolt, with a head upon one side, is passed through each, and then quickly hammered down on the other side to another head, so as to grasp the parts tightly between them. These rivets are usually employed in a red-hot state, both because they are then more easily hammered down, and because in cooling they contract and draw the parts together with great force.

Since the introduction of this process, the greatest improvement has been the substitution of the riveting-machine, invented by Mr. Fairbairn; by means of which the object is secured in considerably less time and at less cost, and which completes the union of the plates with much greater perfection than could possibly be done by the hand. But this new and very superior process has not as yet been successfully applied to the riveting of plates for ships.

On comparing the strength of plates with their riveted joints, it will be necessary to examine the sectional areas taken in a line through the rivet-holes with the section of the plates themselves. It is perfectly obvious that in perforating a line of holes along the edge of a plate, we must reduce its strength; it is also clear that the plate so perforated will be to the plate itself, nearly as the areas of their respective sections, with a small deduction for the irregularities of the pressure of the rivets upon the plate; or, in other words, the joint will be reduced in strength somewhat more than in the ratio of its section through that line to the solid section of the plate. For example, suppose two plates, each two feet wide and three-eighths of an inch thick, to be riveted together with ten three-fourth inch rivets. It is evident that out of two feet, the length of the joint, the strength of the plates is reduced by perforation to the extent of seven and a half inches; and here the strength of the plates will be to that of the joint as 9 : 6.187*, which is nearly the same as the respective areas of the solid plate and that through the rivet-holes; or as 24 : 16·5†. From these facts it is evident that the rivets cannot add to the strength of the plates, their object being to keep the two surfaces of the lap in contact. It may be said that the pressure or adhesion of the two surfaces of the plates would add to the strength; but this is not found to be the case to any great extent, as in almost every instance the experiments indicate the resistance to be in the ratio of their sectional areas.

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* The ratio of the areas. † The ratio of the breadth of metal

When this great deterioration of strength at the joint is taken into account, it cannot but be of the greatest importance that in structures subjected to such violent strains as ships, the strongest method of riveting should be adopted. To ascertain this, a long series of experiments were undertaken by Mr. Fairbairn, some of the results of which will be of interest here. The joint ordinarily employed in ship-building is the *lap-joint*, shown in Figs. 114 and 115. The plates to be united are made to overlap, and the rivets are passed through them, no covering-plates being required, except at the ends of the plate where they butt against each other. It is also a common practice to countersink the rivet-heads on the exterior of the vessel, that the hull may present a smooth surface for her passage through the water. This system of riveting is shown in Fig. 111, where the rivets of the sheathing-plates are countersunk. This system of riveting is only used when smooth surfaces are required; under other circumstances their introduction would not be desirable, as they do not add to the strength of the joint, but to a certain extent reduce it. This reduction is not observable in the experiments; but the simple fact of sinking the head of the rivet into the plate, and cutting out a greater portion of metal, must of necessity lessen its strength, and render it weaker than the plain joint with raised heads.

Fig. 114.

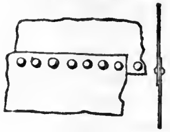
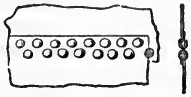


Fig. 115.



There are two kinds of lap-joints, those said to be single-riveted (Fig. 114) and those which are double-riveted (Fig. 115). At first the former were almost universally employed, but the greater strength of the latter has since led to their general adoption in the larger descriptions of vessels. The reason of the superiority is evident. A riveted joint gives way either by shearing off the rivets in the middle of their length, or by tearing through one of the plates in the line of the rivets. In a perfect joint the rivets should be on the point of shearing just as the plates were about to tear· but in practice the rivets are usually made slightly too strong. Hence it is an established rule to employ a certain number of rivets per lineal foot. If these are placed in a single row, the rivet-holes so nearly approach each other that the strength of the plates is much reduced; but if they are arranged in two lines, a greater number may be used, and yet more space left between the holes, and greater strength and stiffness imparted to the plates at the joint.

The results of Mr. Fairbairn's experiments upon the two forms of joint are given in the following summary:

	Cohesive strength of plates. Breaking-weight in lbs. per sq. in.	Strength of single-riveted joints of equal section to the plates, taken through the line of rivets. Breaking-weight in lbs. per sq. in.	Strength of double-riveted joints of equal section to the plates, taken through the line of rivets. Breaking-weight in lbs. per sq. in.
	57,724	45,743	52,352
	61,579	36,606	48,821
	58,322	43,141	58,286
	50,983	43,515	54,594
	51,130	40,249	53,879
	49,281	44,715	53,879
	43,805	37,161	
	47,062		
Mean	52,486	41,590	53,635

The relative strengths will therefore be—

For the plate	1000
Double-riveted joint	1021
Single-riveted joint	791

From the above it will be seen that the single-riveted joints have lost one-fifth of the actual strength of the plates, whilst the double-riveted have retained their resisting powers unimpaired. These are important and convincing proofs of the superior value of the double joint; and in all cases where strength is required, this description of joint should invariably be used.

Comparing these results with those of a former analysis, we have—

1000 : 1021 and 791*
1000 : 933 and 731

Mean . . . 1000 : 977 and 761

which in practice we may safely assume as the correct value of each. Exclusive of this difference, we must, however, deduct thirty per cent. for the loss of metal actually punched out for the reception of the rivets; and the absolute strength of the plates will then be, to that of the riveted joints, as the numbers 100, 68, 46. In some cases, where the rivets are wider apart, the loss sustained is, however, not so great; but in boilers and similar vessels where the rivets require to be close to each other, the edges of the plates are weakened to that extent. Taking into consideration the various circumstances affecting the experimental results, we may fairly

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* The cause of the increase of strength in the double-riveted plates may be attributed to the riveted specimens being made of best iron; whereas the mean strength of the plates is taken from all the irons experimented upon, some of inferior quality, which will account for the high value of the double-riveted joint.

assume the following relative strengths as the value of plates with their riveted joints.

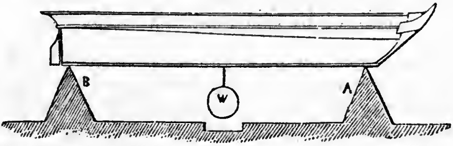
Taking the strength of the plate at	100
The strength of the riveted joint would then be .	70
And the strength of the single riveted joint . .	56

WOOD AND IRON AS MATERIALS FOR SHIP-BUILDING.—We shall consider this point under three heads—

STRENGTH,
DURABILITY,
ECONOMY.

To ascertain the superiority of iron over wood in regard to strength, let us consider the strains to which a vessel is subjected. Let us take, for example, a vessel of similar dimensions to the "Great Western" (the first steamer that successfully crossed the Atlantic), 212 feet long between the perpendiculars, 35 feet beam, and 23 feet from the surface of the main deck to the bottom of the sheathing attached to the keel. Now, considering a vessel of this magnitude, with its machinery and cargo, to weigh 3000 tons, including her own weight; and supposing, in the first instance, that she is suspended upon two points, A and B, resting on the bow and stern, at a distance of 210 feet, as shown in Fig. 116; we should then have to calculate, from some formula yet to be determined by experiment, the ultimate strength of the ship.

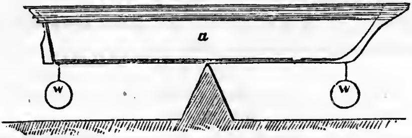
Fig. 116.



To determine this formula with accuracy is a work of research. In the meantime, we are fortunate in having before us that which applies with so much certainty to tubular bridges and tubular girders; and all that is required in this case will be to ascertain the correct sectional area of the plates, to prevent the tearing asunder of the bottom, and the quantity of material necessary to resist the crushing force along the line of the upper-deck on the top. It is true that the necessary data have yet to be determined; but the iron ship-builder cannot be far wrong if he assumes the weight W in the middle (Fig. 116) to be equal to the united weights of the ship and cargo. This, in the case before us, would give an ultimate power of resistance of 3000 tons in the middle, or 6000 tons equally distributed along the ship, with her keel downwards.

Assuming these tests, or the calculation derived therefrom, to be correct, let us now bring the vessel into a totally different position, as in Fig. 117, having the same weight of cargo on board, and supported by a wave, which, for the sake of illustration, we may consider as supporting the vessel upon a single point in the middle.

Fig. 117.



In this position we find the strain reversed; and in the place of the lower part of the hull of a ship being in a state of tension, it is, on the contrary, in a state of compression, and the whole of those parts below the neutral axis are subjected to that strain. On the other hand, the upper part is in a state of tension; and that tension, as well as the compressive strain below, will be found to vary in degree in the ratio of the distances from the centre of the neutral axis *a* (Fig. 117), round which the forces of tension and compression revolve. In this supposed position we may venture to calculate the strengths, in order to ascertain the limit or maximum of security, and act as if the vessel were placed in trying circumstances,—either contending with the rolling seas of a hurricane, or suffering the actual suspension of either portion when taking the ground. In these critical positions, we arrive at the conclusion, that calculations founded upon the formula for wrought-iron tubular beams will determine the strength and resisting powers of an iron ship, and that under every contingency and every circumstance in which the vessel can be placed. Moreover, it will give a wide margin of security under all those forms and conditions of peril to which every vessel navigating the ocean is exposed. We are fully aware that many thousand vessels are now afloat that would not stand one-third of the tests which we have taken; but that is no reason why we should not endeavor to effect more judicious distribution of the material, in order to attain the maximum strength, where human life and the fortunes of the public are at stake.

To show that we have not selected tests which no vessel would stand, we append the following incidents:

In hauling an iron steamer of nearly 400 tons burthen out of a temporary basin, she grounded on the extreme end of the bank, and was left, as the tide receded, with forty feet of her stern entirely without support, and her bow buried in the opposite bank. On the return of the tide, the vessel floated, and immediately afterwards she proceeded on her voyage.

A large steamer, the "Vanguard," ran foul of a reef of rocks on the west coast of Ireland, and continued exposed to the swell of the Atlantic beating her upon them for several days, with comparatively little injury, excepting only the corrugation of the plates along her bottom. She appears to have rested upon a number of small hard rocks from the stem to the full part of the vessel just under the paddle-wheels, and from that part to the stern to have been quite unsupported, except at one place where the keel was broken. Mr. Clark, who went to examine her, states that "although she was beating hard for so many days, no part of her engines was deranged. Her engines were kept constantly at work, and, in his opinion, are now in as permanent working order as ever they were. Had the 'Vanguard' been built of wood instead of iron, she could not have been saved."

"The 'Royal George,' one of the iron steamers running between Liverpool and Glasgow—a vessel of unusual length in proportion to her beam—got on a rock near Greenock at high water, when loaded with about 150 tons of dead weight besides her engines and coals, and was left there high and dry during a whole tide without sustaining any injury. She rested nearly on her centre; and all who saw her were of opinion that no timber vessel could have remained in that position without breaking her back." *

We might adduce numerous other instances in which iron vessels have, without material injury, stood the strains which must have caused a timber vessel to go to pieces. An iron ship is united by riveting into a single firm mass; whilst a wooden vessel is composed of an innumerable number of pieces, all imperfectly joined together, but which are, nevertheless, dependent on each other for support,—so that if any one gives way, the stability of all the rest is endangered.

In his paper on iron as a material for ship-building, Mr. Fairbairn gives the following results of some experiments on the comparative strength of wood and iron, when subjected to pressure from a blunt instrument placed at right angles to the surface of the plate. It will be seen that, in these experiments, an endeavor was made to place the material in circumstances similar to those mentioned above, where the vessel is beating upon hard and unequal ground. In these experiments, the wrought-iron plates were fastened upon a frame of cast-iron, one foot square inside, and one foot six inches outside. The sides of the plate, when hot, were twisted round the frame, to which they were firmly bolted. The force to burst it was applied in the centre by a bolt of iron, terminating in a hemisphere three inches in diameter.

Summary of Results.

	lbs.	Mean : lbs.
In Experiment I., a plate one-fourth of an inch thick was burst by	13,789	16,779
In Experiment II., a plate one-fourth of an inch thick was burst by	19,769	

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* Grantham "On Iron as a Material for Ship-Building."

	lbs.	Mean : lbs.
In Experiment III., a plate half an inch thick was burst by	37,519	37,723
In Experiment IV., a plate half an inch thick was burst by	37,928	

Here the strengths are as the depths, a half-inch plate requiring double the weight to produce fracture that had previously burst a quarter-inch plate.

The experiments on wood were made upon good English oak, of the same width as the iron plates. The specimens were laid upon solid planks twelve inches asunder, and by the same apparatus the rounded end of the three-inch pin was forced through them.

Summary of Results.

						lbs.	Mean : lbs.
Strength of	planks	3	inches	thick	. . . . .	18,941	17,933
"	"	3	"	"	. . . . .	16,925	
"	"	1½	"	"	. . . . .	4,532	4,406
"	"	1½	"	"	. . . . .	4,280	

Here the strength to resist crushing follows the ratio of the square of the depth, as is found to be the case in the transverse fracture of rectangular bodies of constant breadth and span. The experiments show conclusively the superiority of iron in ordinary cases.

DURABILITY.—The durability of iron ships is now established beyond a doubt; and it is generally admitted that they remain fit for service longer than those of timber. At first it was thought that the action of salt-water would cause a rapid oxidation, and very soon disable them; indeed, oxidation has been the rock-ahead of every iron ship for the last twenty years. The evil has been exaggerated; and there are instances of iron ships built twenty years ago, which are still in existence with no sensible appearance of corrosion or decay, and, what is of equal importance, without having required repairs, if we except a few coats of oil-paint, or the application of some other anti-corrosive substance to neutralize the effects of the sea-water. Nature, however, comes to our assistance in this, as in almost every other attempt in the constructive arts, and seems to confirm the proverb, "A bright sword never rusts;" for it is with iron ships as with iron rails—when in constant use there is little, if any, appearance of oxidation.

ECONOMY.—Mr. Grantham, in the work already quoted, comes to the conclusion that iron vessels are on the whole less expensive in construction than similar vessels of wood. But assuming that, when built in the best manner, they cost about the same, still, the iron ship has great advantages. The strength of iron is so great that we are enabled to use a much thinner shell than with wood; and hence there is much more stowage room. The cost of maintaining an iron vessel, repairs, etc., are very small; whilst in a timber vessel they amount to a large sum. Iron vessels are not subject to a dry rot; and we have already seen that they will remain under severe strain comparatively uninjured, when a timber vessel would go to pieces.

It is necessary here to advert to the use of iron as applied to vessels of war. There cannot exist a doubt as to the advantages to be derived from iron as a material for ship-building, and it is as desirable in the navy as in the merchant service; but the great drawback to its application is the effect of shot upon iron plates, and the consequent danger to the vessel if not regularly "armored," but merely constructed of iron like a merchantman. This danger does not arise so much from point-blank shot entering the ship at high velocities, as from shot ranging from a distance, and which strike the vessel with a reduced force. In the first case the shot penetrates and passes through the plates, making a perforation equal in diameter to the shot; but a half-spent shot when it arrives, not only penetrates the side of the ship, but tears up the plates to a distance of some feet on every side. It is from this that the chief danger is to be apprehended. It is useless here to point out that which is now so very apparent to all well informed persons, that the successful application of iron in the building of powerful vessels of war, during the present contest in the United States—eventful in so very many respects—has opened a new era in ocean warfare. So great is this revolution, that the navies of the old world are now rendered comparatively harmless and consequently useless; and the United States, with her "New Ironsides," "Dunderberg," "Dictator," "Puritan," "Roanoke," and other iron-clads, is to-day not only the first military, but the first naval power in the world.

CHAPTER XII.

THE METALS AND ALLOYS MOST COMMONLY USED.

WE have now to consider the following metals: Antimony, Bismuth, Copper, Gold, Lead, Mercury, Nickel, Palladium, Platinum, Rhodium, Silver, Tin, and Zinc. Unlike iron and steel, they do not admit of being hardened beyond that degree which may be produced by simple mechanical means, such as hammering, rolling, etc., neither (with the exception of platinum) do they submit to the process of welding.

On the other hand, their fusibility offers an easy means of uniting and combining many of these metals with great readiness, either singly, or in mixtures of two or several kinds, which are called alloys. By the process of founding, any required form may be given to the fusible metals and alloys: their malleability and ductility are also turned to most useful and varied account; and by partial fusion neighboring metallic surfaces may be united, sometimes *per se*, but more generally by the interposition of a still more fusible metal or alloy called solder.

The author intends therefore to commence with a brief notice of the physical characters and principal uses of the thirteen metals before named, and of their more important alloys. Tables of the cohesive force and of the general properties of metals will be next added to avoid the occasional necessity for reference to other works.

These tables will be followed by some remarks on alloys, which as regards their utility in the arts, may be almost considered as so many distinct metals; this will naturally lead to the processes of melting, mixing and casting the metals; a general notice and explanation of many works, taking their origin in the malleable and ductile properties, will then follow; and the consideration of the metals, and of materials from the three kingdoms, will be concluded by a descriptive account of the modes of soldering.

DESCRIPTION
OF THE
PHYSICAL CHARACTER AND USES
OF
THE METALS AND ALLOYS
COMMONLY EMPLOYED IN
THE MECHANICAL AND USEFUL ARTS.

ANTIMONY is of a silvery white color, brittle and crystalline in its ordinary texture. It fuses at about 800°, or at a dull red heat, and is volatile at a white heat. Its specific gravity is 6.712.

ANTIMONY expands on cooling; it is scarcely used alone, except in combination with similar bars of other metals for producing thermo-electricity: but antimony, which in the metallic state is frequently called "regulus," is generally combined with a large portion of lead, and sometimes with tin, and other metals. *See* LEAD and TIN.

"Antimony and tin, mixed in equal proportions, form a moderately hard, brittle, and very brilliant alloy, capable of receiving an exquisite polish, and not easily tarnished by exposure to the air; it has been occasionally manufactured into speculums for telescopes. Its s. g. is less than the mean of its constituent parts."

BISMUTH is a brittle white metal with a slight tint of red: its specific gravity is 9.822. It fuses at 476° to 507°, and always crystallizes on cooling. According to Chaudet, pure bismuth is somewhat flexible. A cast bar of the metal, one-tenth of an inch diameter, supports, according to Muschenbroëck, a weight of forty-eight-pounds. Bismuth is volatile at a high heat, may be distilled in close vessels. It transmits heat more slowly than most other metals, perhaps in consequence of its texture.

BISMUTH is scarcely used alone, but it is employed for imparting fusibility to alloys, thus:

8 bismuth, 5 lead, 3 tin, constitute a fusible alloy, which melts at 212° F.

2 bismuth, 1 lead, 1 tin, a fusible alloy, which melts at 201° F.

5 bismuth, 3 lead, 2 tin, when combined melt at 199°.

8 bismuth, 5 lead, 4 tin, 1 type metal, constitute the fusible alloy used on the Continent for producing the beautiful casts of the French medals, by the *clichée* process. The metals should be repeatedly melted and poured into drops until they are well mixed.

1 bismuth, and 2 tin, make an alloy found to be the most suitable for rose-engine and eccentric-turned patterns, to be printed from after the manner of letter-press. The thin plates are cast upon a cold surface of metal or stone, upon which a piece of smooth paper is placed, and then a metal ring; the alloy should neither burr nor crumble; if proper, it turns soft and silky; when too crystalline, more tin should be added.

2 bismuth, 4 lead, 3 tin, }
1 bismuth, 1 lead, 2 tin, } constitute pewterers' soft solders.

All these alloys must be cooled quickly to avoid the separation of the bismuth; they are rendered more fusible by a small addition of mercury.

COPPER, with the exception of titanium, is the only metal which has a red color; it has much lustre, is very malleable and ductile, and exhales a peculiar smell when warmed or rubbed. It melts at a bright-red or dull white heat at a temperature intermediate between the fusing points of silver and gold=1996° Fahr. Its specific gravity varies from 8.86 to 8.89; the former being the least density of cast copper, the latter the greatest of rolled or hammered copper.

COPPER is used alone for many important purposes, and very extensively for the following: namely, sheathing and bolts for ships, brewing, distilling, and culinary vessels. Some of the fire boxes for locomotive engines, boilers for marine engines, rollers for calico-printing and paper-making, plates for the use of engravers, etc.

Copper is used in alloying gold and silver, for coin, plate, etc., and it enters with zinc and nickel into the composition of German silver. Copper alloyed with one-tenth of its weight of arsenic is so similar in appearance to silver, as to have been substituted for it.

The alloys of copper, which are very numerous and important, are principally included under the general name, *Brass.* In the more common acceptation, brass means the yellow alloy of copper, with about half its weight of zinc; this is often called by engineers "yellow brass."

Copper alloyed with about one-ninth its weight of tin, is the metal of brass ordnance, which is very generally called gun-metal; similar alloys used for the "*brasses*" or bearings of machinery, are called by engineers, *hard* brass, and also gun-metal; and such alloys when employed for statues and medals are called bronze. The further addition of tin leads to bell metal, and speculum metal, which are named after their respective uses; and when the proportion of copper is exceedingly small the alloy constitutes one kind of pewter.

Copper, when alloyed with nearly half its weight of lead, forms an inferior alloy, resembling gun-metal in color, but very much softer and cheaper, lead being only about one-fourth the value of tin, and used in much larger proportion.

This inferior alloy is called pot-metal, and also cock-metal, because it is used for large vessels and measures, for the large taps or cocks for brewers, dyers and distillers, and those of smaller kinds for household use.

Generally, the copper is only alloyed with one of the metals, zinc, tin, or lead; occasionally with two, and sometimes with the three in various proportions. In many cases, the new metals are carefully weighed according to the qualities desired in the alloy, but random mixtures more frequently occur, from the ordinary practice of filling the crucible in great part with various pieces of old metal, of unknown proportions, and adding a certain quantity of new metal to bring it up to the color and hardness required. This is not done solely from motives of economy, but also from an impression which appears to be very generally entertained, that such mixtures are more homogeneous than those composed entirely of new metals, fused together for the first time.

The remarks I have to offer on these copper alloys will be arranged in the tabular form, in four groups; and to make them as practical as possible, they will be stated in the terms commonly used in the brass-foundry. Thus, when the founder is asked the usual proportions of yellow brass, he will say, 6 to 8 oz. of zinc (to every pound of copper being implied). In speaking of gun-metal, he would not say, it had one-ninth, or 11 per cent. of tin, but simply that it was 1½, 2, or 2¼ oz. (of tin), as the case might be; so that the quantity and kind of the alloy, or the *addition* to the pound of copper, is usually alone named: and to associate the various ways of stating these proportions, many are transcribed in the forms in which they are elsewhere designated.

ALLOYS OF COPPER AND ZINC ONLY.

The marginal numbers denote the ounces of zinc added to every pound of copper.

⅛ to ½ oz. Castings are seldom made of pure copper, as under ordinary circumstances it does not cast soundly; about half an ounce of zinc is usually added, frequently in the shape of 4 oz. of brass to every pound of copper; and by others 4 oz. of brass are added to every two or three pounds of copper.

1 to 1¼ oz. Gilding metal, for common jewelry: it is made by mixing 4 parts of copper with 1 of calamine brass; or sometimes 1 lb. of copper with 6 oz. of brass. The sheet gilding-metal will be found to match pretty well in color with the cast gun-metal, which latter does not admit of being rolled; they may be therefore used together when required.

3 oz. Red sheet brass, made at Hegermühl, or 5½ parts copper, 1 zinc.

3 to 4 oz. Bath metal, pinchbeck, Mannheim gold, similor, and alloys bearing various names, and resembling inferior jeweler's gold greatly alloyed with copper, are of about this proportion: some of them contain a little tin; now, however, they are scarcely used.

6 oz. Brass, that bears soldering well.

6 oz. Bristol brass is said to be of this proportion.

8 oz. Ordinary brass, the general proportion; less fit for soldering than 6 oz., it being more fusible.

8 oz. Is generally the ingot brass, made by simple fusion of the two metals.

9 oz. This proportion is the one extreme of Muntz's patent sheathing. See 10⅜.

10⅜ oz. Muntz's metal, or 40 zinc and 60 copper. "Any proportions," says the patentee, "between the extremes, 50 zinc and 50 copper, and 37 zinc 63 copper, will roll and work at the red-heat;" but the first-named proportion, or 40 zinc to 60 copper is preferred.

The metal is cast into ingots, heated to a red-heat, and rolled and worked at that heat into ships' bolts and other fastenings and sheathing.

12 oz. Spelter-solder for copper and iron is sometimes made in this proportion; for brass work, the metals are generally mixed in equal parts. See 16 oz.

12 oz. Pale yellow metal, fit for dipping in acids, is often made in this proportion.

16 oz. Soft spelter-solder, suitable for ordinary brass work, is made of equal parts of copper and zinc. About 14 lbs. of each are melted together and poured into an ingot mould with cross ribs, which indents it into little squares of about 2 lbs. weight; much of the zinc is lost. These lumps are afterwards heated nearly to redness upon a charcoal fire, and are broken up one at a time with great rapidity on an anvil or in an iron pestle and mortar. The heat is a critical point; if too great, the solder is beaten into a cake or coarse lumps and becomes tarnished; when the heat is proper, it is nicely granulated, and remains of a bright yellow color; it is afterwards passed through a sieve. Of course the ultimate proportion is less than 16 oz. of zinc.

16 oz. Equal parts is the one extreme of Muntz's patent sheathing. See 10⅔.

16½ oz. Mosaic gold, which is dark-colored when first cast, but on dipping assumes a beautiful golden tint. When cooled and broken, all yellowness must cease, and the tinge vary from reddish fawn or salmon color, to a light purple or lilac, and from that to whiteness. The proportions are stated as from 52 to 58 zinc to 50 of copper, or 16¼ to 17 oz. to the pound.

32 oz. or 2 zinc to 1 copper, a bluish-white, brittle alloy, very brilliant, and so crystalline that it may be pounded cold in a mortar.

128 oz. or two ounces of copper to every pound of zinc; a hard crystalline metal differing but little from zinc, but more tenacious; it has been used for laps or polishing disks.

REMARKS ON THE ALLOYS OF COPPER AND ZINC.

These metals seem to mix in all proportions.

The addition of zinc continually increases the fusibility, but from the extremely volatile nature of zinc, these alloys cannot be arrived at with very strict regard to proportion.

The red color of copper slides into that of yellow brass at about 4 or 5 oz. to the pound, and remains little altered unto about 8 or 10 oz.; after this it becomes whiter, and when 32 oz. of zinc are added to 16 of copper, the mixture has the brilliant silvery color of speculum metal, but with a bluish tint.

These alloys, from about 8 to 16 oz. to the pound of copper, are extensively used for dipping, as in an enormous variety of furniture work; in all cases the metal is annealed before the application of the scouring or cleaning processes, and of the acids, bronzes and lackers subsequently used.

The alloys with zinc retain their malleability and ductility well, unto about 8 or 10 ounces to the pound; after this, the crystalline character slowly begins to prevail. The alloy of

2 zinc and 1 copper, before named, may be crumbled in a mortar when cold.

The ordinary range of good yellow brass, that files and turns well, is from about 4½ to 9 oz. to the pound. With additional zinc, it is harder and more crystalline; with less, more tenacious, and it hangs to the file like copper; the range is wide, and small differences are not perceived.

ALLOYS OF COPPER AND TIN ONLY.

The marginal numbers denote the ounces of tin added to every pound of copper.

Ancient Copper and Tin Alloys.

¾ oz.	Ancient bronze nails, flexible, or 20 copper, 1 tin.	
1¾ oz.	Soft bronze, or . . 9 to 1	According to Pliny, as quoted by Wilkinson. Ancient weapons and tools, by various analyses, or 8 to 15 per cent. tin; metals from 8 to 12 per cent. tin, with two parts zinc added to each 100, for improving the bronze color.
2 oz.	Medium bronze, or 8 to 1	
2¼ oz.	Hard bronze, or . 7 to 1	
6 to 8 oz.	Ancient mirrors.	

Modern Copper and Tin Alloys.

1 oz.	Soft gun metal, that bears drifting, or stretching from a perforation.
1⅓ oz.	A little harder alloy, fit for mathematical instruments; or 12 copper and 1 very pure grain tin.
1½ oz.	Still harder, fit for wheels to be cut with teeth.
1½ to 2 oz.	Brass ordnance, or 8 to 12 per cent. tin; but the general proportion is one-ninth part of tin.
2 oz.	Hard bearings for machinery.
2½ oz.	Very hard bearings for machinery. By Muschenbroek's Tables it appears that the proportion 1 tin and 6 copper is the most tenacious alloy; it is too brittle for general use, and contains 2¼ oz. to the pound of copper.
3 oz.	Soft musical bells.
3½ oz.	Chinese gongs and cymbals, or 20 per cent. tin.
4 oz.	House bells.
4½ oz.	Large bells.
5 oz.	Largest bells.
7¼ to 8¼ oz.	Speculum metal. Sometimes one ounce of brass is added to every pound as the means of introducing a trifling quantity of zinc, at other times small proportions of silver are added; the employment of arsenic is by some recommended.

The object agreed upon by all experimentalists appears to be the exact saturation of the copper with the tin, and the proportionate quantities *differ very materially* (*in this* *and all other alloys), according to the respective degrees of purity* of the metals: for the most perfect alloys to this group, Swedish copper, and grain tin, should be used.

When the copper is in excess, it imparts a red tint easily detected; when the tin is in excess, the fracture is granulated and also less white. The practice is to pour the melted tin into the fluid copper when it is at the lowest temperature that a mixture by stirring can be effected, then to pour the mixture into an ingot and to complete the combination by remelting in the most gradual manner, by putting the metal into the furnace as soon almost as the fire is lighted: trial is made of a little piece taken from the pot immediately prior to pouring.

32 oz. of tin to one pound of copper, makes the alloy called by the pewterers "*temper*," which is added in small quantities to tin, for some kinds of pewter, called "*tin and temper*," in which the copper is much less than 1 per cent.

REMARKS ON THE ALLOYS OF COPPER AND TIN ONLY.

These metals seem to mix in all proportions.

The addition of tin continually increases the fusibility, although when it is added cold it is apt to make the copper pasty, or even to set in a solid lump in the crucible.

The red color of the copper is not greatly impaired in those proportions used by the engineer, namely, up to about 2½ ounces to the pound; it becomes grayish white at 6, the limit suitable for bells, and quite white at about 8, the speculum metal; after this, the alloy becomes of a bluish cast.

The tin alloy is scarcely malleable at 2 ounces, and soon becomes very hard, brittle, and sonorous; and when it has ceased to serve for producing sound, it is employed for reflecting light.

The tough tenacious character of copper under the tools rapidly gives way; alloys of 1½ cut easily, 2½ assume about the maximum hardness without being crystalline; after this they yield to the file by crumbling in fragments rather than by ordinary abrasion in shreds, until the tin very greatly predominates, as in the pewters, when the alloys become the more flexible, soft, malleable, and ductile, the less copper they contain.

ALLOYS OF COPPER AND LEAD ONLY.

The marginal numbers denote the ounces of lead added to every pound of copper.

2 oz. A red-colored and ductile alloy.

4 oz. Less red and ductile; neither of these is so much used as the following, as the object is to employ as much lead as possible

6 oz. Ordinary pot-metal, called dry pot-metal, as this quantity of lead will be taken up without separating on cooling; this is brittle when warmed.

7 oz. This alloy is rather short, or disposed to break.

8 oz. Inferior pot-metal, called wet pot-metal, as the lead partly oozes out in cooling, especially when the new metals are mixed; it is therefore always usual to fill the crucible in part with old metal, and to add new for the remainder. This alloy is very brittle when slightly warmed. More lead can scarcely be used, as it separates on cooling.

REMARKS ON THE ALLOYS OF COPPER AND LEAD ONLY.

These metals mix in all proportions until the lead amounts to nearly half, after this they separate in cooling.

The addition of lead greatly increases the fusibility.

The red color of copper is soon deadened by the lead; at about 4 ounces to the pound the work has a bluish leaden hue when first turned, but changes in an hour or so to that of a dull gun-metal character.

When the lead does not exceed about 4 oz. the mixture is tolerably malleable, but with more lead it soon becomes very brittle and rotten: the alloy is greatly inferior to gun-metal, and is principally used on account of the cheapness of the mixture, and the facility with which it is turned and filed.

ALLOYS OF COPPER, ZINC, TIN, AND LEAD, ETC.

This group refers principally to gun-metal alloys, to which more or less zinc is added by many engineers. The quantity of tin in every pound of the alloy, which is expressed by the marginal numbers, principally determines the hardness.

M. Keller's statues at Versailles are found, as the mean of four analyses, to consist of:

Copper	91.40	or about	14⅜	ounces.
Zinc	5.53	"	1	ounce.
Tin	1.70	"	0⅜	"
Lead	1.37	"	0¼	"

In 100 parts or the 16 ounces.

1½ to 2¼ oz. tin to 1 lb. copper used for bronze medals, or 8 to 15 per cent. tin, with the addition of 2 parts in each 100 of zinc, to improve the color.

The modern so-called bronze medals of our Mint are of pure copper, and are afterwards bronzed superficially.

1½ oz. tin, ½ zinc to 16 oz. copper. Pumps and works requiring great tenacity.

1½ oz. tin,	2 oz. brass,	16 oz. copper	For wheels to be cut into teeth.
1¾ "	2 "	16 "	
2 "	1½ "	16 "	For turning work.
2¼ "	1½ "	16 "	For nuts of coarse threads and bearings.

The engineer who uses these five alloys recommends melting the copper alone; the small quantity of brass is then melted in another crucible, and the tin in a ladle,—the two latter are added to the copper when it has been removed from the furnace. The whole are stirred together and poured into the moulds without being run into ingots. The real quantity of tin to every pound of copper is about one-eighth oz. less than the number stated, owing to the addition of the brass, which increases the proportion of copper.

1⅞ oz. tin, 1⅞ oz. zinc, to 1 lb. copper. This alloy, which is a tough, yellow, brassy, gun-metal, is used for general purposes. It is made by mixing 1½ lb. tin, 1½ lb. zinc, and 10 lbs. of copper. The alloy is first run into ingots.

2½ oz. tin, ½ oz. zinc, to 1 lb. copper. Used for bearings to sustain great weights.

2½ oz. tin, 2½ oz. zinc, to 1 lb. copper, were mixed by Chantrey, and a razor was made from the alloy. It proved nearly as hard as tempered steel, and exceedingly destructive to new files, and none others would touch it.

1 oz. tin, 2 oz. zinc, 16 oz. brass. Best hard white metal for buttons.

½ oz. tin, 1½ oz. zinc, 16 oz. brass. Common white metal for buttons.

10 lbs. tin, 6 lbs. copper, 4 lbs. brass, constitute white solder. The copper and brass are first melted together, the tin is added, and the whole stirred and poured through birch twigs into water to granulate it; it is afterwards dried and pulverized cold in an iron pestle and mortar. This white solder was introduced as a substitute for silver solder in making gilt buttons. Another button solder consists of 10 parts copper, 8 of brass, and 12 of spelter or zinc.

REMARKS ON ALLOYS OF COPPER, ZINC, TIN, AND LEAD, ETC.

ORDINARY YELLOW BRASS (copper and zinc) is rendered very sensibly harder, so as not to require to be hammered, by a small addition of tin, say ¼ or ½ oz. to the lb. On the other hand by the addition of ¼ to ½ oz. of lead, it becomes more malleable, and casts more sharply. Brass becomes a little whiter for the tin, and redder for the lead. The addition of nickel to copper and zinc constitutes the so-called German silver.

GUN METAL (copper and tin) very commonly receives a small addition of zinc; this makes the alloy mix better, and to lean to the character of brass by increasing the malleability without materially reducing the hardness. The zinc, which is sometimes added in the form of brass, also improves the color of the alloy both in the recent and bronzed states. Lead in small quantity improves the ductility of gun-metal, but at the expense of its hardness and color; it is seldom added. Nickel has been proposed as an addition to gun-metal by O'Donovan, of Dublin, and antimony by his countryman, Dr. Ure.

Pot Metal (copper and lead) is improved by the addition of tin, and the three metals will mix in almost any proportions. When the tin predominates, the alloy so much the more nearly approaches the condition of gun-metal. Zinc may be added to pot metal in very small quantity, but when the zinc becomes a considerable amount, the copper takes up the zinc, forming a kind of brass, and leaves the lead at liberty, and which in great measure separates in cooling. Zinc and lead are also very indisposed to mix alone, although a little arsenic assists their union by "killing" the lead, as in shot metal. Antimony also facilitates the combination of pot metal; 7 lead, 1 antimony, and 16 copper, mixed perfectly well the first fusion, and the alloy was decidedly harder than 4 lead and 16 copper, and apparently a better metal. "Lead and antimony, though in small quantity, have a remarkable effect in diminishing the elasticity and sonorousness of the copper alloys."

GOLD is of a deep and peculiar yellow color. It melts at a bright red heat, equivalent to 2016° of Fahrenheit's scale, and when in fusion appears of a brilliant greenish color. Its specific gravity is 19.3. It is so malleable that it may be extended into leaves which do not exceed the one two hundred and eighty-two thousandth of an inch in thickness, or a single grain may be extended over 56 square inches of surface. This extensibility of the metal is well illustrated by gilt buttons, 144 of which are gilt by 5 grains of gold, and less than even half that quantity is adequate to giving them a very thin coating. It is also so ductile that a grain may be drawn out into 500 feet of wire. The pure acids have no action upon gold.

Gold in the pure or fine state is not employed in bulk for many purposes in the arts, as it is then too soft to be durable. The gold foil used by dentists for stopping decayed teeth is perhaps as nearly pure as the metal can be obtained; it contains about 6 grains of alloy in the pound troy, or the one-thousandth part. Every superficial inch of this gold foil or leaf weighs ¾ of a grain, and is 42 times as thick as the leaf used for gilding.

The wire for gold lace prepared by the refiners for gold-lace manufacturers, requires equally fine gold, as when alloyed it does not so well retain its brilliancy. The gold in the proportion of about 100 grains to the pound troy of silver, or of 140 grains for double-gilt wire, is beaten into sheets as thin as paper; it is then burnished upon a stout red-hot silver bar, the surface of which has been scraped perfectly clean. When extended by drawing, the gold still bearing the same relation as to quantity, namely, the 57th part of the weight becomes of only one-third the thickness of ordinary gold-leaf used for gilding. In water-gilding, fine gold is amalgamated with mercury, and washed over the gild-metal (copper and tin), the mercury attaches itself to the metal, and when evaporated by heat it leaves the gold behind in the dead or frosted state: it is brightened with the burnisher. By the electrotype process a still thinner covering of pure gold may be deposited on silver, steel, and other metals. French watch-makers introduced this method of protecting the steel pendulum springs of marine chronometers and other time-pieces from rust.

Fine gold is also used for soldering chemical vessels made of platinum.

GOLD ALLOYS.

Gold-leaf for gilding contains from 3 to 12 grains of alloy to the oz., but generally 6 grains. The gold used by respectable dentists, for plates, is nearly pure, but necessarily contains about 6 grains copper in the oz. troy, or one 80th part; others use gold containing upwards of one-third of alloy; the copper is then very injurious.

With *copper*, gold forms a ductile alloy of a deeper color, harder and more fusible than pure gold; this alloy, in the proportion of 11 of gold to 1 of copper, constitutes English *standard gold;* its density is 17.157, being a little below the mean, so that the metals slightly expand on combining. One troy pound of this alloy is coined into $46\frac{29}{40}$ English sovereigns, or 20 troy pounds into 934 sovereigns and a half. (The pound was formerly coined into 44 guineas and a half). The standard gold of France consists of 9 parts of gold and 1 of copper.

For *Gold Plate* the French have three different standards: 92 parts gold, 8 copper; also 84 gold, 16 copper; and 75 gold, 25 copper.

In England, the purity of gold is expressed by the terms 22, 18, 16, 12, 8, carats, etc. The pound troy is supposed to be divided into 24 parts, and the gold, if it could be obtained perfectly pure, might be called 24 carats fine.

The "Old Standard Gold," or that of the present British currency, is called fine, there being 22 parts of pure gold to 2 of copper.

The "New Standard," for watch-cases, etc. is 18 carats of fine gold, and 6 of alloy. No gold of inferior quality to 18 carats, or the "New Standard," can receive the Hall mark; and gold of lower quality is generally described by its commercial value.

The alloy may be entirely silver, which will give a green color, or entirely copper for a red color; but the copper and silver are more usually mixed in the one alloy according to the taste and judgment of the jeweler.

The following alloys of gold are transcribed from the memoranda of the proportions employed by a practical jeweler of considerable experience. When it is otherwise expressed, it will be understood all these alloys are made with fine gold, fine silver, and fine copper, obtained direct from the refiners. And to insure the standard gold passing the test of the Hall, 3 or 4 grains additional of gold are usually added to every ounce.

First Group. Different kinds of gold that are finished by polishing, burnishing, etc., without necessarily requiring to be colored:

The gold of 22 carats fine is so little used, on account of its expense and greater softness, that it has been purposely omitted.

18 carats, or New Standard gold, of yellow tint:

15 dwt.	0 grs. gold.
2 dwt.	18 grs. silver.
2 dwt.	6 grs. copper.
20 dwt.	0 grs.

18 carats of red tint:

15 dwt.	0 grs. gold.
1 dwt.	18 grs. silver.
3 dwt.	6 grs. copper.
20 dwt.	0 grs.

16 carats or Spring gold: this, when drawn or rolled very hard, makes springs little inferior to those of steel.

1 oz. 16 dwt. gold.	or 1.12
6 dwt. silver.	— .4
12 dwt. copper.	— .12
2 oz. 14 dwt.	2. 8

$15 gold of yellow tint, or the fine gold of the jewelers; 16 carats nearly:

1 oz.	0 dwt. gold.
	7 dwt. silver.
	5 dwt. copper.
1 oz.	12 dwt.

$15 gold of red tint, or 16 carats:

1 oz.	0 dwt. gold.
	2 dwt. silver.
	8 dwt. copper.
1 oz.	10 dwt.

Second Group. Colored golds: these all require to be submitted to the process of wet-coloring, which will be explained; they are used in much smaller quantities, and require to be very exactly proportioned.

Full red gold:
5 dwt. gold.
5 dwt. copper.
10 dwt.

Red gold:
10 dwt. gold.
1 dwt. silver,
4 dwt. copper.
15 dwt.

Green gold:
5 dwt. 0 grs. gold.
21 grs. silver.
5 dwt. 21 grs.

Gray gold: (Platinum is also called gray gold by jewelers.)
3 dwt. 15 grs. gold.
1 dwt. 9 grs. silver.
5 dwt. 0 grs.

Blue gold: scarcely used:
5 dwt. gold.
5 dwt. steel filings.
10 dwt.

Antique gold, of a fine greenish-yellow color:
18 dwt. 9 grs. gold, or 18. 9
21 grs. silver, — 1. 3
18 grs. copper,— .12
20 dwt. 0 grs. 20. 0

Third Group. Gold solders: these are generally made from gold of the same quality and value as they are intended for, with a small addition of silver and copper, thus:

Solder for 22 carat gold:
1 dwt. 0 grs. of 22 carat gold.
2 grs. silver.
1 gr. copper.
1 dwt. 3 grs.

Solder for 18 carat gold:
1 dwt. 0 grs. of 18 carat gold.
2 grs. silver.
1 gr. copper.
1 dwt. 3 grs.

Solder for $15 gold:*
1 dwt. 0 grs. of $15 gold.
10 grs. silver.
8 grs. copper.
1 dwt. 18 grs.

Solder for $10 gold: but middling silver solder is more generally used.
1 dwt. fine gold.
1 dwt. silver.
2 dwt. copper.
4 dwt.

Dr. Hermstadt's imitation of gold, which is stated not only to resemble gold in color, but also in specific gravity and ductility, con-

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* By others, 4 grains of brass are added to the solder; it then fuses beautifully and is of good color. Zinc is sometimes added to other good solders to increase their fusibility, the zinc (or brass when used) should be added at the last moment, to lessen the volatilization of the zinc.

sists of 16 parts of platinum, 7 parts of copper, and 1 zinc, put in a crucible, covered with charcoal powder, and melted into a mass.

Gold alloyed with platinum is also rather elastic, but the platinum whitens the alloy more rapidly than silver.

LEAD appears to have been known in the earliest ages of the world. Its color is bluish white; it has much brilliancy, is remarkably flexible and soft, and leaves a black streak on paper: when handled it exhales a peculiar odor. It melts at about 612°, and by the united action of heat and air, is readily converted into an oxide. Its specific gravity, when pure, is 11.445; but the lead of commerce seldom exceeds 11.35.

LEAD is used in a state of comparative purity for roofs, cisterns, pipes, vessels for sulphuric acid, etc. Ships were sheathed with lead and with wood, from before the Christian era to 1450, after which wood was more commonly employed, and in 1790 to 1800 copper sheathing became general; of late years, lead with a little antimony has likewise been used, also an alloy of copper and zinc and galvanized sheet iron. The most important alloys of lead are those employed for printers' type, namely, about

3 lead, 1 antimony, for the smallest, hardest and most brittle types.
4 lead, 1 antimony, for small, hard, brittle types.
5 lead, 1 antimony, for types of medium size.
6 lead, 1 antimony, for large types.
7 lead, 1 antimony, for the largest and softest types.

In addition to lead and antimony, type-metal also contains from 4 to 8 per cent. of tin, and sometimes 1 to 2 per cent. of copper; but as old metal is always used with the new, the proportions are not exactly known.

Stereotype-plates are made of 20 parts of lead, 4 of antimony, and 1 of tin.

Baron Wetterstedt's patent sheathing for ships, consists of lead with from 2 to 8 per cent. of antimony; about 3 per cent. is the usual quantity. The alloy is rolled into sheets.

Similar alloys, and those of lead and tin in various preparations, are much used for emery wheels and grinding-tools of various forms by the lapidary, engineer, and others. The latter also employs these readily-fused alloys for temporary bearings, guides, screw nuts, etc.

Organ pipes consist of lead alloyed with about half its quantity of tin to harden it. The mottled or crystalline appearance so much admired shows an abundance of tin.

Shot metal is said to consist of 40 lbs. of arsenic to one ton of lead.

In casting sheet-lead, the metal was poured from a swing-trough upon a long and nearly horizontal table covered with a thin layer of coarse damp sand, previously levelled with a metal rule or strike. The thickness of the fluid metal was determined by running the strike along the table before the lead cooled, the excess being thus swept into a spill-trough at the lower end of the table; but the sheet-lead now more commonly used, is cast in a thick slab, and reduced between laminating rollers; it is known as "milled-lead."

The metal for organ-pipes is prepared by allowing the metal to escape through the slit in a trough, as it is slid along a horizontal table, so as to leave a trail of metal behind it; the thickness of the metal is regulated by the width of the slit through which it runs, and the rapidity of the traverse; a piece of cloth or ticken is stretched upon the casting table. The metal is planed to thickness, bent up and soldered into the pipes.

Lead pipes are cast as hollow cylinders and drawn out upon triblets; they are also cast of indefinite length without drawing. A patent was taken out for casting a sheath of tin within the lead, but it has been abandoned.

Lead shot are cast by letting the metal run through a narrow slit, into a species of colander at the top of a lofty tower; the metal escapes in drops, which for the most part assume the spherical form before they reach the tank of water into which they fall at the foot of the tower, and this prevents their being bruised. The more lofty the tower, the larger the shot that can be produced; the good and the bad shot are separated by throwing small quantities at a time upon a smooth board nearly horizontal, which is slightly wriggled; the true or round shot run to the bottom, the imperfect ones stop by the way, and are thrown aside to be re-melted; the shot are afterwards riddled or sifted for size, and churned in a barrel with black lead.

MERCURY is a brilliant white metal, having much of the color of silver, whence the terms *hydrargyrum, argentum vivum,* and *quicksilver.* It has been known from very remote ages. It is liquid at all common temperatures; solid and malleable at 40° F., and contracts considerably at the moment of congelation. It boils and becomes vapor at about 670°. Its specific gravity at 60° is 13.5. In the solid state its density exceeds 14. The specific gravity of murcurial vapor is 6.976.

MERCURY is used in the fluid state for a variety of philosophical instruments, and for pressure gages for steam-engines, etc. It is sometimes, although rarely, employed for rendering alloys more fusible; it is used with tin-foil for silvering looking-glasses, and it has been employed as a substitute for water in hardening steel. Mercury forms amalgams with bismuth, copper, gold, lead, palladium, silver, tin, and zinc.

Mercury is commonly used for the extraction of gold and silver from their ores by amalgamation. and also in water-gilding.

NICKEL is a white brilliant metal, which acts upon the magnetic needle, and is itself capable of becoming a magnet. Its magnetism is more feeble than that of iron, and vanishes at a heat somewhat below redness, 630°. It is ductile and malleable. Its specific gravity varies from 8.27 to 8.40 when fused, and after hammering, from 8.69 to 9.00. It is not oxidized by exposure to air at common temperatures, but when heated in the air it acquires various tints like steel; at a red-heat it becomes coated by a gray oxide.

NICKEL is scarcely used in the simple state, but principally used together with copper and zinc, in alloys that are rendered the harder and whiter the more nickel they contain; they are known under the names of albata, British plate, electrum, German silver, pakfong, teutanag, etc.: the proportions differ much according to price; thus the

Commonest are 3 to 4 parts nickel, 20 copper, and 16 zinc.

Best . are 5 to 6 parts nickel, 20 copper, and 8 to 10 zinc.

About two-thirds of this metal is used for articles resembling plated goods, and some of which are also plated; the remainder is employed for harness, furniture, drawing and mathematical instruments, spectacles, the tongues for accordions, and numerous other small works.

The *white copper* of the Chinese, which is the same as the German silver of the present day, is composed of 31.6 parts of nickel, 40.4 of copper, 25.4 of zinc, and 2.6 of iron, 17.48 ——— 53.39 ——— 13.0 ———.

The white copper manufactured at Sutil in the duchy of Saxe Hildburghausen, is said by Keferstein to consist of copper 88.000, nickel 8.753, sulphur with a little antimony 0.750, silex, clay, and iron 1.75. The iron is considered to be accidentally introduced into these several alloys along with the nickel, and a minute quantity is not prejudicial.

Iron and steel have been alloyed with nickel; the former (the same as the meteoric iron which always contains nickel) is little disposed to rust: whereas the alloy of steel with nickel is worse in that respect than steel not alloyed.

PALLADIUM is of a dull-white color, malleable and ductile. specific gravity is about 11.3, or 11.86 when laminated.

fuses at a temperature above that required for the fusion of gold.

PALLADIUM is a soft metal, but its alloys are all harder than the pure metal. With silver it forms a very tough malleable alloy, fit for the graduations of mathematical instruments, and for dental surgery, for which it is much used by the French. With silver and copper, palladium makes a very springy alloy, used for the points of pencil-cases, inoculating lancets, tooth-picks, or any purpose where elasticity and the property of not tarnishing are required. Thus alloyed it takes a high polish. Pure palladium is not fusible at ordinary temperatures, but at a high temperature it agglutinates so as to be afterwards malleable and ductile.

This useful metal has recently been found in some abundance in the gold ores of the Minas Geraës district. Palladium is calculated thoroughly to fulfil many of the purposes to which platinum and gold are applied in the useful arts, and from its low specific gravity it may be obtained at about half the price of an equal *bulk* of platinum, and at one-eighth that of gold; and it equally resists the action of mineral acids and sulphuretted hydrogen.

Palladium was used in the construction of the balances for the United States Mint.

PLATINUM is a white metal, extremely difficult of fusion, and unaltered by the joint action of heat and air. It varies in density from 21 to 21.5, according to the degree of mechanical compression which it has sustained. It is extremely ductile, but cannot be beaten into such thin leaves as gold and silver.

The particles of the generality of the metals, when separated from the foreign matters with which they are combined, are joined into solid masses by simple fusion; but platinum being nearly infusible when pure, requires a very different treatment.

The platinum is first dissolved chemically, and it is then thrown down in the state of a precipitate; next it is partly agglutinated in the crucible into a spongy mass, and is then compressed whilst cold in a rectangular mould by means of a powerful fly-press or other means, which in operating upon 500 ounces, converts the platinum into a dense block about 5 inches by 4, and 2½ inches thick. This block is heated in a smith's forge, with two tuyeres meeting at an angle, at which spot the platinum is placed, amidst the charcoal fire. When it has reached the welding point, or almost a blue heat, it receives one blow under a heavy *drop*, or a vertical hammer somewhat like a pile-driving engine; it then requires to be reheated, and it thus receives a fresh blow about every twenty minutes, and in a week or ten days it is sufficiently welded or consolidated on all sides to admit of being forged into bars, and converted into sheets, rods, or wires by the ordinary means.

The motive for operating upon so great a quantity is for making the large pans for concentrating sulphuric acid in only two or three pieces, which are soldered together with fine gold. In France 2000 ounces are sometimes welded into one mass, so that the vessels may be absolutely entire. For small quantities the treatment is the same, but in place of the drop, the ordinary flatter and sledge-hammer are used.

Platinum is exceedingly tough and tenacious, and "hangs to the file worse than copper;" on which account, when it is used for the graduated limbs of mathematical instruments, the divisions should be cut with a diamond-point, which is the best instrument for fine graduations of all kinds, and for ruling grounds, or the lined surfaces for etchings.

Platinum is employed in Russia for coin. This valuable metal is also used for the touch-holes of fowling-pieces, and in various chemical and philosophical apparatus in which resistance to fusion or to the acids is essential.

The alloys of platinum are scarcely used in the arts; that with a small quantity of copper is employed in Paris for dental surgery.

"Dr. Von Eckart's alloy contains platinum 2.40, silver 3.53, and copper 11.71. It is highly elastic, of the same specific gravity as silver, and not subject to tarnish; it can be drawn to the finest wire from $\frac{1}{8}$ of an inch diameter without annealing, and does not lose its elasticity by annealing. It is highly sonorous, and bears hammering red-hot, rolling and polishing."

Dr. Ryan added to silver one-fourth of its weight of platinum, and he considers that it took up one-tenth its weight. The alloy became much harder than silver, capable of resisting the tarnishing influences of sulphur and hydrogen, and was fit for graduations.

An alloy of platinum with ten parts of arsenic is fusible at a heat a little above redness, and may therefore be cast in moulds. On exposing the alloy to a gradually-increasing temperature in open vessels, the arsenic is oxidized and expelled, and the platinum recovers its purity and infusibility.

Tin also so greatly increases the fusibility of platinum that it is hazardous to solder the latter metal with tin-solder, although gold is so used.

Platinum, as well as gold, silver and copper, are deposited by the electrotype process; and silver plates thus platinized are employed in the galvanic battery.

RHODIUM is a white metal very difficult of fusion. Its specific gravity is about 11; it is extremely hard; when pure the acids do not dissolve it.

Rhodium has been long employed for the nibs of pens, which have been also made of ruby, mounted on shafts of spring gold. These kinds have had to endure for the last seven or eight years the rivalry of "Hawkins's Everlasting Pen," of which latter, the author, from many months' constant use, can speak most favorably. "The everlasting pen," says the inventor, "is made of gold tipped with a natural alloy, which is as much harder than rhodium as steel is harder than lead; will endure longer than the ruby; yields ink as freely as the quill; is easily wiped; and if left unwiped is NOT CORRODED."

Mr. Hawkins employs the natural alloy of iridium and osmium, two scarce metals discovered by Mr. Tennant, of Belfast, amongst the grains of platinum. The alloy is not malleable, and is so hard as to require to be worked with diamond powder. The metals rhodium, iridium, and osmium, are not otherwise employed in the arts than for pens, although steel has been alloyed with rhodium.

The inventor of the gold pen, Mr. Hawkins, is an American.

SILVER is of a more pure white than any other metal. It has considerable brilliancy, and takes a high polish. Its specific gravity varies between 10.4, which is the density of cast silver, and 10.5 to 10.6, which is the density of rolled or stamped silver. It is so malleable and ductile, that it may be extended into leaves not exceeding the ten-thousandth of an inch in thickness, and drawn into wire much finer than a human hair. Silver melts at a bright-red heat, at 1873° of Fahrenheit's scale, and when in fusion appears extremely brilliant.

SILVER is but little used in the pure unalloyed state, on account of its extreme softness, but it is generally alloyed with copper in about the same proportion as in our coin, and none of inferior value can receive the "Hall mark." Diamonds are set in fine silver, and in silver containing 3 to 12 grs. of copper in the ounce. The work is soldered with pure tin.

The sheet metal for plated works is prepared by fitting together very truly a short stout bar of copper and a thinner plate of silver. When scraped perfectly clean they are tied strongly together with binding wire, and united by partial fusion without the aid of solder. The plated metal is then rolled out, and the silver always remains perfectly united and of the same proportional thickness as at first. Additional silver may be burnished on hot, when the surfaces are scraped clean, as explained under gold. This is done either to repair a defect, or to make any part thicker for engraving upon, and the uniformity of surface is restored with the hammer. In addition to its use for articles of luxury, the important service of copper plated with silver for the parabolic reflectors of light-houses must not be overlooked. These are worked to the curve with great perfection by the hammer alone.

Plated spoons, forks, harness, and many other articles, are made of iron, copper, brass, and German silver, either cast or stamped into shape. The objects are then filed and scraped perfectly clean; and fine silver, often little thicker than paper, is attached with the aid of tin solder and heat. The silver is rubbed close upon every part with a burnisher.

The electrotype process is also used for plating several of the metals with silver, which it does in the most uniform and perfect manner. The silver added is charged by weight at about three times the price of the metal. The German silver, or albata, is generally used for the interior substance, as when the silver is partially worn through the white alloy is not so readily detected as iron or copper.

SILVER ALLOYS.

The alloy with *copper* constitutes plate and coin. By the addition of a small proportion of copper to silver, the metal is rendered harder and more sonorous, while its color is scarcely impaired. Even with equal weights of the two metals, the compound is white. The maximum of hardness is obtained when the copper amounts to one-fifth of the silver.

"For *silver plate*, the French proportions are 9½ parts silver, ½ copper; and for trinkets, 8 parts silver, 2 copper."

Silver solders are made in the following proportions:

Hardest silver solder, 4 parts fine silver, and 1 part copper; this is difficult to fuse, but is occasionally employed for figures.

Hard silver solder, 3 parts silver, and 1 part brass wire, which is added when the silver is melted, to avoid wasting the zinc.

Soft silver solder for general use, 2 parts fine silver, and 1 part brass wire. By some few, ¾ part of arsenic is added, to render the solder more fusible and white, but it becomes less malleable; the arsenic must be introduced at the last moment, with care to avoid its fumes.

Silver is also soldered with tin solder (2 tin, 1 lead), and with pure tin.

Silver and mercury are used in the plastic metallic stopping for teeth.

TIN has a silvery-white color with a slight tint of yellow; it is malleable, though sparingly ductile. Common tin-foil, which is obtained by beating out the metal, is not more than one-thousandth of an inch in thickness, and what is termed *white Duch metal* is in much thinner leaves. Its specific gravity fluctuates from 7.28 to 7.6, the lightest being the purest metal. When bent it occasions a peculiar crackling noise, arising from the destruction of cohesion amongst its particles.

When a bar of tin is rapidly bent backwards and forwards, several times successively, it becomes so hot that it cannot be held in the hand. When rubbed, it exhales a peculiar odor. It melts at 442°, and, by exposure to heat and air, is gradually converted into a protoxide.

Pure tin is commonly used for dyers' kettles; it is also sometimes employed for the bearings of locomotive carriages and other machinery. This metal is beaten into very large sheets, some of which measure 200 by 100 inches, and are of about the thickness of an ordinary card: the small sized foil is stated not to exceed one-thousandth of an inch in thickness. The metal is first laminated between rollers, and then spread one sheet at a time upon a large iron surface or anvil, by the direct blows of hammers with very long handles; great skill is required to avoid beating the sheets into holes. The large sheets of tin-foil are only used for silvering looking-glasses by amalgamation with mercury. Tin-foil is also used for electrical purposes. The amalgam used for electrical machines, is 7 tin, 3 zinc, and 2 mercury.

TIN is drawn into wire, which is soft and capable of being bent and unbent many times without breaking; it is moderately tenacious and completely inelastic. Tin tube is extensively used for gas fitting and many other purposes by Le Roy & Co., of New York; it has been recently introduced in an ingenious manner for the formation of very cheap vessels, for containing artists' and common colors, besides numerous other solid substances and fluids, required to be hermetically sealed, with the power of abstracting small quantities.

Tin plate is an abbreviation of tinned iron plate; the plates of charcoal iron are scoured bright, pickled, and immersed in a bath of melted tin covered with oil, or with a mixture of oil and common resin; they come out thoroughly coated. Tinned iron wire is similarly prepared: there are several niceties in the manipulation of each of these processes, which cannot be noticed in this place.

Tin is one of the most cleanly and sanatory of metals, and is largely consumed as a coating for culinary vessels, although the quantity taken up in the tinning is exceedingly small, and which was noticed by Pliny.

Tin imparts hardness, whiteness and fusibility to many alloys, and is the basis of different solders, and other important alloys, all of which have a low power of conducting heat.

PEWTER is principally tin; mostly lead is the only addition, at other times copper, but antimony, zinc, etc., are used with the above, as will be separately adverted to. The exact proportions are unknown even to those engaged in the manufacture of pewter, as it is found to be the better mixed when it contains a considerable portion of old metal to which new metal is added by trial.

Some pewters are made very common; when cast they are black, shining and soft; when turned, dull and bluish. Other pewters only contain one fifth or one-sixth of lead; these when cast are white, without gloss and hard; such are pronounced very good metal, and are but little darker than tin. The French legislature sanctions the employment of 18 per cent. of lead with 82 of tin as quite harmless in vessels for wine and vinegar.

The finest pewter, frequently called "tin and temper," consists mostly of tin, with a very little copper, which makes it hard and somewhat sonorous, but the pewter becomes brown-colored when the copper is in excess. The copper is melted, and twice its weight of tin is added to it, and from about ½ to 7 lbs. of this alloy or the "temper," are added to every block of tin weighing from 360 to 390 pounds.

Antimony is said to harden tin and to preserve a more silvery color, but is little used in pewter. Zinc is employed to cleanse the metal rather than as an ingredient; some stir the fluid pewter with a thin strip, half zinc and half tin; others allow a small lump of zinc to float on the surface of the fluid metal whilst they are casting, to lessen the oxidation.

White metal is said to consist of 3½ cwt. of block tin, 28 lbs. antimony, 8 lbs. copper, and 8 lbs. brass; it is cast into ingots and rolled into very thin sheets.

Tin solders are very much used in the arts.

1 tin, 3 lead, the coarse plumber's solder, melts at about 500 F.

2 tin, 1 lead, the ordinary or fine tin solder, melts at about 360 F.

ZINC is a bluish-white metal, with considerable lustre, rather hard, of a specific gravity of about 6.8 in its usual state, but, when drawn into wire, or rolled into plates, its density is augmented to 7 or 7.2. In its ordinary state at common temperatures it is tough, and with difficulty broken by blows of the hammer. It becomes very brittle when its temperature approaches that of fusion, which is about 773°; but at a temperature a little above 212°, and between that and 300°, it becomes ductile and malleable, and may be rolled into thin leaves, and drawn into moderately fine wire, which, however, possesses but little tenacity. When a mass of zinc, which has been fused, is slowly cooled, its fracture exhibits a lamellar and prismatic crystalline texture.

ZINC, which is commercially known as "Spelter," although it is always brittle when cast, has of late years taken its place amongst the malleable metals; the early stages of its manufacture into sheet, foil and wire are stated to be conducted at a temperature somewhat above that of boiling water; and it may be afterwards bent and hammered cold, but it returns to its original crystalline texture when remelted. It has been applied to many of the purposes of iron, tinned-iron, and copper; it is less subject to oxidation from the effects of the atmosphere than the iron, and much cheaper, although less tenacious, ductile, or durable than the copper. The sheet metals when bent lengthways of the sheet (or like a roll of cloth), are less disposed to crack than if bent sideways; in this respect zinc and sheet iron are the worst: the risk is lessened when they are warmed.

Zinc is applied as a coating to preserve iron from rust.

Zinc mixed with one-twentieth its weight of speculum metal may be melted in an iron ladle, and made to serve for some of the purposes of brass, such as common chucks. The alloy is sufficient to modify the crystalline character, but reserves the toughness of the zinc; it will not, however, bear hammering either hot or cold. Four atoms of zinc and one of tin, or 133.2 and 57.9, make a hard, malleable, and less crystalline alloy.

Biddery ware, manufactured at Biddery, a large city, 60 miles N.W. of Hyderabad in the East Indies, and also at Benares, is said to consist of copper 16 oz., lead 4 oz., and tin 2 oz., melted together; and to every 3 oz. of this alloy, 16 oz. of spelter or zinc are added. The metal is used as an inferior substitute for silver, and resembles some sorts of pewter.

The foregoing alloys are mostly derived from actual practice, and although it has been abundantly shown that alloys are most perfect, when mixed according to atomic proportions, or by multiples of their chemical equivalents, yet this excellent method is little adopted, owing to various interferences.

For example, it is in most cases necessary from an economic view, to mix some of the old alloys (the proportions of which are uncertain), along with the new metals. In most cases also, unless the fusion and refusion of the alloys are conducted with considerably more care than ordinary practice ever attains, or really demands, the loss by oxidation completely invalidates any nice attempts at proportion; and which proportions can be alone exactly arrived at when the combined metals are nearly or quite pure.

The chemical equivalents of the metals upon the hydrogen scale are appended; thus for mixtures of any metals, say tin and zinc, instead of taking arbitrary quantities, one atom of tin or 57.9 parts by weight, should be combined with 1, 2, 3, 4 or 5 atoms of zinc, or any multiple of 32.3 parts, and so with all other metals.

In the following table the first column of figures denotes the comparative strength of the metals, glass being considered as unity; thus steel of razor temper is nearly 16 times as strong as glass of equal size; and by the second column, it is seen that a bar of steel one inch square is pulled asunder by a load of 150,000 lbs.

Note.—The following Alloys having been omitted in their proper places are here inserted together.

Babbitt's Anti-Attrition Metal—Directions for Preparing and Fitting.—Melt 4 lbs. of copper, add. by degrees, 12 lbs. best quality Banca tin, 8 lbs. regulus of antimony, and 12 lbs. more of tin while the composition is in a melted state.

After the copper is melted and 4 or 5 lbs. of tin have been added, the heat should be reduced to a dull red, to prevent oxidation; then add the remainder of the metal as above. In melting the composition it is better to keep a small quantity of powdered charcoal on the surface of the metal. The above composition is called "hardening." For lining the boxes, take one lb. of this *hardening* and melt it with 2 lbs. of Banca tin, which produces the lining metal for use. Thus the proportions for *lining metal* are 4 lbs. of copper, 8 lbs. of regulus of antimony, and 96 lbs. of Banca tin.

The article to be lined, having been cast with a recess for the lining, is to be nicely fitted to a *former*, which is made of the same shape as the bearing. Drill a hole in the article for the reception of the metal, say a half or three-quarters of an inch, according to the size of it. Coat over the part not to be tinned with a clay wash, wet the part to be tinned with alcohol, and sprinkle on it powdered sal ammoniac; heat it till a fume arises from the sal ammoniac, and then immerse it in melted Banca tin, taking care not to heat it so that it will oxidize.

After the article is tinned, should it have a dark color, sprinkle a little sal ammoniac on it, which will make it of a bright silver color. Cool it gradually in water, then take the *former* to which the article has been fitted, and coat it over with a thin clay wash, and warm it so that it will be perfectly dry; heat the article until the tin begins to melt, lay it on the *former* and pour in the metal, which should not be so hot as to oxidize, through the drilled hole, giving it a head, so that as it shrinks it will fill up. After it has sufficiently cooled remove the *former*.

A shorter method may be adopted when the work is light enough to handle quickly, namely—When the article is prepared for tinning, it may be immersed in the lining metal instead of the tin, brushed lightly in order to remove the sal ammoniac from the surface, placed immediately on the former and lined at the same heating.

Fenton's Anti-Friction Metal.—7½ parts of grain zinc, 7½ of purified zinc, and 1 of antimony.

Alloy of the Standard Measure used by Government.—576 parts copper, 59 of tin, and 48 of brass (yellow, 2 copper to 1 of zinc).

Tutenague.—8 parts of copper, 5 of zinc, and 3 of nickel.

Expansion Metal.—9 parts of lead, 2 of antimony, and 1 of bismuth.

TABLES OF THE COHESIVE FORCE OF SOLID BODIES.

Table I.—Metals.

(*h*) and (*l*) mark the highest and lowest result which Muschenbroëk obtained from each kind of iron.

METALS.	Specific cohesion. Glass I.	Coh. force of a square inch in lbs. avoir.	Specific gravity.	Hardness.	AUTHORITY.
STEEL.					
Razor temper	15.927	150,000	[†] 7.78 to	[§]	Muschenbroëk, Encyclo. Brit., art. *Strength.*
Soft	12.739	120,000	7.84	11	Idem.
IRON.					
Wire	12.004	113,077	from 7.6 to 7.8[†]	from 8 to 9[†]	Sickingen, Ann. de Chimie, xxv. 9.
German bar, mark BR(h)	9.880	93,069			Muschenb. Int. ad Phil. Nat. i. 426.
Swedish bar (*h*)	9.445	88,972			Idem.
German bar, mark L (*h*)	9.119	85,000			Idem.
Wire	9.108	85,797			Buffon, Œuvres de Gauthey, ii. 153.
Bar	8.964	84,443			Emerson, Mechanics, 115.
Liege bar (*h*)	8.794	82,839			Muschenb. Int. ad Phil. Nat. i. 426.
Spanish bar	8.685	81,901			Idem.
Bar	8.581	80,833			Soufflot Rondelet's L'Art de Bâtir, iv. 500.
Bar	8.492	80,000			Edin. Encyclo., art. *Bridge,* 544.
Oosement bar (*h*)	8.142	76,697			Muschenb. Intr. ad Phil. Nat. i. 426.
Cable	7.752	73,024			Annals of Phil. vii. 320.
German bar, mark L (*l*)	7.382	69,538			Muschenb. Intr. ad Phil. Nat. i. 426.
German bar, common	7.339	69,133			Idem.
Swedish bar Oosement bar } (*l*)	7.296	68,728			Idem.
Bar of best quality	7.006	66,000			Rumford, Phil. Mag. x. 51.
Liege bar (*l*)	6.621	62,369			Muschenb. Intr. ad Phil. Nat. i. 426.
German bar, mark BR(*l*)	6.514	61,361			Idem.
Bar[*]	6.480	61,041			Perronet. Œuv. de Gauthey, ii. 154.
Bar of good quality	5.839	55,000			Rumford, Phil. Mag. x. 51.
Cable	5.787	54,513			Annals of Phil. x. 311.
Bar, fine-grained	5.306	49,982			Rondelet, L'Art. de Bâtir, iv. 502.
——medium fineness	3.618	34,081			Idem.
——coarse-grained	2.172	20,460			Idem.
CAST IRON.					
French[‡]	7.470	70,367			Navier, Œuv. de Gauthey, ii. 150.
German	7.250	68,295	7.807		Muschenb. Intr. ad Phil. Nat. i. 417.
French, soft[‡]	6.754	63,622			Rondelet, L'Art. de Bâtir, iv. 514.
English[‡]	5.520	52,000			Banks, Gregory's Mechan. i. 129. Ex. i.
French[‡]	5.412	50,981			L'Ecole des Ponts, etc. Gaut. ii. 150.
———[‡]	4.540	42,666			Gauthey, Œuvres, ii. 150.
English, soft[‡]	4.334	40,824		[§]	Banks, Greg. Mech. i. 148. Ex. iii.

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[*] This is the mean result of thirty-three experiments.

[†] Kirwan, Elem. Miner. ii. 155.

[‡] Calculated from experiments on the transverse strength, by arts. 14 and 15.

[§] Yielding to the file without difficulty.

TABLES OF THE COHESIVE FORCE OF SOLID BODIES.

Table I.—*Continued.*

METALS.	Specific cohesion. Glass I.	Coh. force of a square inch in lbs. avoir.	Specific gravity.	Hardness.	AUTHORITY.
CAST-IRON.					
French gray*	4.000	37,680			Rondelet, L'Art. de Bâtir, iv. 514.
Gray, of Cruzot, 2d fusion*	3.257	30,680			Ramus, Gauthey, ii. 150.
Gray, of Cruzot, 1st fusion*	3.202	30,162			Idem.†
COPPER.					
Wire	6.606	61,228			Sickingen, Ann. de Chimie, xxv. 9.
Cast, Barbary	2.396	22,570	8.182		Muschenb. Intr. ad Phil. Nat. i. 417.
—— Japan	2.152	20,272	8.726	8‡	Idem.
PLATINUM.					
Wire	5.995	56,473	20.847		Morveau, Ann. de Chimie, xxv. 8.
Wire	5.625	52,987		8§	Sickingen, Ann. de Chimie, xxv. 9.
SILVER.					
Wire	4.090	38,257			Sickingen, Ann. de Chimie, xxv. 9.
Cast	4.342	40,902	11.091	7§	Muschenb. Intr. ad Phil. Nat. i. 417.
GOLD.					
Wire	3.279	30,888			Sickingen, Ann. de Chimie, xxv. 9.
Cast	2.171	20,450	19.238	0‡	Muschenb. Intr. ad Phil. Nat. i. 417.
TIN.					
Wire	0.7568	7,129		6‡	Morveau, Ann. de Chim. lxxi. 194.
Cast, English black	0.706	6,650			Muschenb. Intr. ad Phil. Nat. i. 417.
—— idem	0.565	5,322	7.295		Idem.
—— Banca	0.3906	3,679	7.2165		Idem.
—— Malacca	0.342	3,211	6.1256		Idem.
BISMUTH.					
Cast	0.345	6,250	9.810	7§	Muschenb. Intr. ad Phil. Nat. i. 417.
——	0.3193	3,008	9.926		Idem. i. 454.
ZINC.					
Wire	2.394	22,551		6‡	Morveau, Ann. de Chim. lxxi. 194.
Patent sheet	1.762	16,616			By my trial.
Cast, Goslar, from	0.3118	2,937	7.215		Muschenb. Int. ad Phil. Nat. i. 417.
to	0.2855	2,689			
LEAD.					
Milled	0.3533	3,328	11.407	5§	By my trial.
Wire	0.334	3,146	11.348		Muschenb. Intr. ad Phil. Nat. i. 452.
Wire	0.274	2,581	11.282		Idem.
Wire	0.2704	2,547			Morveau, Ann. de Chim. lxxi. 194.
Cast, English	0.094	885	11.479		Muschenb. Intr. ad Phil. Nat. i. 452.
Antimony, cast	0.1126	1,060	4.500	6‡	Muschenb. Intr. ad Phil. Nat. i. 417.

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* Calculated from experiments on the transverse strength, by arts. 14 and 15.

† In the operation of casting, the surface of the iron always becomes much harder, and is more tenacious than the internal parts; hence the strength of a small specimen is always greater than that of a large one.

N. B.—When the specific gravity is not referred to a separate authority, it is to be considered that of the specimen of which the cohesive force is given.

‡ Kirwan's Miner. vol. ii.

§ Thomson's Chemistry, vol. i.

TABLES OF THE COHESIVE FORCE OF SOLID BODIES.

Table II.—Alloys.

ALLOY OF				Specific cohesion. Glass I.	Cohesion of square inch in lbs. avoir.	Specific gravity.	AUTHORITY.
	Parts.		Parts.				
Gold.........	2	Silver........	1	2.972	28,000		Musch. Encyclop. Brit. art.
Gold.........	5	Copper.......	1	5.307	50,000		Idem. [*Strength.*
Silver.........	5	Copper.......	1	5.148	48,500		Idem.
Silver.........	4	Tin...........	1	4.352	41,000		Idem.
Brass.........		....		4.870	45,882		Muschenb., Colson, i. 242.
Copper.......	10	Tin...........	1	3.407	32,093		Musch. Intr. ad Phil. Nat.
Copper.......	8	Tin...........	1	3.831	36,088		Idem. [i. 428.
Copper.......	6	Tin...........	1	4.687	44,071		Idem.
Copper.......	4	Tin...........	1	3.794	35,739		Idem.
Copper.......	2	Tin...........	1	0.108	1,017		Idem.
Copper.......	1	Tin...........	1	0.077	725		Idem.
Tin, English	10	Lead.........	1	0.733	6,904		Musch. Intr. ad Phil. Nat.
Tin, ——	8	Lead.........	1	0.841	7,922		Idem. [i. 438.
Tin, ——	6	Lead.........	1	0.849	7,997		Idem.
Tin, ——	4	Lead.........	1	1.126	10,607		Idem.
Tin, ——	2	Lead.........	1	0.793	7,470		Idem.
Tin, ——	1	Lead.........	1	0.751	7,074		Idem.
Tin, Banca	10	Antimony...	1	1.187	11,181	7.359	Musch. Intr. ad Phil. Nat.
Tin, ——	8	Antimony...	1	1.049	9,881	7.276	Idem. [i. 442.
Tin, ——	6	Antimony...	1	1.341	12,632	7.228	Idem.
Tin, ——	4	Antimony...	1	1.431	13,480	7.192	Idem.
Tin, ——	2	Antimony...	1	1.277	12,029	7.105	Idem.
Tin, ——	1	Antimony...	1	0.338	3,184	7.060	Idem.
Tin, ——	10	Bismuth.....	1	1.347	12,688	7.576	Musch. Intr. ad Phil. Nat.
Tin, ——	4	Bismuth.....	1	1.772	16,692	7.613	Idem. [i. 443.
Tin, ——	2	Bismuth.....	1	1.488	14,017	8.076	Idem.
Tin, ——	1	Bismuth.....	1	1.276	12,020	8.146	Idem.
Tin, ——	1	Bismuth.....	2	1.063	10,013	8.58	Idem.
Tin, ——	1	Bismuth.....	4	0.836	7,875	9.009	Idem.
Tin, ——	1	Bismuth.....	10	0.411	3,871	9.439	Idem.
Tin, ——	10	Zinc, Indian	1	1.371	12,914	7.288	Musch. Intr. ad Phil. Nat.
Tin, ——	2	Zinc..........	1	1.595	15,025	7.000	Idem. [i. 444.
Tin, ——	1	Zinc..........	1	1.682	15,844	7.321	Idem.
Tin, ——	1	Zinc..........	2	1.701	16,023	7.100	Idem.
Tin, ——	1	Zinc..........	10	0.602	5,671	7.130	Idem.
Tin, English	1	Zinc, Goslar	1	0.958	9,024		Musch. Intr. ad Phil. Nat.
Tin, ——	2	Zinc..........	1	1.164	10,964		Idem. [i. 446.
Tin, ——	4	Zinc..........	1	1.089	10,258		Idem.
Tin, ——	8	Zinc..........	1	1.126	10,607		Idem.
Tin, ——	1	Antimony...	1	0.154	1,450	7.000	Musch. Intr. ad Phil. Nat.
Tin, ——	3	Antimony...	2	0.338	3,184		Idem. [i. 448.
Tin, ——	4	Antimony...	1	1.202	11,323		Idem.
Lead, Scotch	1	Bismuth.....	1	0.777	7,319	10.931	Musch. Intr. ad Phil. Nat.
Lead, ——	2	Bismuth.....	1	0.620	5,840	11.090	Idem. [i. 454.
Lead, ——	10	Bismuth.....	1	0.300	2,826	10.827	Idem.

TABULAR VIEW OF SOME OF THE PROPERTIES OF METALS.

	Specific gravity.	Chemical equivalents.
Platinum	20.98	98.8
Gold	19.258	199.2
Iridium	18.680	98.8
Tungsten	17.50	99.7
Mercury	13.568	202.
Palladium	11.50	53.3
Lead	11.35	103.6
Rhodium	11.0	52.2
Silver	10.47	108.
Bismuth	9.80	71.
Uranium	9.00	217.
Copper	8.89	31.6
Cadmium	8.60	55.8
Cobalt	8.53	29.5
Nickel	8.27	29.5
Iron	7.78	28.
Molybdenum	7.40	47.7
Tin	7.30	57.9
Zinc	7.00	32.3
Manganese	6.85	27.7
Antimony	6.70	64.6
Tellurium	6.10	64.2
Arsenic	5.8	37.7
Titanium	5.3	24.3
Sodium	0.972	23.3
Potassium	0.865	39.15

Alloys possessed of greater specific gravity than the mean of their components.

Gold and Zinc.
— Tin.
— Bismuth.
— Antimony.
— Cobalt.
Silver and Zinc.
— Lead.
— Tin.
— Bismuth.
— Antimony.
Copper and Zinc.
— Tin.
— Palladium.
— Bismuth.
— Antimony.
Lead and Bismuth.
— Antimony.
Platinum and Molybdenum.
Palladium and Bismuth.

FUSIBILITY.

		Fahrenheit.	
Fusible below a red heat.	Mercury	39 deg.	
	Potassium	136 "	
	Sodium	190 "	
	Tin	442 "	
	Bismuth	497 "	
	Lead	612 "	
	Tellurium, rather less fusible than lead.		
	Arsenic, undetermined.		
	Zinc	773 "	
	Antimony, a little below a red heat.		
	Cadmium, about	442 "	
	Silver	1873 deg.	
Infusible below a red heat.	Copper	1996 "	
	Gold	2016 "	
	Cobalt, rather less fusible than iron.		
	Iron, cast	2786 "	
	Iron, malleable		requiring the highest heat of a smith's forge.
	Manganese		
	Nickel, nearly the same as Cobalt.		
	Palladium		Almost infusible and not to be procured in buttons by the heat of a smith's forge, but fusible before the oxyhydrogen blowpipe.
	Molybdenum		
	Uranium		
	Tungsten		
	Chromium		
	Titanium		
	Cerium		
	Osmium		
	Iridium		
	Rhodium		
	Platinum		
	Columbium		

Alloys having a specific gravity inferior to the mean of their components.

Gold and Silver.
— Iron.
— Lead.
— Copper.
— Iridium.
— Nickel.
Silver and Copper.
Copper and Lead.
Iron and Bismuth.
— Antimony.
— Lead.
Tin and Lead.
— Palladium.
— Antimony.
Nickel and Arsenic.
Zinc and Antimony.

TABULAR VIEW OF METALS—*Continued.*

HARDNESS.

Titanium	Harder than Steel.
Manganese	
Platinum	Scratched by Calcspar.
Palladium	
Copper	
Gold	
Silver	
Tellurium	
Bismuth	
Cadmium	
Tin	
Chromium	Scratch glass.
Rhodium	
Nickel	Scratched by glass.
Cobalt	
Iron	
Antimony	
Zinc	
Lead	Scratched by the nail.
Potassium	Soft as wax (at 60 deg.)
Sodium	
Mercury	Liquid.

BRITTLENESS.

The following metals are brittle, and most of them may even be reduced to powder.

Antimony.
Arsenic.
Bismuth.
Cerium.
Chromium.
Cobalt.
Columbium.
Manganese.
Molybdenum.
Rhodium.
Tellurium.
Titanium.
Tungsten.
Uranium.

MALLEABILITY,

Or admit of being extended by the hammer.

Gold.
Silver.
Copper.
Tin.
Cadmium.
Platinum.
Lead.
Zinc.
Iron.
Nickel.
Palladium.
Potassium.
Sodium.
Frozen Mercury.

DUCTILITY,

Or admit of being drawn into wires.

Gold.
Silver.
Platinum.
Iron.
Copper.
Zinc.
Tin.
Lead.
Nickel.
Palladium
Cadmium.

TENACITY.

Weights sustained by wires 0.787 of a line diameter.

Iron	549	lbs.	250	dec. pts.
Copper	302	"	278	"
Platinum	274	"	320	"
Silver	187	"	137	"
Gold	150	"	753	"
Zinc	109	"	540	"
Tin	34	"	630	"
Lead	27	"	621	"

Elasticity and sonorousness belong to the hardest metals only, and are most evident in certain alloys.

Odor and taste are most remarkable in copper, iron, and tin.

LINEAR DILATATIONS BY HEAT.

Dimensions which a bar takes at 212°, whose length at 32° is 1.000000; also its dilatation in vulgar fractions.

Platinum	1.00091085	or one	1097th	part.
Palladium	1.00100000	"	1000th	"
Antimony	1.00108300	"	923d	"
Cast iron	1.00111025	"	901st	"
Steel	1.00121286	"	824th	"
Wrought Iron	1.00124860	"	801st	"
Bismuth	1.00139200	"	718th	"
Gold	1.00149824	"	667th	"
Copper	1.00179633	"	557th	"
Gun metal (C.8,T.1)	1.00181700	"	550th	"
Brass	1.00190663	"	524th	"
Speculum metal	1.00193300	"	517th	"
Silver	1.00200183	"	499th	"
Tin	1.00235840	"	424th	"
Lead	1.00285768	"	350th	"
Zinc	1.00297650	"	336th	"

The above are the mean proportions of the various examples of each metal, given in Ure's Dictionary of Chemistry and elsewhere.

POWER OF CONDUCTING HEAT.

*From Despretz's Experiments.**

	Conducting power.
Gold	100
Platinum	98.1
Silver	97.3
Copper	89.82
Iron	37.41
Zinc	36.37
Tin	30.38
Lead	17.96
Marble	2.34
Porcelain	1.22
Brick earth	1.13†

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* Ann. de Chim. et de Phys. xix. 97.

† Traité Elémentaire de Physique, par M. Despretz, p. 20, as quoted by Dr. Thomson, on Heat and Electricity, p. 103.

WEIGHTS OF WROUGHT-IRON, STEEL, COPPER, AND BRASS WIRE AND PLATES.

The specific gravities to determine the weights of the following-named metals, and the calculations of them, were taken and made by Charles H. Haswell, of New York, for the well-known manufacturers, Messrs. J. R. Brown & Sharpe, of Providence, R. I. Diameter and thickness determined by American gage:—

No. of Gage.	Size of each number.	Wire—per Lineal foot.				Plates—per Lineal Foot.			
		Wrought Iron.	Steel.	Copper.	Brass.	Wrought Iron.	Steel.	Copper.	Brass.
	Inch.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
0000	.46000	.560740	.566030	.640513	.605176	17.25	17.48	20.838	19.688
000	.40964	.444683	.448879	.507946	.479908	15.3615	15.5663	18.5567	17.5326
00	.36480	.352659	.355986	.402830	.380666	13.68	13.8624	16.5254	15.6134
0	.32486	.279665	.282303	.319451	.301816	12.1823	12.3447	14.7162	13.904
1	.28930	.221789	.223891	.253342	.239353	10.8488	10.9934	13.1053	12.382
2	.25763	.175888	.177548	.200911	.189818	9.6611	9.7899	11.6706	11.0266
3	.22942	.139480	.140796	.159323	.150522	8.6033	8.7180	10.3927	9.8192
4	.20431	.110616	.111660	.126353	.119376	7.6616	7.7638	9.2552	8.7445
5	.18194	.087720	.088548	.100200	.094666	6.8228	6.9137	8.2419	7.787
6	.16202	.069565	.070221	.079462	.075076	6.0758	6.1568	7.3395	6.9345
7	.14428	.055165	.055685	.063013	.059545	5.4105	5.4826	6.5359	6.1752
8	.12849	.043751	.044164	.049976	.047219	4.8184	4.8826	5.8206	5.4994
9	.11443	.034699	.035026	.039636	.037437	4.2911	4.3483	5.1837	4.8976
10	.10189	.027512	.027772	.031426	.029687	3.8209	3.8718	4.6156	4.3609
11	.090742	.021820	.022026	.024924	.023549	3.4028	3.4482	4.1106	3.8838
12	.080808	.017304	.017468	.019766	.018676	3.0303	3.0707	3.6606	3.4586
13	.071961	.013722	.013851	.015674	.014809	2.6985	2.7345	3.2598	3.0799
14	.064084	.010886	.010909	.012435	.011746	2.4032	2.4352	2.9030	2.7428
15	.057068	.008631	.008712	.009859	.009315	2.1401	2.1686	2.5852	2.4425
16	.050320	.006845	.006909	.007819	.007587	1.9058	1.9312	2.3021	2.1751
17	.045257	.005407	.005478	.006199	.005857	1.6971	1.7198	2.0501	1.937
18	.040303	.004304	.004304	.004916	.004645	1.5114	1.5315	1.8257	1.725
19	.035890	.003413	.003445	.003899	.003684	1.3459	1.3638	1.6258	1.5361
20	.031961	.002708	.002734	.003094	.002920	1.1985	1.2145	1.4478	1.3679
21	.028462	.002147	.002167	.002452	.002317	1.0673	1.0816	1.2893	1.2182
22	.025347	.001703	.001719	.001945	.001838	.95051	.96319	1.1482	1.0849
23	.022571	.001350	.001363	.001542	.001457	.84641	.8577	1.0225	.96604
24	.020100	.001071	.001081	.001223	.001155	.75375	.7638	.91053	.86028
25	.017900	.0008491	.0008571	.0009699	.0009163	.67125	.6802	.81087	.76612
26	.015940	.0006734	.0006797	.0007692	.0007267	.59775	.60572	.72208	.68223
27	.014196	.0005340	.0005391	.0006099	.0005763	.53231	.53941	.64303	.60755
28	.012641	.0004235	.0004275	.0004837	.0004570	.47404	.48036	.57264	.53103
29	.011257	.0003358	.0003389	.0003835	.0003624	.42214	.42777	.50994	.48180
30	.010025	.0002663	.0002688	.0003042	.0002874	.37594	.38095	.45413	.42907
31	.008928	.0002113	.0002132	.0002413	.0002280	.3348	.33926	.40444	.38212
32	.007950	.0001675	.0001691	.0001913	.0001808	.29813	.3021	.36014	.34026
33	.007080	.0001328	.0001341	.0001517	.0001434	.2655	.26904	.32072	.30302
34	.006304	.0001053	.0001065	.0001204	.0001137	.2364	.23955	.28557	.26981
35	.005614	.00008366	.00008445	.0000956	.00009015	.21053	.21333	.25431	.24028
36	.005000	.00006625	.00006687	.0000757	.0000716	.1875	.19	.2265	.2140
37	.004453	.00005255	.00005304	.00006003	.00005671	.16699	.16921	.20172	.19059
38	.003965	.00004166	.00005205	.00004758	.00004496	.14869	.15067	.17961	.1697
39	.003531	.00003305	.00003336	.00003775	.00003566	.13241	.13418	.15995	.15113
40	.003144	.00002620	.00002644	.00002992	.00002827	.1179	.11947	.14242	.13456
Specific Gravities ..		7.774	7.847	8.880	8.386	7.200	7.296	8.698	8.218
Weights of a cub. ft.		585.87	490.45	554.988	524.16	450.	456.	543.6	513.6

CHAPTER XIII.

REMARKS ON THE CHARACTERS OF THE METALS AND ALLOYS.

HARDNESS, FRACTURE, AND COLOR OF ALLOYS.—The object of the present chapter is to explain in a general way some of the peculiarities and differences amongst alloys, prior to entering on the means of melting the metals, without which process alloys cannot be made: yet notwithstanding that the list contains the greater number of the alloys in ordinary use, and many others, it is merely a small fraction of those which might be made.

It is also stated that metals appear to unite with one another in every proportion, precisely in the same manner as sulphuric acid and water. Thus there is no limit to the number of alloys of gold and copper. The same might be said of many other metals, and when the alloys compounded of three, four, or more metals, are taken into account, the conceivable number of alloys becomes almost unlimited. It is certain, however, that metals have a tendency to combine in definite proportion; for several atomic compounds of this kind occur native. It is indeed possible that the variety of proportions in alloys is rather apparent than real, arising from the mixture of a few definite compounds with each other, or with uncombined metal; an opinion not only suggested by the mode in which alloys are prepared, but in some measure supported by observation.

It appears to be scarcely possible to give any sufficiently general rules, by which the properties of alloys may be safely inferred from those of their constituents; for although, in many cases, the working qualities and appearance of an alloy, may be nearly a mean proportional between the nature and quantities of the metals composing it; yet in other and frequent instances the deviations are excessive, as will be seen by several of the examples referred to.

Thus, when lead, a soft and malleable metal, is combined with antimony, which is hard, brittle, and crystalline, in the proportions of from twelve to fifty parts of lead to one of antimony; a flexible alloy is obtained, resembling lead, but somewhat harder, and which is rolled into sheets for sheathing ships. Six parts of lead and one of antimony are used for the large soft printers' types, which will bend slightly, but are considerably harder than the foregoing; and three parts of lead and one of antimony are employed for the smallest types, that are very hard and brittle, and will not bend at all; antimony being the more expensive metal, is used in the smallest quantity that will suffice.

In this alloy the antimony fulfills another service besides that of imparting hardness: antimony somewhat expands on cooling, whereas lead contracts very much, and the antimony, therefore, within certain limits, compensates for this contraction, and causes the alloy to retain the full size of the moulds.

Sometimes, from motives of economy, the neighboring parts of machinery are not wrought accurately to correspond one with the other, but lead is poured in to fill up the intermediate space, and to make contact; as around the brass nuts in the heads of some screw presses, in the guides or followers for the same, and some other parts of either temporary or permanent machinery. Antimony is quite essential in all these cases to prevent the contraction the lead alone would sustain, and which would defeat the intended object, as the metal would otherwise become smaller than the space to be filled.

A little tin is commonly introduced into types, and likewise copper in minute quantity; iron and bismuth are also spoken of; the last is said to be employed on account of its well-known property of expanding in cooling, so as to cause the types to swell in the mould, and copy the face of the letter more perfectly, but although I find bismuth to have been thus used it appears to be neither common nor essential in printing-types.

The difference in specific gravity between lead and antimony constantly interferes, and unless the type metal is frequently stirred, the lead, from being the heavier metal, sinks to the bottom, and the antimony is disproportionally used from the surface.

In the above examples, the differences arising from the proportions appear intelligible enough, as when the soft lead prevails, the mixture is much like the lead; and as the hard, brittle antimony is increased, the alloy becomes hardened, and more brittle: with the proportion of four to one, the fracture is neither reluctant like that of lead, nor foliated like antimony, but assumes very nearly the grain and color of some kinds of steel and cast-iron. In like manner, when tin and lead are alloyed, the former metal imparts to the mixture some of its hardness, whiteness, and fusibility, in proportion to its quantity; as seen in the various qualities of pewter, in which however copper, and sometimes zinc or antimony are found.

The same agreement is not always met with; as nine parts of copper, which is red, and one part of tin, which is white, each *very* malleable and ductile metals, make the tough, rigid metal used in brass ordnance, from which it obtains its modern name of gun-metal, but which neither admits of rolling nor drawing into wire; the same alloy is described by Pliny as the soft *bronze* of his day. The continual addition of the tin, the *softer metal,* produces a gradual increase of hardness in the mixture; with about one-sixth of tin the alloy assumes its maximum hardness consistent with its application to mechanical uses; with one-fourth to one-third tin it becomes highly elastic and sonorous, and its brittleness rather than its hardness is greatly increased.

When the copper becomes two, and the tin one part, the alloy is so hard as not to admit of being cut with steel tools, but crumbles under their action; when struck with a hammer or even suddenly warmed it flies in pieces like glass, and clearly shows a structure highly crystalline, instead of malleable. The alloy has no trace of the red color of the copper, but it is quite white, susceptible of an exquisite polish, and being little disposed to tarnish, it is most perfectly adapted to the reflecting speculums of telescopes and other instruments, for which purpose it is alone used.

Copper, when combined *in the same proportions* with a different metal, also light-colored and fusible, namely, two parts of copper, with one of zinc, (which latter metal is of a bluish-white, and *crystalline,* whereas tin is very ductile,) makes an alloy of entirely opposite character to the speculum metal; namely, the soft yellow brass, which becomes by hammering very elastic and ductile, and is very easily cut and filed.

Again, the same proportions, namely, two parts of copper and one of lead, make a common inferior metal, called pot-metal, or cock-metal, from its employment in those respective articles. This alloy is much softer than brass, and hardly possesses malleability; when, for example, the beer-tap is driven into the cask, immediately after it has been scalded, the blow occasionally breaks it in pieces, from its reduced cohesion.

Another proof of the inferior attachment of the copper and lead exists in the fact that, if the moulds are opened before the castings are almost cold enough to be handled, the lead will ooze out and appear on the surface in globules. This also occurs to a less extent in gun-metal, which should not on that account be too rapidly exposed to the air; or the tin *strikes to the surface,* as it is called, and makes it particularly hard at those parts, from the proportional increase of the tin. In casting large masses of gun-metal, it frequently happens that little hard lumps, consisting of nearly half tin, work up to the surface of the runners or pouring places, during the time the metal is cooling.

In brass, this separation scarcely happens, and these moulds may be opened whilst the castings are red hot, without such occurrence; from which it appears that the copper and zinc are in more perfect chemical union than the alloys of copper with tin and with lead.

MALLEABILITY AND DUCTILITY OF ALLOYS.—The malleability and ductility of alloys are in a great measure referable to the degrees in which the metals of which they are respectively composed, possess these characters.

Lead and tin are malleable, flexible, ductile, and inelastic whilst cold, but when their temperatures much exceed about half way towards their melting heats they are exceedingly brittle and tender, owing to their reduced cohesion.

The alloys of lead and tin partake of the general nature of these two metals; they are flexible when cold, even with certain additions of the brittle metals, antimony and bismuth, or of the fluid metal mercury; but they crumble with a small elevation of temperature, as these alloys melt at a lower degree than either of their components, to which circumstance we are indebted for the tin solders.

Zinc, when cast in thin cakes, is somewhat brittle when cold, but its toughness is so far increased when it is raised to about 300° F. that its manufacture into sheets by means of rollers is then admissible; it becomes the malleable zinc, and retains the malleable and ductile character, in a moderate degree, even when cold, but in bending rather thick plates it is advisable to warm them to avoid fracture; when zinc is remelted, it resumes its original crystalline condition. It is considered that most of the sheet zinc contains a very little lead.

Zinc and lead will not combine without the assistance of arsenic, unless the lead is in very small quantity. The arsenic makes this and other alloys very brittle, and it is besides dangerous to use. Zinc and tin make, as may be supposed, somewhat hard and brittle alloys, but none of the zinc alloys, except that with copper to constitute brass, are much used.

Gold, silver, and copper, which are greatly superior in strength to the fusible metals above named, may be forged either when red-hot or cold, as soon as they have been purified from their earthy matters, and fused into ingots; and the alloys of gold, silver, and copper, are also malleable, either red-hot or cold.

Fine, or pure gold and silver, are but little used alone. The alloy is in many cases introduced less with the view of depreciating their value than of adding to their hardness, tenacity, and ductility. The processes which the most severely test these qualities, namely, drawing the finest wires, and beating gold and silver leaf, are not performed with the pure metals, but gold is alloyed with copper for the red tint, with silver for the green, and with both for intermediate shades. Silver is alloyed with copper only, and when the quantity is small its color suffers but slightly from the addition, although its working qualities are greatly improved, pure silver being little used.

The alloys of similar metals having been considered, it only remains to observe that when dissimilar metals are combined, as those of the two opposite groups; namely, the fusible lead, tin, or zinc, with the less fusible copper, gold, and silver, the malleability of the alloys when cold is less than that of the superior metal; and when heated barely to redness, they fly in pieces under the hammer; and, therefore, brass, gun-metal, etc., when red-hot, must be treated with precaution and tenderness. It will be remembered the action of rollers is more regular than that of the hammer, and soon gives rise to the fibrous character, which, so far as it exists in metals, is the very element of strength when it is uniformly distributed throughout their substance. This will be seen by the inspection of the relative degrees of cohesion possessed by the same metal when in the conditions of the casting, sheet, or wire, shown by the table, and to which quality or the tenacity of the alloys we shall now devote a few lines.

Strength or Cohesion of Alloys.—The strength or cohesion of the alloys is in general greatly superior to that of any of the metals of which they are composed. For example, on comparing some of the numbers of the table on pages 206 and 208, it will be seen that the relative weights, which tear asunder a bar one inch square of the several substances, stand as follows,—all the numbers being selected from Muschenbroëk's valuable investigations, so that it may be presumed the same metals, and also the same means of trial, were used in every case.

Alloys.			Cast Metals.			
10 Copper,	1 Tin,	32,093 lbs.	Barbary Copper,	22,570 lbs.	English Block Tin,	6,650
8 —	1 —	36,088 “	Japan —	20,272 “	Do. —	5,322
6 —	1 —	44,071 “			Banca Tin,	3,679
4 —	1 —	35,739 “			Malacca Tin,	3,211
2 —	1 —	1,017 “				
1 —	1 —	725 “				

The inspection of these numbers is highly conclusive, and it shows that the engineer agrees with theory and experiment in selecting the proportion 6 to 1 as the strongest alloy; and that the philosopher, in choosing the most reflective mixture, employs the weakest but one,—its strength being only one-third to one-sixth that of the tin, or one-twentieth that of the copper, which latter constitutes two-thirds its amount.

It is much to be regretted that the valuable labors of Muschenbroëk have not been followed up by other experiments upon the alloys in more general use. One curious circumstance will be observed, however, in those which are given, namely, that in the following alloys, which are the strongest of their respective groups, the tin is always four times the quantity of the other metal; and they all confirm the circumstance of the alloys having mostly a greater degree of cohesion than the stronger of their component metals.

Alloys.			Cast Metals.	
4 English Tin,	1 Lead,	10,607 lbs.	Lead,	885 lbs.
4 Banca Tin,	1 Antimony,	13,480 “	Antimony,	1,060 “
4 — —	1 Bismuth,	16,692 “	Zinc,	2,689 “
4 English Tin,	1 Goslar Zinc,	10,258 “ *	Bismuth,	3,008 “
4 — —	1 Antimony,	11,323 “	Tin,	3,211 to 6,650 “

Fig. 118 represents a very ingenious instrument, denominated an alloy-balance. It is intended for weighing those metals the proportions of which are stated decimally: its principle, which is so simple as hardly to require explanation, depends upon the law that weights in equilibrium are inversely as their distances from the point of support.

For weighing out any precise number of pounds or ounces, in the common way, the arms of the ordinary scale-beam are made as

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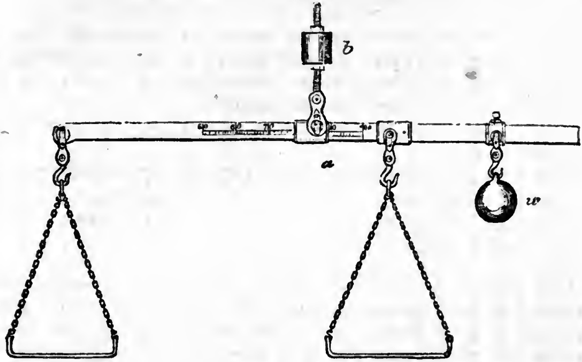
* This, in truth, is an exception; it barely equals in strength the alloys with 8 and 2 parts of tin to 1 of zinc, but is superior to that of equal parts. It corroborates the great increase of strength in alloys generally.

nearly equal as possible; so that the weights, and the articles to be weighed, may be made to change places, in proof of the equality of the instrument. But to weigh out an alloy, say of 17 parts tin and 83 copper, unless the quantities were either 17 and 83 lbs. or ounces, would require a little calculation.

Fig. 118.



This is obviated, if the point of suspension *a*, of the alloy-balance, which is hung from any fixed support *b*, is adjusted until the arms are respectively as 17 to 83; and for this purpose the half of the beam is divided into fifty equal parts numbered from the one end; and, prior to use, it only remains to adjust the weight, *w*, so as to place the empty balance in equilibrium. A quantity of copper, rudely estimated, having been suspended from the short arm of the balance, the proportionate quantity of the tin will be denoted with critical accuracy, when, by its gradual addition, the beam is exactly restored to the horizontal line; should the alloy consist of three or more parts, the process of weighing is somewhat more complex.

The annexed table was calculated by the author, for converting the proportions of alloys stated decimally, into avoirdupois weight. It applies with equal facility to alloys containing two or many components, so as to bring them readily within the power of ordinary scales.

TABLE FOR CONVERTING DECIMAL PROPORTIONS

Into Divisions of the Pound Avoirdupois.

Decimal.	oz.	dr.	Decimal.	oz.	dr.	Decimal.	oz.	dr.	Decimal.	oz.	dr.
.78		1	13.28	2	1	25.78	4	1	38.28	6	1
1.56		2	14.06	2	2	26.56	4	2	39.06	6	2
2.34		3	14.84	2	3	27.34	4	3	39.84	6	3
3.12		4	15.62	2	4	28.12	4	4	40.62	6	4
3.91		5	16.41	2	5	28.91	4	5	41.41	6	5
4.69		6	17.19	2	6	29.69	4	6	42.19	6	6
5.47		7	17.97	2	7	30.47	4	7	42.97	6	7
6.25	1	0	18.75	3	0	31.25	5	0	43.75	7	0
7.03	1	1	19.53	3	1	32.03	5	1	44.53	7	1
7.81	1	2	20.31	3	2	32.81	5	2	45.31	7	2
8.59	1	3	21.09	3	3	33.59	5	3	46.09	7	3
9.37	1	4	21.87	3	4	34.37	5	4	46.87	7	4
10.16	1	5	22.66	3	5	35.16	5	5	47.66	7	5
10.94	1	6	23.44	3	6	35.94	5	6	48.44	7	6
11.72	1	7	24.22	3	7	36.72	5	7	49.22	7	7
12.50	2	0	25.06	4	0	37.50	6	0	50.00	8	0

Application of the Table.

The Chinese Packfong, similar to our German silver, is said to consist of—

40.4 parts of	Copper	equivalent to	6 oz. 4 drams, nearly.
25.4 —	Zinc		4 — 0 — full.
31.6 —	Nickel		5 — 1 — nearly.
2.6 —	Iron		0 — 3 — full.
100.0 parts			16 oz. 0 — Avoird's.

All nice attempts at proportion are, however, entirely futile, unless the metals are perfectly pure; for example, it is a matter of common observation that for speculums a variable quantity of from seven and a half to eight and a half ounces of tin is required for the exact saturation of every pound of copper, and upon which saturation the efficiency of the compound depends; bells of exactly similar quality sometimes thus require the dose of tin to vary from three and a half to five ounces to the pound of copper, according to the qualities of the metals.

The variations in the purity of the metals obtained from different localities are abundantly demonstrated by the disagreement in the cohesive strengths of the two in question, more particularly the tin, as seen on page 214, and which can be only ascribed to their respective amounts of impurity. Any other supposition than the presence of foreign matter, would necessarily go to disprove the fact of the metals being simple bodies, and therefore strictly alike when absolutely pure, wheresoever they may have been obtained.

FUSIBILITY OF ALLOYS.—In concluding this slight view of some of the general characters of alloys, it remains to consider the influence of heat, both as an agent in their formation and as regards the degree in which it is required for their after-fusion; the lowest available temperature being the most desirable in every such case.

Metals do not combine with each other in their solid state, owing to the influence of chemical affinity being counteracted by the force of cohesion. It is necessary to liquefy at least one of them, in which case they always unite, provided their mutual attraction is energetic. Thus, brass is formed when pieces of copper are put into melted zinc; and gold unites with mercury at common temperatures by mere contact.

The agency of mercury in bringing about *triple* combinations of the metals, both with and without heat, is also very curious and extensive. Thus, in *water-gilding*, the silver, copper, or gilding metal, when chemically clean, is rubbed over with an amalgam of gold containing about eight parts of mercury; this immediately attaches itself, and it is only necessary to evaporate the mercury, which requires a very moderate heat, and the gold is left behind. *Water-silvering* is similarly accomplished.

Cast-iron, wrought-iron, and steel, as well as copper and many other metals, may be tinned in a similar manner. An amalgam of tin and mercury is made so as to be soft and just friable; the metal to be tinned is thoroughly cleaned, either by filing or turning, or if only tarnished by exposure, it is cleaned with a piece of emery-paper or otherwise, without oil, and then rubbed with a thick cloth moistened with a few drops of muriatic acid. A little of the amalgam then rubbed on with the same rag, thoroughly coats the cleaned parts of the metal by a process which is described as *cold-tinning;* other pieces of metal may be attached to the tinned parts by the ordinary process of tin-soldering.

In making the tinned iron plates, the scoured and cleaned iron plates are immersed in a bath of pure melted tin, covered with pure tallow, the tin then unites with every part of the surfaces; and in the ordinary practice of tinning culinary vessels of copper, pure tin is also used. The two metals, however, must then be raised to the melting heat of tin; but the presence of a little mercury enables the process to be executed at the atmospheric temperature, as above explained.

In M. Mallet's recently patented processes for the protection of iron from oxidation and corrosion, and for the prevention of the fouling of ships, one proceeding consists in covering the iron with zinc.

The ribs or plates for iron ships are immersed in a cleansing bath of equal parts of sulphuric or muriatic acid and water, used warm; the works are then hammered, and scrubbed with emery or sand, to detach the scales and to thoroughly clean them; they are then immersed in a preparing bath of equal parts of saturated solutions of muriate of zinc and sal-ammoniac, from which the works are transferred to a fluid metallic bath, consisting of 202 parts of mercury and 1292 parts of zinc, both by weight (being in the proportion of one atom of mercury to forty atoms of zinc); to every ton weight of which alloy, is added about one pound of either potassium or sodium (the metallic bases of potash and soda), the latter being preferred. As soon as the cleaned iron works have attained the melting heat of the triple alloy, they are removed, having become thoroughly coated with zinc.

The affinity of this alloy for iron is, however, so intense, and the peculiar circumstances of surface as induced upon the iron presented to it by the preparing bath are such, that care is requisite least by too long an immersion the plates are not partially or wholly dissolved. Indeed where the articles to be covered are small, or their parts minute, such as wire, nails or small chain, it is necessary before immersing them to permit the triple alloy to dissolve or combine with some wrought-iron, in order that its affinity for iron may be partially satisfied and thus diminished. At the proper fusing temperature of this alloy, which is about 680° Fahr., it will dissolve a plate of wrought-iron of an eighth of an inch thick in a few seconds.

The Palladiumizing Process.—The articles to be protected are to be first cleansed in the same way as in the case of zincing; namely, by means of the double salts of zinc and ammonia, or of manganese and ammonia; and then to be thinly coated over with palladium, applied in a state of amalgam with mercury.

In the opinion of eminent chemists and metallurgists, *all* the metals, even the most refractory which nearly, or quite refuse to melt in the crucible when alone, will gradually run down when surrounded by some of the more fusible metals in the fluid state; in a manner similar to the solution of the metals in mercury, as in the amalgams, or the solutions of solid salts in water. The surfaces of the superior metals are, as it were, dissolved, washed down, or reduced to the state of alloys, layer by layer, until the entire mass is liquefied.

Thus nickel, although it barely fuses alone, enters into the composition of German silver by aid of the copper, and whilst it gives whiteness and hardness, it also renders the mixture less fusible. Platinum combines very readily with zinc, arsenic, and also with tin and other metals; so much so that it is dangerous to melt either of those metals in a platinum spoon; or to solder platinum with common tin solder, which fuses at a very low temperature: although platinum is constantly soldered with fine gold, the melting point of which is very high in the scale. Again, the circumstances that some of the fusible bismuth alloys melt below the temperature of boiling water, or at less than half the melting heat of tin, their most fusible ingredient, show that the points of fusion of alloys are equally as difficult of explanation or generalization as many other of the anomalous circumstances concerning them.

This much, however, may be safely advanced, that alloys, without exception, are more easily fused than the superior metal of which they are composed; and extending the same view to the *relative* quantities of the components, it may be observed that the hard solders for the various metals and alloys, are in general made of the self-same material which they are intended to join, but with small additions of the more fusible metals. The solder should be, as nearly as practicable, equal to the metal on which it is employed, in hardness, color, and every property except fusibility; in which it must excel just to an extent that, when ordinary care is used, will avoid the risk of melting at the same time, both the object to be soldered and likewise the softer alloy or solder by which it is intended to unite its parts.

It would appear as if every example of soldering in which a more fusible alloy is interposed, were also one of superficial alloying. Thus, when two pieces of iron are united by copper, used as a solder, it seems to be a natural conclusion that each surface of the iron becomes alloyed with the copper: and that the two alloyed surfaces are held together from their particles having been fused in contact, and run into one film. It is much the same when brass or spelter solder is used, except that triple alloys are then formed at the surfaces of the iron, and so with most other instances of soldering.

And in cases where metallic surfaces are coated by other metals, the latter being at the time in a state of fusion, as in tinned-iron plates and silvered copper; may it not also be conceived, that between the two exterior surfaces, which are doubtless the simple metals, a thin film of an alloy compounded of the two does in reality exist? And in those cases in which the coating is laid on by the aid of mercury, and without heat, the circumstances are very similar, as the fluidity of mercury is identical with the ordinary state of fusion of other metals, although the latter require higher temperatures than that of our atmosphere.

When portions of the same metal are united by partial fusion, and without solder, as in the process described as *burning together*, and more recently known as the "*autogenous*" mode of soldering, no alloy is formed, as the metals simply fuse together at their surfaces.

Neither can it be supposed that any formation of alloy can occur, where the one metal is attached to the other by the act of burnishing on with heat, as in making gilt wire, but without a temperature sufficient to fuse either of the metals. The union in this case is probably mechanical, and caused by the respective particles or crystals of the one metal being forced into the pores of the other, and becoming attached by a species of entanglement, similar to that which may be conceived to exist throughout solid bodies. This process, almost more than any other in common use, requires that the metals should be perfectly or chemically clean;

for which purpose they are scraped quite bright before they are burnished together, so that the junction may be next approaching to that of solids generally.

And, lastly, when metals are deposited upon other metals by chemical or electrical means, the addition frequently appears to be a detached sheath, and which is easily removed; indeed, unless the metal to be coated is chemically clean, and that various attendant circumstances are favorable, the sound and absolute union of the two does not always happen, even when carefully aimed at.

It is time, however, that we proceed to the description of the methods of forming the ordinary alloys, the subject of the succeeding matter.

CHAPTER XIV.

MELTING AND MIXING THE METALS.

THE VARIOUS FURNACES, ETC., FOR MELTING THE METALS.—The subject upon which we have now to enter consists of two principal divisions, namely, the melting and combining of the metals, and the formation of the moulds into which the fluid metals are to be poured. In the foundry the two processes are generally carried on together, so that by the time the mould is completed, the metal may be ready to be poured into it; but as in conveying these several particulars the one process must have precedence, I propose to commence with the means ordinarily employed in melting and mixing the metals, in order to associate more closely all that concerns the alloys. In accordance with ordinary practice, the formation of the moulds will be described whilst the metals may be supposed to be in course of fusion; the concluding remarks will be on pouring, or filling the moulds, the act strictly speaking of casting, and which completes the work.

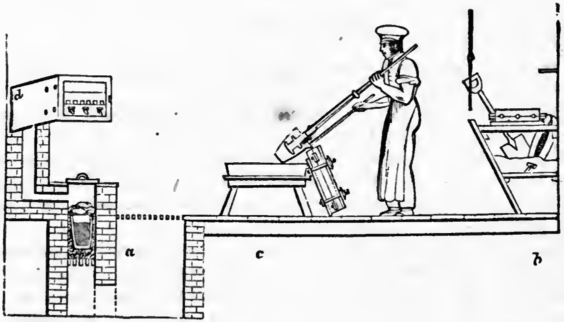
The fusible metals, or those not requiring the red-heat, are melted when in small quantities in the ordinary plumber's ladle over the fire; otherwise larger cast-iron ladles or pans are used, beneath which a fire is lighted; for very large quantities and various manufacturing purposes, such as casting sheet-lead, and lead pipe, and also for type-founding, the metals are melted in iron pans set in brickwork, with a fire-place and ash-pit beneath, much the same as an ordinary laundry copper, and the metals are removed from the pans with ladles.

The pewterers and some others call the melting pan *a pit*, although it is erected entirely *above* the floor; and as their meltings are made up in great part of old metal, which is sometimes wet or damp, they have iron doors to enclose the mouth of the pan, in case any of the metal should be splashed about from the moisture reaching the fluid metal.

Antimony, copper, gold, silver, and their alloys, are for the most part melted in crucibles within furnaces similar to the kind used by the brass founders, which is represented at *a*, Fig. 119; the entire figure represents the imaginary section of a brass foundry with the moulding trough, *b*, for the sand on the side opposite the furnace, the pouring or spill trough, *c*, in the centre, and the core oven *d*, which is usually built in the wall close against one of the flues; but these matters will be described hereafter.

The brass furnace is usually built within a cast-iron cylinder, about 20 to 24 inches diameter and 30 to 40 inches high, which is erected over an ash-pit arrived at through a loose grating on a level with the floor of the foundry. The mouth of the furnace stands about 8 or 10 inches above the floor, and its central aperture is closed with a plate now usually of iron, although still called a *tile;* the inside of the furnace is contracted to about 10 inches diameter by fire-bricks set in Stourbridge clay, except a small aperture at the back about 4 or 5 inches square, leading into the chimney.

Fig. 119.



There are generally three or four such furnaces standing in a row, and separate flues proceed from all into the great chimney or stack, the height of which varies from about twenty to forty feet, and upwards, the more lofty it is the greater the draught; every furnace has also a damper to regulate its individual fire.

It is quite essential for constant work to have several furnaces, in order that one or two may be in use, whilst the others lie idle to allow of their being repaired, as they rapidly burn away, and when the space around the crucible exceeds about 2 or 3 inches, the fuel is consumed unnecessarily quick; the furnace is then contracted to its original size with a dressing of road drift and water applied like mortar, the fire is lighted immediately, and urged vigorously to glaze the lining. Road drift, or. the scrapings of the ordinary turn-pike roads, principally silex and alumina, is often used for the entire lining of the furnaces. The refuse sand from the glass grinders, which contain flint glass, is also used for repairing them.

It is also convenient to have several furnaces for another reason, as when a single casting requires more than the usual charge of one furnace, namely, about 40 to 60 lbs., two or more fires can be used. When the quantity of brass to be melted exceeds the charge of three or four ordinary air furnaces, the common blast furnace for iron is sometimes used as a temporary expedient; the practice, however, is bad, as it causes great oxidation and waste. The greatest quantities of metal, as for large bells, statues, and ordnance, amounting sometimes to several tons, are commonly melted in reverberatory furnaces.

The furnaces used by the gold and silver refiners are in many respects similar to the brass burnace *a*, Fig. 119, but they are built as a stunted wall along one or more sides of the refinery, and entirely above the floor of the same. The several apertures for the fuel and crucible are from 9 to 16 inches square, or else cylindrical, and 12 to 20 inches deep; the front edge of the wall is horizontal, and stands about 30 inches from the ground, but from the mouth of the furnace backwards it is inclined at an angle of about 20 to 40 degrees, so that the tiles, or the iron covers of the furnace, lie at that angle. A narrow ledge cast in the solid with the iron plates covering the upper surface of the wall, retains the tiles in their position.

The small kinds of air furnaces are of easy construction, but as a temporary expedient almost any close fire may be used, including some of the German stoves and hot-air stoves, that is for melting brass, which is more fusible than copper; although it is much the most convenient that the fire be open at the top, so that the contents of the crucible may be seen without the necessity for its removal from the fire. Such stoves, however, radiate heat in a somewhat inconvenient manner, and to a much greater extent than the various portable furnaces, most of which are lined with fire-brick or clay; the lining concentrates the heat and economizes the fuel. Many of these portable furnaces answer not only for copper but also for iron, when they have a good draft; it may happen, however, that the chemical furnaces are equally as inaccessible to the amateur as those expressly constructed for the metals.

Country blacksmiths, who are frequently called upon to practice many trades, sometimes melt from ten to fifteen pounds of brass in the ordinary forge fire, but there is considerable risk of cracking the earthen crucible at the point exposed to the blast; a wrought-iron pot is sometimes resorted to, but this is not very enduring, as the brass will soon cause it to burn into holes and leak.

OBSERVATIONS ON THE MANAGEMENT OF THE FURNACE, AND ON MIXING ALLOYS.—The fuel for the brass furnace is always hard coke, which is prepared in ovens and broken into lumps about the size of hens' eggs: in lighting the fire, a bundle of shavings, chips, of cork, or any similar combustible, is first thrown in and ignited, and then some coke or charcoal is added. It is also usual to put the pot in the fire at an early stage, and with its mouth downwards: by this means the thin edge which admits the most easily of expansion gets hot first, and the heat plays within the crucible, so as to warm it gradually: it is not reversed until the whole is red hot: putting it in bottom downwards would be almost certain to cause it to crack.

The pot is now bedded upon the fuel, and the brass-founder, whilst making up the fire, puts an iron cover with a long central handle over the mouth of the pot, to prevent the small cokes which are now thrown on from entering the same. Next, the charge of metal is put in the crucible, and three or four large pieces of coke are placed across the mouth of the pot; the tile is put on the furnace, the damper is then adjusted to heat the crucible quickly, and the whole is left to itself until the metal is run down.

The gold and silver refiners and jewelers manage their furnaces much in the same way, except that they support the crucible upon a hollow earthen stand placed on the fire-bars to catch any leakage, and also put an earthen cover over its mouth. They generally use coke, although charcoal is a purer fuel, and is laid *upon* the fluid metals to prevent oxidation. The above, and the so-called blue pots, or black-lead pots, are not burned until they are put into the fire for use; but the Hessian pots, the English brown or clay pots, the Cornish and the Wedgwood crucibles, are all burned before use.

It may be further observed, that the pots for brass are too porous for gold and silver, as they *suck up* too much of the same: the black-lead pots are closer and better for the precious metals, and they withstand change of temperature best of any kind; they are however the most expensive, but cannot be safely used with fluxes. The Hessian crucibles resist the fluxes, and serve with care for several consecutive meltings; the English clay pots, which resemble the Hessian, are safe for one or sometimes for more meltings, and their cost is trifling. The pots for gold and silver are occasionally coated or luted externally with clay as a protection.

The generality of the metals are far more disposed to oxidation when in the melted condition than when solid; it is therefore usual, whilst they are in the crucible, to protect their surfaces from the air with some flux, to lessen their disposition to oxidize.

In the iron furnace, the slag from the lime floats on the metal and fulfils this end; many brass-founders always throw broken glass, charcoal dust, sandiver, or sal-enixon, into the melting pot; by others these precautionary measures are altogether neglected. The black and white fluxes, borax, and saltpetre are also used for the precious metals, and oil or resin for the more fusible, as lead or tin; but excess of heat should be at all times avoided.

The generality of the fusible metals may be mixed in all proportions. Those in which the melting points are tolerably similar may be easily combined, such as lead with tin, or gold with silver or copper; these appear to call for no instructions beyond moderation in the heat employed, but the difficulty of making definite and uniform alloys increases when the melting point of the metals, or their qualities or quantities, are widely dissimilar.

In mixing alloys with new metals, it is usual to melt the less fusible first, and subsequently to add the more fusible; the mixture is then stirred well together, and common opinion seems to be in favor of running the metal into an ingot mould, as the second fusion is considered more thoroughly to incorporate the mixture. Sometimes, with the same view, the alloy is granulated, by pouring it from the crucible into water, either from a considerable height through a colander, or over a bundle of birch twigs, which subdivide it into small pieces; others condemn such practices, and greatly prefer the first fusion, in order to avoid oxidation, and departure from the intended proportions.

But in many, and perhaps in most cases, it is the practice to fill the melting pan, or the crucible, in part with old alloy, consisting of fragments of spoiled or worn-out work; and to which is added, partly by calculation but principally by trial, a certain quantity of new metals. This is not always done from motives of economy alone, but from the opinion that such mixtures cast and work better than those made entirely of new metals.

When small quantities of metal of difficult fusion, are added to large proportions of others which are much more fusible, the whole quantities are not mixed at once. Thus in pewter, it would be scarcely possible to throw into the melted tin the half per cent. or the one per cent. of melted copper with any certainty of the two combining properly, and it is therefore usual to melt the copper in a crucible, and to add to it two or three times its weight of melted tin; this, as it were, dilutes the copper, and makes the alloys known as *temper*, which may be fused in a ladle, and added in small quantities to the fluid pewter or to the tin, as the case may be, until on trying the mixture by the assay its proportions are considered suitable.

The metal for printers' type is often mixed nearly in the same manner; the copper is first melted alone in a crucible, the antimony is melted in another crucible, and is poured into the copper; sometimes a little lead is also added. The hard alloy and the tin are then introduced to the mass of type-metal or lead, also in great measure by trial, as old metal mostly enters into the mixture.

The composition of Britannia metal is as follows: 3½ cwt. of best block tin; 28 lbs. of martial regulus of antimony; 8 lbs. of copper, and 8 lbs. of brass. The amalgamation of these metals is effected by melting the tin, and raising it just to a red heat in a stout cast-iron pot or trough, and then pouring into it, first the regulus, and afterwards the copper and brass, from the crucibles in which they have been respectively melted, the caster meanwhile stirring the mass about during this operation, in order that the mixture may be complete.

It would appear, however, much more likely and consistent that a similar mode is adopted in making this alloy, as in pewter and type-metal; namely, that the copper and brass are melted together in one crucible, the antimony then added from another crucible, and perhaps also a little tin; this would dilute the hard metals, and make a fusible compound, to be added to the remainder of the tin when raised a very little beyond its fusing point, so as to maintain fluidity when the whole were mixed and stirred together, previously to being poured into ingots. By this treatment the tin would be much less exposed to waste.

When a very oxidizable or volatile metal, as zinc, is mixed with another metal the fusing point of which is greatly higher, as with copper for making the important alloy brass, whatever weight of each may be put into the crucible, it is scarcely possible to speak with any thing like certainty of the proportions of the alloy produced, from the rapid and nearly uncontrollable manner in which the waste of the zinc occurs.

Various means have been devised at different times for combining these two metals.

Although the most direct way of forming the different kinds of brass is by immediately combining the metals together, one of them, which is most properly called brass, was manufactured long before zinc, one of its component parts, was known in its metallic form. The ore of the latter metal was cemented with sheets of copper, charcoal being present. The zinc was formed and united with the copper, without becoming visible in a distinct form. The same method is still practised for making brass.

The best way of uniting zinc with copper, in the first instance, will be to introduce the copper in thin slips into the melted zinc, till the alloy requires a tolerable heat to fuse it, and then to unite it with the melted copper.

Some persons thrust the whale of the copper, in thin plates, into the melted zinc, which rapidly dissolves them; and the mass is kept in a pasty condition until within a few minutes of the time of pouring, when they augment the heat to the degree required for the casting process.

But the plan which is the most expeditious, and now most usually adopted, is to thrust the broken lumps of zinc beneath the surface of the melted copper with the tongs, which mode will be more particularly described; but howsoever conducted, a considerable waste of the zinc will inevitably occur.

It is also certain that every successive fusion wastes, in some degree, the more oxidizable metal, so that the original proportion is more and more departed from, especially with the least excess of heat; and when the metals are not well covered with flux. The loose oxide frequently mixes with the metal; this in brass gives rise to the white-colored stains, and the little cavities filled with the white oxide of zinc; and in gun-metal the stains and streaks are blacker, and the oxide of tin (or putty powder) being much harder than the former, is sadly destructive to the tools. The vitreous fluxes collect these oxides, and are therefore serviceable; but when in excess, they are liable to run into the mould when the metal is poured. The chemist generally uses covers to the crucibles, to lessen the access of air, and therefore the oxidation; but the brass-founder frequently leaves the metal entirely uncovered. No considerable waste occurs until the metal is entirely fused and rather hotter than is required for pouring, which is indicated by the zinc beginning to burn at the surface with a blue flame.

The loss which occurs in melting brass-filings is a proof that the granulation of the metals is not always desirable; and unless the brass-filings are well *drawn*, by a group of magnets, to free them from particles of iron and steel, the latter often spoil the castings, as they become so exceedingly hard as to resist the file or turning-tool, and can be only removed by the hammer and cold-chisel.

In collecting the several alloys given at pages 180 to 203, especially those of copper, I found great difficulty in reconciling many of the statements derived from books; and therefore, to place the matter upon a surer basis, and also with some other views, I determined to mix a series of the copper alloys, in quantities of from one to two pounds each, pursuing, as nearly as possible, the common course of foundry work, to make the results practical and useful.

My first intention was to weigh the metals into the crucible, and to find, by the weight of the product, the amount of loss in every case, as well as the quality of the alloy. Commencing with this view, with copper and zinc, the several attempts entirely failed, owing to the extremely volatile nature of the latter metal, especially when exposed to the high temperature of melted copper. The difficulty was greatly increased owing to the very large extent of surface exposed to the air compared with that which occurs when greater quantities are dealt with, and the increased rapidity with which the whole was cooled.

The zinc was added to the melted copper in various ways, namely,—in solid lumps, in thin sheets hammered into balls, poured in when melted in an iron ladle: and all these, both whilst the crucible was in the fire and after its removal from the same. The surface of the copper was in some cases covered with glass or charcoal, and in others uncovered, but all to no purpose, as from one-eighth to one-half the zinc was consumed with most vexatious brilliancy, according to the modes of treatment: and these methods were therefore abandoned as hopeless.

I was the more diverted from the above attempts by the well-known fact that the greatest loss always occurs in the first mixing of the two metals, and which the founder is in general anxious to avoid. Thus, when a very small quantity of zinc is required, as for the so-called copper casting, about 4 oz. of brass are added to every 2 or 3 lbs. of copper. And in ordinary work, a pot of brass weighing 40 lbs. is made up of 10, 20, or 30 lbs. of old brass, and two-thirds of the remainder of copper. These are first melted. A short time before pouring, the one-third of the new metals, or the zinc, is plunged in when the temperature of the mass is such that it just avoids sticking to the iron rod with which it is stirred.

In mixing the copper and zinc for my experiments on brass, an entirely different course was therefore determined upon, namely, to melt the metals on a large scale, and in the usual proportion—that is, 24 lbs. of copper to 12 lbs. of zinc—to learn the first loss of zinc when conducted with ordinary care. Then to remelt a quantity of the alloy over and over again, taking a trial-bar every time in order to ascertain the average loss of zinc in every fusion. From the residue of the original mixture, to make the alloys containing less zinc, by a proportional addition of copper; and those alloys containing more zinc, by a similar addition of zinc. And lastly, to have the whole of the bars assayed, to determine the absolute proportion of copper and zinc contained in all, and from these analyses to select my series of specimens, as nearly in agreement as I could with the proportions in common use. This method answered every expectation.

Twenty-four pounds of copper, namely, clean ship's bolts, were first melted alone to ascertain the loss sustained by passing through the fire, which was found to be barely ¼ oz. on the whole. A similar weight of the same copper was weighed out, and also 12 lbs. of the best Hamburg zinc, in cakes about ¾ inch thick, which were broken into pieces.

The copper was first melted, and when the whole was nearly run down the coke was removed to expose the top of the pot, which was watched until the *boiling* of the copper, arising probably from escape of bubbles of air locked up at the lower part of the semi-fluid mass, ceased, and the copper assumed a bright red but sluggish appearance. The zinc was then added.

Precaution is necessary in introducing the first quantity of zinc not to *set* the copper, which is liable to occur if a large quantity of cold metal is thrown in, simply from the abstraction of heat; and it is also necessary to warm the zinc, that it may be perfectly dry, as the least moisture would drive the metal out of the pot with dangerous violence. A small lump of zinc, therefore, was taken in the tongs, held beside the pot for a few moments, and then put in with the tongs with an action between a stir and a plunge, regardless of the flare, and of the low crackling noise, just as if butter had been thrown in. The zinc was absorbed, and the surface of the pot was clear from its fumes almost immediately. The remainder of the zinc was then directly added, in about eight pieces, one at a time, much in the same manner, but the danger of setting the copper nearly ceases when a small quantity of the spelter is introduced. After every addition the pot was free from flame in a few moments. A handful of broken glass was then thrown in, the tile replaced, and the whole allowed to stand for about fifteen minutes to raise the metal to the proper heat for pouring, which is denoted by the *commencement* of the blue fumes of the zinc.

The pot was then taken from the fire, well stirred for one minute, and poured; the weight of the brass yielded was 34 lbs. 12½ oz., showing a loss of 1 lb. 3½ oz., or one-tenth of the zinc, or the one-thirtieth part of the whole quantity. This experiment was repeated, and the loss was then 1 lb. 3 oz., the difference being only ½ an oz. By analysis, the mean of the two brasses was 31¼ per cent. zinc; or instead of being 8 oz. to the pound, it was only 7¼ oz.

Twelve pounds of each of these experimental mixtures were remelted six times, a bar weighing about one pound and a half being taken every time; the two series of trials were conducted in different foundries, by different men, and quite in the ordinary course of work; but the loss per cent. of zinc was in the six experiments exactly alike in each series, that is, each bar, after the sixth melting, contained 22½ per cent. or 4⅝ oz. to the pound of copper. The second fusion in each case sustained the greatest loss, (say nearly two-fold;) and in the others, taking all the accidental circumstances into account, the loss might be pronounced nearly alike every fusion

In making the alloys with more zinc; the calculated weight of the first alloy was melted, and the amount of zinc was warmed and plunged in with the tongs, whilst the pot was in the fire, the whole was stirred and quickly poured: the losses in weight were rather large, but this is common when the zinc is in great quantity. To make the alloys containing less zinc than the alloy, the calculated weight of copper was first made red-hot and the respective portion of the brass alloy was then put in the pot, by which means the two ran down nearly together: it being found that the copper, if entirely melted before the brass was added, incurred a risk of being set at the bottom of the pot; and remelting the mass, wasted the zinc. These alloys came out much nearer to their intended weights.

In making the tin and copper alloys, very little difficulty was experienced. The copper was put into the pot together with a little charcoal, which was added to assist the fusion and also to cause the alloy to run clean out; as in pouring gun-metal a small quantity is usually left on the lip of the crucible, which would have been an interference in these experiments. When the copper had ceased boiling, and was at a bright red heat, it was taken from the fire, and the tin previously melted in a ladle, was thrown in; every mixture was well stirred and poured immediately.

In the fourteen alloys thus formed, each weighing about a pound and a half, namely, ½, 1, 1½, etc., up to 8 oz. of tin to the pound of copper, (missing the 6½ and 7½,) no material loss was sustained in nine instances, and in the other five it never exceeded ⅛ oz., and that quantity was probably lost rather in fragments than by oxidation.

Alloys of 2, 4, 6 and 8 ounces of lead to the pound of copper, were made exactly under the same circumstances as the last.

Messrs. Barron and Brother, of New York, manufacture a very effective and economical furnace, which supplies the necessary quantity of air; for in the combustion of fuel only a certain quantity of air is required, either an excess or deficiency is prejudicial to proper combustion.

The metals are melted by this furnace in less time, and at a less expense of fuel than any that have fallen under my notice.

In less than ten minutes, gold, silver, and copper can be melted by the furnace of Barron and Brother. The first size will melt from 4 to 12 ounces of gold with about a quart of coal; the second size will melt 50 to 120 ounces with about two quarts; and the third size will melt from 100 to 500 ounces with three or four quarts of coal.

It is a difficulty of no ordinary description to ascertain the temperature of a furnace with sufficient accuracy. Every fire and every furnace is continually changing its temperature. When a furnace is charged with a fresh supply of fuel, its temperature is lowered by the absorption of heat which the cold fuel takes up when thrown upon the fire.

The temperature is lowered by a rush of cold air through the open door. Experiments made by the pyrometer showing the mean temperature of the flues in a steam-engine boiler, and the effects produced by the admission of air through a permanent and regulated apparatus behind the bridge, indicate that in making the quantity of water evaporated by one pound of coal as the measure of economy, the mean of nearly the whole experiments is about 12½ per cent. in favor of a regulated and continuous supply of air. In order to insure economy and effect in the combustion of fuel, a large supply of air must be admitted to the furnace, and that in the ratio of 10 volumes of air to 1 of coal gas. Perfect combustion is the prevention of smoke. And it is found that in order to render the residue of the products of combustion transparent or smokeless, a supply of air amounting to ten times the gases evolved must be admitted.

CHAPTER XV.

CASTING AND FOUNDING.

METALLIC MOULDS.—We are indebted to the fusibility of the metals, for the power of giving them with great facility and perfection, any required form, by pouring them whilst in the fluid state into moulds of various kinds, of which the castings become in general the exact counterparts. This property is of immeasurable value.

Some few objects are cast in open moulds, so that the upper surface of the fluid metal assumes the horizontal position the same as other liquids, as in casting ingots, flat plates, and some few other objects; but in general the metals are cast in close moulds, so that it becomes necessary to provide one or more apertures or *ingates* for pouring in the metal, and for allowing the escape of the air which previously filled the moulds.

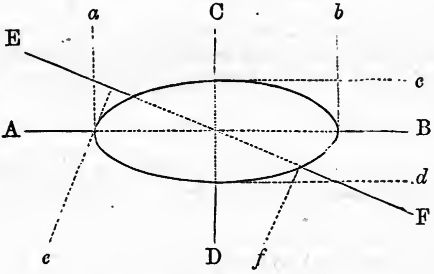
When these moulds are made of metal, they must be sufficiently hot not to chill or solidify the fluid metal before it has time to adapt itself thoroughly to every part of the mould: and when the moulds are made of earthy matters, although moisture is essential to their formation, little or none should remain at the time they are filled.

The earthen moulds must be also sufficiently pervious to air, that any vapor or gases which may be formed, either at the moment of pouring in the metal or during its solidification, may have free vent to escape; otherwise, if these gases are rapidly formed, there is great danger of the metal being driven out of the mould with a violent explosion, or when more slowly formed and locked up without sufficient freedom for escape, the casting will be said to be *blown*, as some of the bubbles of air will displace the fluid metal and render it spongy or porous. It not unfrequently happens that castings which appear externally good and sound, are full of hidden defects, because the surface being first cooled, the bubbles of air will attempt to break their way through the central and still soft parts of the casting.

The explanatory diagram, Fig. 120, is intended to elucidate some of the circumstances concerning the construction of moulds, which in the greater number of cases are made only in two parts, but in other cases are divided into several. The figure to be moulded is supposed to be a rod of elliptical section, the mould for which might be divided into two parts through the line A, B, because no part of the figure projects beyond the lines *a*, *b*, drawn from the margin of the model at right angles to the line of division, and in which direction the half of the mould would be removed or *lifted*; the model could be afterwards drawn out from the second half of the mould in a similar manner.

The mould could be also parted upon the line C, D, because in that direction likewise, no part of the model extends beyond the lines *c, d,* which show the direction in which the mould would be then lifted.

Fig. 120.



The mould, however complex, could be also parted either upon A B or C D, provided no part of the model outstepped the rectangle formed by the dotted lines *b, c,* or was undercut.

But considering the figure 120 to be turned bottom upwards, and with the line E, F, horizontal, the removal of the entire half of the mould upon the lines *e, f,* would be impossible, because in raising the mould perpendicularly to E, F, that portion of the mould situated within the one perpendicular *e,* would catch against the overhanging part of the oval towards A. Were the mould of metal, and therefore rigid, it would be entirely locked fast, or it would not "*deliver*;" were the mould of sand, and therefore yielding, it would break and leave behind that part between A and E which caused the obstruction. Consequently, in such a case, the mould would be made with a small loose part between A and E, so that when the principal portion, from A to F, had been lifted perpendicularly or in the direction of the line *e,* the small undercut piece, A to E, might be withdrawn *sideways,* on which account it would be designated by the iron founder a *drawback,* by the brass founder a *false core.*

All the patterns in the mould, Fig. 121, could be extracted from each half the mould, because none of them encroach beyond the perpendicular line, or that in which the mould is lifted; *a* and *b,* could be laid in exactly upon the diagonal, or upon one flat side, or partly embedded; and in like manner *f, g, h,* might be sunk more or less into the mould, their sides being perpendicular; but the patterns in Fig. 122 being undercut, the division of the mould into two parts *only* would be impracticable, and false cores or subdivisions would be required in the manner represented, the construction of which will be hereafter detailed.

Extending these same views to a more complex object, such as a bust, it will be conceived that the mould must be divided into so many pieces, that none of them will be required to embrace any overhanging part of the figure. For instance, were it attempted

Fig. 121.

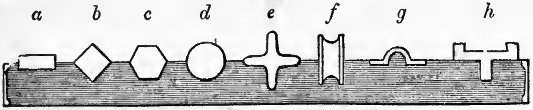
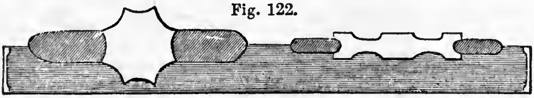


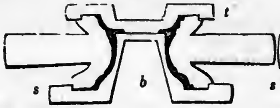
Fig. 122.



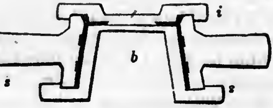
to mould a human head, so that the parting might pass through the central line of the face and down the back, the two halves could not be separated if they were made each in a single piece; as the inner angles of the eyes, the spaces behind the ears, and the curls of the hair would obstruct it, and the head could be only thus moulded by making false cores or loose pieces at these particular places, in the manner illustrated by the former figures. These would require to be accurately adapted to the surrounding parts, by pins and contrivances to ensure their re-taking their true positions. These remarks, however, are only advanced by way of general illustration, as figure casting is the most refined part of the art of moulding.

Metal moulds are employed for many works in the easily-fused metals, which are required to be produced in large quantities, and with great similitude and economy: the examination of which moulds will serve to demonstrate many of the points of construction and proceeding. Thus the common bullet mould is made like a pair of pliers, the jaws of which are conjointly pierced with a hole or passage leading into a spherical cavity; the aperture is equally divided between the two halves of the mould, so that in fact the division is truly upon the diametrical line both of the sphere and the runner, or the largest part of each, otherwise the pliers could not be opened to remove the bullet when cast. Iron shot for great guns are likewise cast in iron moulds, by which they also possess great accuracy of form and size.

Figs. 123

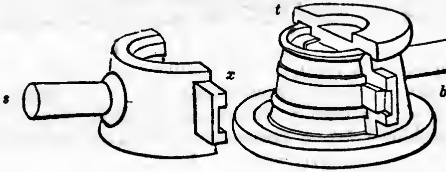


124.



Figs. 123 to 126 represent the moulds for casting pewter inkstands: these moulds are a little more complex, and are each made in four parts; the black portions represent the sections of the inkstands to be cast. The moulds each consist of a top piece or *cap t*, a bottom or *core b*, and two sides or *cottles, s s;* in Fig. 126, the one side is removed, in order to expose the casting, and the top piece *t* is supposed to be sawn through to make the whole more distinct. It will be seen, the top and bottom parts have each a rebate like the lid of a snuff-box, which embraces the external edges of the two side pieces *s s*, and the latter divide as in the bullet mould, exactly upon the diametrical line of the inkstand, which in a circular object is of course the largest part; the positions of the parts are therefore strictly maintained.

Figs. 125 **126.**



When the mould has been put together, laid upon its side, and filled through *x*, the ingate, or as it is technically called, the *tedge*, it is allowed to stand about a minute or two, and then the top *t*, is knocked off by one or two light blows of a pewter mallet; the mould is then held in the hand and the bottom part or core is knocked out of the casting by the edge; lastly, the two sides are pulled asunder by their handles, and the casting is removed from the one in which it happens to stick fast; but it requires cautious handling not to break it. The face of the mould is slightly *coated* with red ochre and white of egg, to prevent the casting adhering to the same, and to give the works a better face; the first few castings are generally spoiled, until in fact the mould becomes properly warmed.

Most of the works made in the very useful material, pewter, are cast in gun-metal moulds, which require much skill in their construction; thus a pewter tankard, with a hinged cover and spout, consists of six pieces, every one of which requires a different mould; thus,

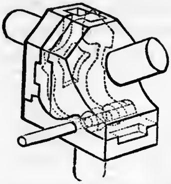
1. The body has a mould in four parts, like that for the inkstand, but it is filled in the erect position through two ingates, which are made through the top piece *t*, of the mould:

2. The bottom requires a mould in two parts, and is poured at the edge:

3. The cover is cast in the same manner; and thus far the

moulds are all made in the lathe, in which useful machine these castings are also finished before being soldered together:

Figs. 127



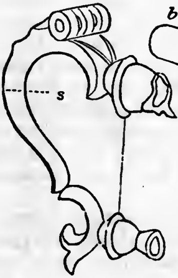
128.

4. The spout requires a mould in two parts:

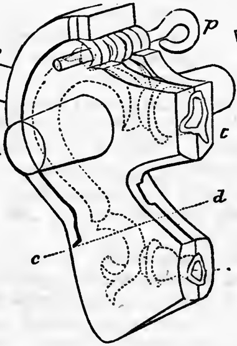
5. The piece, Fig. 128, by which the cover is hinged to the handle, requires a much more complex mould, which divides in four parts, as shown in Fig. 127, and much resembles, except in external form, the remaining mould: namely,

6. For the handle, which mould, like the last consists of four pieces fitted together with various ears and projections; they are represented in their relative positions in Fig. 130, with the exception of the piece *a*, Fig. 131, which is detached and shown bottom upwards. Fig. 129 shows the pewter handle separately, with the three knuckles for joining on the cover: and on reference to Fig. 130, of the five parts through which the pin *p*, is thrust, the two external pieces belong respectively to the sides *c*, and *d*, of the mould, the others are parts of the casting, and the two hollows are formed by the two solid knuckles fixed to the detached piece of the mould *a*, Fig. 131. At the time of pouring, the pin *p*, serves to connect the three parts *a*, *c*, *d*, together, and also to form the whole in the casting, for the pin of the joint.

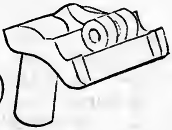
Figs. 129



130



131



132.

Fig. 132 shows the section of the mould upon the dotted line *s*: by this it will be seen the handle is cast hollow, as almost immediately the mould has been filled through *t*, all but the thin external shell is poured out again, and the weight is reduced to less than half. To extract the handle the pin *p* is first twisted out;

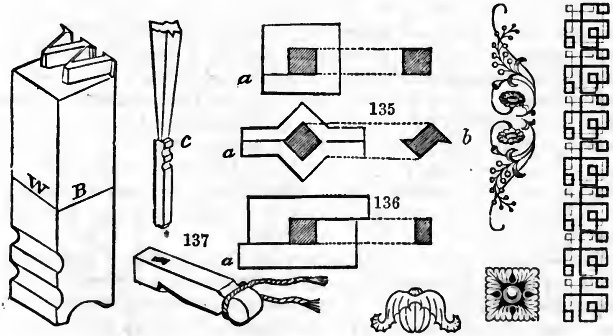
then the joint piece *a*, is removed: next the back piece *b*; and lastly the two sides *c*, *d*, are pulled asunder.

Tin or pewter bearings for locomotive carriages, have been cast in appropriate metal moulds; and such materials are very useful to the mechanist for many temporary purposes, such as collars, bearings, screws and nuts, either for difficult positions, or where no screw tap is at hand and the resistance is moderate; in such cases the parts of the machine constitute one portion of the mould, the apertures being closed with moist loam: the processes are most successful when the parts can be made warm and the clay is nearly dry.

The most important, exact, and interesting example of casting in metallic moulds is that of type-founding, the description of which, as well as drawings of the mould, have been repeatedly given; some of the peculiarities only of this art, will be therefore noticed. Each complete set of types consists of five alphabets, A, A, a, *A*, *a*, besides many other characters, in all about two hundred, and which are required to be most strictly alike in every respect, except in *device* and *width;* the width is the greatest for the W and M, and the least for the i and !. Every required measure of the types (represented on an enlarged scale in Fig. 133), is determined by the *mould alone*, and not by any after correction.

TYPE FOUNDING.

Figs. 133 **138** **134**



If the moulds for the rectangular shafts of the types were made as in Figs. 134 or 135, the usual forms of square moulds, they would not admit of alteration in width, as shifting *a*, Fig. 134, would produce no change, and Fig. 135 would thereby produce the form *b*. The mould which is used is made in two L formed parts, as in Fig. 136, whence it follows that shifting the part *a*, to the right or left increases or decreases the width of the type without interfering with its thickness, or, as it is technically called, its *body*, (B, Fig. 133,) the width, W, is adjusted by a piece called the *register*, fixed at the bottom of the mould.

The device is changed by placing across the bottom of the mould one of the two hundred little pieces of copper, Fig. 137, called *matrices*, into which the face of the latter is impressed by very beautifully formed punches The length of the letter is determined by contraction at the upper part of the mould, as shown at *c*, Fig. 138, which represents the type as it leaves the mould; the metal is poured with a *jerk*, to make a sharp impression of the matrix: the mould, which is held in the left hand, and the ladle in the right, being jerked simultaneously upwards, at the moment of filling the mould, and without which the face of the type would be rounded and quite imperfect. The *breaks c*, or the runners of the types, are first broken off, and after a slight correction of the sides, the hollows or channels in the feet are planed out of a whole column of them, fixed between bars of wood, without touching the square shoulders which determine the lengths of the types, and are left as originally cast.

In some types with a large face and much detail, such as the illustrations given on the last page, the motion of the hand is barely sufficient to give the momentum required to throw the metal into the matrix, and produce a clean sharp impression. A machine is then used, which may be compared to a small forcing-pump, by which the mould is filled with the fluid metal; but from the greater difficulty of allowing the air to escape, such types are in general considerably more unsound in the shaft or body; so that an equal bulk of them only weigh about three-fourths as much as types cast in the ordinary way by hand, and which for general purposes is preferable and more economical.

Some other variations are resorted to in type-founding; sometimes the mould is filled at twice, at other times the faces of the types are *dabbed*, (the *clichée* process;) many of the large types and ornaments are stereotyped, and either soldered to metal bodies, or fixed by nails to those of wood. The music type, and ornamental borders and dashes, display much very curious power of combination.

The *clichée* process is rather stamping than casting. The melted alloy is placed in a *paper* tray, and stirred with a card until it assumes the pasty condition. The *metal* die, or mould, is then "dabbed" upon the soft metal, as in sealing a letter, but with a little more of sluggish force.

By the type-founding machine invented by Mr. Bruce, of N. Y., and employed in the extensive foundry of Collins and M'Leester, of Philadelphia, 3600 letters may be cast in an hour, much more sound and as perfect as those cast by hand.

PLASTER OF PARIS MOULDS AND SAND MOULDS.—Other examples of metallic moulds might be given, but there are far more frequent cases in which one single casting is alone required; or else the number is so small, or the pieces themselves are so large or peculiar, that the construction of metal moulds would be found almost or quite impracticable, even without reference to an equally fatal barrier, the expense.

In making these single copies in the metals of considerable fusibility, plaster of Paris is sometimes employed; thus, after the printer has arranged the loose types into a page, and the requisite corrections have been made, a stereotype, or *solid* type, is taken of the whole as a thin sheet of metal, which serves to be printed from almost as well as the original letters: and its small cost enables the printer to retain it for future use, after the types themselves have served perhaps for a hundred similar regenerations, and are ultimately worn out.

The stereotype founder takes a copy of the entire mass of type in plaster of Paris; this is dried in an oven, and placed *face downwards* within a cast-iron mould, like a covered box, open at the four top-corners. The mould and plaster-cast are heated to the fusing temperature of the type-metal, and gradually lowered into a pan or bath of the same by means of a crane; the hot fluid metal runs in at the corners of the mould, and raises the inverted plaster, which latter would rise entirely to the surface but for the restraint of the cover of the mould.

Type-metal is about eleven times as heavy as water; and if the mould be immersed four inches below the surface, it is subjected to a pressure equal to that of a column of water forty-four inches high, or above two pounds upon every square inch.

The necessity of this arrangement is shown when a few ounces of type-metal are poured from a ladle on the face of the plaster; the metal looks like a dump, almost without any mark of the letters, whereas the stereotype-cast is nearly as sharp as the original type. The immersion fulfils the same end as the jerk of the hand-caster, or of the pump occasionally employed: and the long continuance of the mould in the fluid metal allows ample time for the air to escape in bubbles to the surface; after which the mould is raised and cooled in a vessel of water, and the plaster is mostly destroyed in its removal.

Plaster of Paris, although it may be, and frequently is used for the fusible metals, such as lead, tin, and pewter, cannot be employed alone for iron, copper, brass, and many other metals, the intense melting heats of which would calcine the material, and cause it to crumble; even the soft metals should not be very hot, or they will make the plaster of Paris blister off in flakes or dust. We must therefore seek a substitute better capable of enduring the heat; and likewise susceptible of receiving definite forms; for which purpose damp sand, with a small natural or subsequent admixture of clay or loam, is found to be perfectly adapted.

The moulding-sand cannot, however, be used without external support, and which is given by shallow iron frames without tops or bottoms, called flasks, represented in Figs. 139 and 140. The bottom part, 4, 5, is supposed to have been rammed full of sand, and to stand upon a flat board, 6. The model of the plain flat bar which is to be cast, is now laid on the surface of the sand, that of the round bar is imbedded half way in the same, and the mould is dusted with dry parting sand.

Fig. 139.

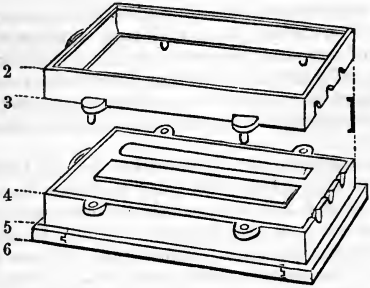
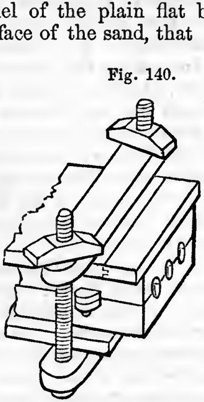


Fig. 140.



The top part of the flask 2, 3, is shown still empty, and in the act of being attached to 4, 5 by its pins, which enter corresponding holes in the latter, easily but without shake: 2, 3 is also rammed full of sand, and covered with a top board, 1, not represented to avoid confusion. The mould is now opened, the models are removed, and channels are scooped out from the ends of the cavities left by the models, to the hollows or pouring-holes at the end of the flask: the parts are all replaced in the order 1 to 6, represented in Fig. 139, and the whole are fixed together by screw clamps, so as to assume the condition of Fig. 140.

The flask is now placed almost perpendicularly beside the pouring-trough, and the metal is poured into it from the crucible, as shown in Fig. 119, p. 221; but the flask, if small, is put on the surface of the pouring or spill-trough, and propped up with a short bar.

This brief sketch of the entire process of moulding and casting in sand moulds, will be now followed by some remarks in greater detail: first on the patterns of the objects to be cast; secondly, on the conditions required in the sand; and thirdly, the process of moulding simple and solid bodies. The section then following will be devoted to moulding cored works, and figures, after which a few lines will be given upon the subject of filling the moulds.

Patterns, Moulds, and Moulding Simple Objects.—The perfection of castings depends much on the skill of the pattern-maker, who should thoroughly understand the practice of the moulder, or he is liable to make the patterns in such a manner that they cannot be used, or at any rate be well used.

Straight-grained deal, pine, and mahogany, are the best woods for making patterns, as they stand the best; screws should be used in preference to nails, as alterations are then more easily made in the models, and glue joints, such as dovetails, tenons, and dowels, are also good as regards the after use of the saw and plane for corrections and alterations.

Foundry patterns should be always made a little taper in the parts which enter most deeply into the sand, in order to assist their removal from the same, when their purposes will not be materially interfered with by such tapering. The pattern-maker, therefore, works most of the thickness, and the sides or edges, both internal and external, a little out of parallel or square, perhaps as much as about one-sixteenth to one-eighth of an inch in the foot, sometimes much more.

When foundry patterns are exactly parallel, the friction of the sand against their sides is so great when they penetrate deeply, that it requires considerable force to extract them; and which violence tears down the sand, unless the patterns are much knocked about in the mould, to enlarge the space around them. This rough usage frequently injures the patterns, and causes the castings to become irregularly larger than intended, and also defective in point of shape, from the mischief sustained by the moulds; all which evils are lessened when the patterns are made consistently taper and very smooth.

It must be distinctly and constantly borne in mind, that although patterns require all the methods, care, and skill, of good joinery or cabinet-making, they must not, like such works, be made quite square and parallel, for the reasons stated. Sharp, internal angles should in general be also avoided, as they leave a sharp edge or arris in the sand, which is liable to be broken down in the removal of the pattern; or to be washed down on the entry of the metal into the mould. Either the angle of the model should be filled with wood, wax, or putty, or the sharp edges of the sand should be chamfered off with the knife or trowel. Sharp internal angles are very injudicious in respect also to the strength of castings, as they seem to denote where they will be likely to break; and more resemble carpentry than good metallic construction.

Before the patterns reach the founder's hands, all the glue that may have been used in their construction should be carefully scraped off, or it will adhere to and pull down the sand. The best way is to paint or varnish wooden patterns, so as to prevent them from absorbing moisture, as they will then hang to the sand much less, and will retain their forms much better. Whether painted or not, they deliver more freely from the mould when they are well brushed with black lead, like a stove.

In patterns made in the lathe, exactly the same conditions are required; the parts which enter deeply into the sand should be neither exactly cylindrical nor plane surfaces, but either a little coned, or rounding, as the case may be; and the internal angles should not be turned exactly to their ultimate form, but rather filled in, or rounded, to save the breaking down of the sharp edges of the mould.

Foundry patterns are also made in metal; these are very excellent, as they are permanent; and when very small are less apt to be blown away by the bellows used for removing the loose sand and dust from the moulds. To preserve iron patterns from rusting, and to make them deliver more easily, they should be allowed to get slightly rusty, by lying one night on the damp sand; next, they should be warmed sufficiently to melt beeswax, which is then rubbed all over them, and in great part removed, and then polished with a hard brush when cold. Wax is also used by the founder for stopping up any little holes in the wooden patterns; whitening is likewise employed, as a quicker but less careful expedient; and very rough patterns are seared with a hot iron. The good workman, however, leaves no necessity for these corrections, and the perfection of the pattern is well repaid by the superior character of the castings.

Metal patterns frequently require to have holes tapped into them for receiving screwed wires, by way of handles for lifting them out of the sand; and in like manner, large wooden patterns should have screwed metal plates let into them, for the same purpose, or the founder is compelled to drive pointed wires into them, to serve as handles, which is an injurious practice.

The flasks or casting-boxes for containing the sand, are made of various sizes. Each side is about 2 to 3 inches deep. They are poured at the edge when placed nearly vertical; but for large brass works the practice of the iron-founder is generally followed, who mostly pours his work horizontally, through a hole in the top, as will be explained. The pins of the flask should fit easily, but without shake, or the two halves will shift about and cause a disagreement or slip in the casting. The tools used in making the moulds are few and simple, namely, a sieve, shovel, rammer, strike, mallet, a knife, and two or three loosening wires and little trowels, which it is unnecessary to describe.

The principal materials for making foundry moulds are very fine sand and loam. They are found mixed in various proportions, so that the respective quantities proper for different uses cannot be well defined; but it is always judicious to employ the least quantity of loam that will suffice. These materials are seldom used in their new or recent states for brass castings, although more so for iron, and the moulds made of fresh sand are always dried, as will be explained.

The ordinary moulds are made of the old damp sand, and they are generally poured immediately, or whilst they are *green;* sometimes they are more or less dried upon the face. The old working fine sand is considerably less adhesive than the new, and of a dark-brown color. This arises from the brick-dust, flour, and charcoal-dust used in moulding becoming mixed with the general stock, which therefore requires occasional additions of new sand or loam, so that when slightly moist and pressed firmly in the hand it may form a moderately hard compact lump.

Red brick-dust is generally used to make the partings of the mould, or to prevent the damp sand in the separate parts of the flask from adhering together.

The face of the mould which receives the metal is generally dusted with meal-dust, or waste flour; but in large works, powdered chalk, and also wood or tan ashes, are used, from being cheaper. The moulds for the finest brass castings are faced either with charcoal, loamstone, rottenstone, or a mixture of the same. The moulds are frequently inverted and dried over a dull fire of cork shavings, or when dried they are smoked over pitch or black resin lighted in an iron ladle.

The gold and silver casters frequently use a lighted link for facing their sand-moulds, and some of the type-founders' metallic moulds are smoked over a lamp. All these modes deposit a fine layer of soot upon the moulds.

The cores, or loose internal parts of the moulds for forming holes and recesses, are made of various proportions of new sand, loam and horse-dung, as will be explained in the section on cored works. They all require to be thoroughly dried, and those containing horse-dung must be well burned at a red heat; this consumes the straw and makes them porous, and of a brick-red.

In making the various moulds, it becomes necessary to pursue a medium course between the conditions best suited to the formation of the mould and those best suited to filling them with the red-hot metal without risk of failure or accident. Thus, within certain limits, the more loam and moisture the sand contains, and the more closely it is rammed, the better will be the impression of the model; but at the same time the moist and impervious condition of the mould would then incur the greater risk of accident. both from the moisture and from the non-escape of the air. Therefore the policy, on the score of safety, is to use the sand as dry as practicable, so as to avoid the delay of after-drying, and also to keep the mould porous.

The founder, therefore, compromises the matter by using a little *facing* sand containing rather more loam, for the face of the green moulds for general work; and in those cases where much loam is used, the moulds are *thoroughly* dried by heat, which is not generally necessary with ordinary sand moulds.

The power of conducting heat is considerably less in red-hot iron than in copper and brass, and therefore the moulds for the latter require to be in a drier condition than those which may be used for iron; but in either case the presence of superfluous moisture is always attended with some danger to the individual as well as to the work.

The above is the reason generally assigned for the fact that the iron-founders may and do use their moulds with safety when sensibly more moist than is admissible for brass and copper castings.

It is confirmatory of the fact that the more dense the mould, the drier it must be, as the sand used by iron-founders is also coarser and therefore more porous than that employed by brass-founders.

Another point has also to be considered: as castings contract considerably in cooling, in moulding large and slight works the face of the mould must not be too strongly rammed, nor too much dried, or its strength may exceed that of the red-hot metal whilst in the act of shrinking. The result would be, that in contracting, the casting would be rent or torn asunder from the restraint of the mould; whereas it should have the preponderance of strength, so as to pull down the face of the sand instead of being itself destroyed. But the exact condition both of the mould and of the melted metal, must be determined by the nature of the object to be cast,—matters which can be only referred to with the development of the practice of the foundry, and upon which we shall now commence.

The sand having been prepared, and the appropriate flask and boards selected, the moulder first examines every pattern separately to determine the most appropriate way of inserting it in the flask, as explained by Fig. 121, p. 232; also to see that patterns, such as *f* and *h*, therein shown, are smallest at the parts entering the most deeply into the sand, in order that they may *deliver* well. It should also be noticed whether they are perfectly smooth, and that there is no glue hanging about them, which would cause them to adhere and to pull down the moist sand.

The bottom flask, 4, 5, p. 238, is placed on a board not less than an inch or two longer and wider than itself, with the face 4, downwards, and it is filled from the side 5. A small portion of the strong facing-sand is rubbed through a fine sieve; the remainder is thrown in from the trough with the shovel, and the moulder drives the whole moderately hard into the flask, either with a mallet, the handle of the spade, or other rammer; or else he jumps up by aid of the rope suspended from the ceiling, and treads the sand in with his feet. The surface is then struck off level with a straight metal bar or scraper, a little loose sand is sprinkled on the surface, upon which another board is placed, and rubbed down close.

The two boards and the flask contained between them are then all three turned over together. This requires them to be brought to the front of the moulding-trough, so that the individual may rest his chest against them, and his fore-arms upon the edges of the top board; he then grasps the three together at the back part with his outstretched hands, and, thus retained in contact, the whole are quickly turned over upon the front edge of the moulding-trough, and then slid back upon the transverse bearers or *blocks* to the usual position.

The top board is afterwards taken off, the clean surface of moist sand, then exposed, is well dusted over with red brick-dust, crushed fine, and contained in a linen bag. The mouth of the bag is held in the right hand, and the bottom corner in the left, and both hands are shaken up and down together to scatter the dry powder uniformly over the flask. A part of the loose powder is removed with the hand-bellows, and the bottom half of the mould is then ready for receiving the patterns.

The models are next arranged upon the face of the sand at 4, so as to leave space enough to prevent the parts breaking one into the other, and also for the passages by which the metal is to be introduced, and the air allowed to escape. When there are only two or three pieces to be cast, a separate runner is often made to each of them from one of the holes in the end of the flask. When several small patterns are to be moulded, they are arranged on both sides a central runner, or *ridge*, from which small passages lead into every section of the mould. The whole mass when poured has been compared to a great fern leaf with its leaflets, and is usually called a *spray*.

Those patterns which are cylindrical or thick, are partly sunk in the sand by scraping out hollow recesses with the bowl of an old copper spoon, and knocking the model into the sand with the mallet. Afterwards the general surface is repaired to agreement with the *diametrical line* of the model, or its largest section, as the case may be, by means of a knife or a little piece of sheet steel, something like the worn-out blade of a desert-knife bent up a little at the end, or else with very small trowels.

After the sand is made good to the edges of the patterns, the brick-dust is again shaken over them, so that the patterns may receive a slight share as well as the general surface of the sand. The upper part of the flask 2, 3, is then fitted to the lower, or 4, 5, by the pins, and this half likewise is made up. First a little strong sand is sifted in; it is then filled up from the trough, rammed down, and struck off as before, the dry powder serving to prevent the two halves from sticking together.

In order to open the mould for the extraction of the models, a board is placed on the top of flask 2, 3, and struck smartly at different parts with the mallet; the tool is then laid aside and the upper part of the flask and its board are lifted up *very gently and quite level*, after which it is inverted on its board—and now each of the inner faces of the mould is exposed. Should it happen that any considerable portion of the mould, say a part as large as a shilling, is broken down in one piece, the *cavity* is moistened with the end of the knife, the mould is again carefully closed, and lightly struck before the removal of the patterns. It is probable on the second lifting such piece will be picked up.

The breaks are carefully repaired before the extraction of the patterns, to effect which they are driven slightly sideways with blows of the mallet, given on a short wire or punch, so as to loosen them by enlarging the space around them. The patterns are then lifted out very carefully with the finger-nails, or sometimes a pointed wire is driven a little way into the pattern to serve as a handle to lift it by. This process requires some delicacy not to tear away the sand, which accident must be carefully repaired, sometimes by replacing the loose pieces, at other times with a little new sand picked out of any unused part of the mould.

A steel wire, pointed and hardened, is convenient as a *picker out.* and when fixed in the pattern and stuck sideways it serves as a *loosening bar* likewise.

Should the flask only contain one or two objects, the ingate or runner is now scooped out of the sand, so as to lead from the object to the pouring hole, and when several objects are contained, a large central channel, and lesser passages sideways, are made as before mentioned. The entrance round about the pouring hole is smoothed and compressed with the thumb that it may not break down when the metal is poured, and all the loose sand is carefully blown out of the mould, both parts of which may be placed edgeways for the more convenient application of the bellows if necessary.

The succeeding processes are to dust the faces of both halves of the mould with meal dust or waste flour, as explained with regard to the brick-dust, and to replace the mould and boards. The whole of them are then carried to the spill-trough, upon the edge of which they are rested whilst the one board is placed exactly level with the end of the flask, but the board on the side from which the crucible will be poured, is placed about two inches below, as in Fig. 140, p. 238, and the hand-screws are fixed on as shown. The mould is now held mouth downwards, that any sand loosened in the screwing down may be allowed to fall out, and the flask, according to its size, is supported either on the ground or on the surface of the trough by aid of a little bar resting against the clamp. It is now quite ready to be filled—the particulars of which process will be described when the remarks on moulding are concluded.

In works that require the first side or 3, 4 to be cut away for embedding the models, it is usual when the second part or 2, 3 has been made, to destroy the first or *false* side (which is only hastily made), and to repeat it in a more careful manner by inverting the lower flask upon 2, 3, proceeding in all other respects as before, by which means a much more accurate and sound mould is produced.

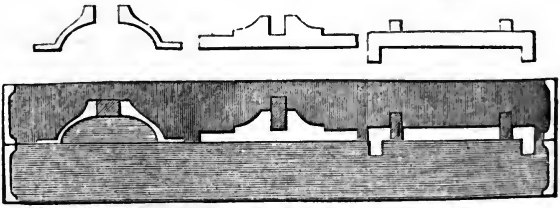
When many copies of the same patterns are required, an *odd side* is prepared, that is, a flask is chosen to which there are two bottom sides, 4, 5. One of these latter is very carefully arranged with all the patterns, but which are only embedded *barely half way,* so that when 2, 3, is filled and both are turned over, the whole of the patterns are left in the new side; a second side, 4, 5, is moulded to serve for receiving the metal, as the mould is destroyed every time the metal is poured in. By this plan the trouble of re-arranging the patterns for every separate mould is saved, as they are merely replaced in the odd side, and the routine of forming the two working sides is repeated.

Moulding Cored Works.—If the objects to be cast require to be so moulded that when they leave the sand they may contain one or several holes, they are said to be cored, and in such cases, a variety of methods are practised for introducing internal moulds or cores, which shall intercept the flow of the metal, and prevent it from forming one solid mass at those respective parts. For example, the pins inserted in the pewterers' moulds, Figs. 127 and 130, page 234, for producing the holes in the joints, are essentially cores. Various other methods are pursued, the three most usual of which are represented in Figs. 141, 142, and 143: the upper figures show the exact sections of the three models or casting patterns; the lower figure represents the two halves of the mould, which are respectively shaded with perpendicular and horizontal lines, the cores are shaded obliquely; and the white open spaces show the hollows to be occupied by the metal when it is poured in.

First. Many works are said to deliver their own cores; of such kind is Fig. 141, in which the cavity extends through the model, and exactly represents that which is required in the casting; the hole is either made quite parallel, or a little larger one side than the other, and gradually taper between the two. In some cases, when the hole is sufficiently taper, it delivers its own core as a continuation of the general mass of sand filling the one side of the flask; but in many or most cases, the space in the model is rammed full of strong sand at first, and it is then moulded as if to produce a plain solid casting. Before the mould is finally closed for pouring, the sand core is pushed carefully out of the pattern, and inserted in the mould; to denote its precise position, one side of the core is scored with one or two deep marks in the first instance, which cause similar ridges or guides in the mould.

Secondly. When the hole extends only part way through, the hole of the pattern, Fig. 142, is fitted with a solid plug, sawn and filed out of soft unburnt brick, principally sand (or the common Flanders brick), the core is made long enough to project about as much as its own diameter, and the work is moulded as if to be cast with a solid pin, instead of a hole. The last step is to extract

Figs. 141 142 143.



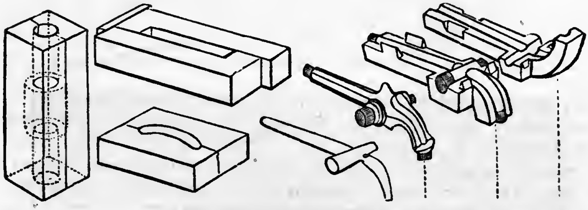
the filed core, and to insert it into the hollow formed by itself in the flask.

Thirdly. The patterns for iron work and some others are mostly made with *prints* instead of holes, as in Fig. 143; that is, the pattern-maker places square or round pieces on one or both sides of the pattern, where the square or round holes are respectively required; and the founder has moulds for forming cores of corresponding diameters or sections, and in lengths of about two to twelve inches; short pieces of which are cut off as may be required.

For example, some core-boxes are made like Fig. 144, for cylindrical cores; these divide through the axis, and are kept in position by pins; at the time when they are rammed they are fixed together by wood or iron staples, embracing three sides of the mould, or else by screw clamps. For straight cores, say one inch wide, twelve inches long, and half-inch thick, the pieces of wood, Fig. 145, are also one inch thick, with an opening between them of twelve inches long and half-inch wide. This core-box is laid on a flat board, it is also held together with clamps, but without pins in the core-box, as the projection at the one end gives the position; it is rammed flush with both sides, and the two parts can be then separated obliquely. If it is preferred to make the cores to the precise lengths instead of cutting them off, this core-box admits of contraction in length, in the manner of the type mould, Fig. 136, p. 235, and by placing thin slips between the two halves it may be temporarily increased in width but not in thickness. Fig. 146 is a similar core-box for a casting with circular mortises; this requires pins or projections at each end, as it cannot be opened obliquely. Core-boxes are sometimes made of plaster of Paris, wood is much better, and metal is the best of all.

Many works require core-boxes to be made expressly for them; thus the dotted line in Fig. 144 shows an enlargement in the centre for coring a hole of that particular section. Figs. 147 and 148 represent the two halves of a brass or lead core-box suitable to the

Figs. 144 145



146 150 149 148 147.

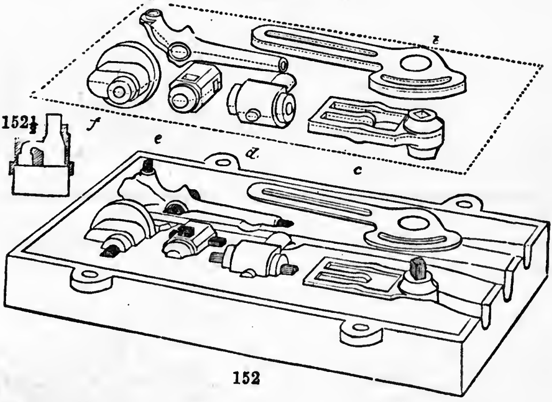
stop-cock, Fig. 149; and Fig. 150 shows the core itself after its removal from the part 148 in which it is also figured. In 149, the model from which the object is moulded, the shaded parts represent the projections, or *core-prints,* which *imprint* within the mould the places where the extremities of the core, Fig. 150, are supported when placed therein.

The various kinds of core-boxes are rammed full of new sand, sometimes with extra loam; the long cores are strengthened by wires; they are carefully removed from the boxes and thoroughly dried before use, in the oven prepared for the purpose.

Others perfer sand, horse-dung, and a very little loam, for making cores; these are dried, and then well burned, for which purpose they are put into an empty crucible within the fire, the last thing at night, and allowed to remain until the morning. This consumes the small particles of straw, and renders them more porous, in consequence of which the works become sounder from the free escape of air, the necessity of which was adverted to in the earlier part of this subject, and cannot be too much insisted upon.

Fig. 151 represents several examples of coring: in this view the works are represented of their ultimate forms, that is, with the holes in them; in Fig. 152, the models are arranged in the flask, with the runners all prepared, the prints of the cores being in every case shaded for distinction. Thus *a* is the stopcock, of which explanation has been already given; *b,* has a straight and a circular mortise; this pattern *delivers its own core,* in the manner referred to in Fig. 141, as the model is made with mortises like the finished work: *c* only requires a perpendicular square core; *d,* a round core parallel with the face of the flask, and in this manner all tubes and sockets are cast whether of uniform or irregular bore, *see* Fig. 144; *e,* has two rectangular cores crossing each other at right angles:

Fig. 151



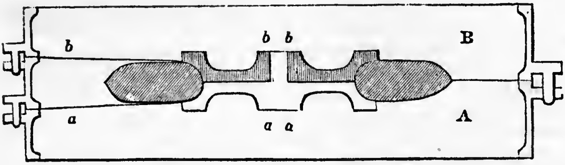
152½

152

and *f*, is the cap of a double-acting pump, the core for which is shown in section by the white part of Fig. 152½, the shaded portions being the metal: the great aperture leads to the piston, the two smaller are for valves opening inwards and outwards; this of course requires a metal core-box capable of division in two parts, and made exactly to the particular form.

In addition to the cores used for making holes and mortises, much ingenious contrivance is displayed in the cores employed for other works of every-day occurrence, the undercut parts of which would retain them in the sand but for the employment of these and analogous contrivances. It will be now readily understood that if, in the Fig. 122, p. 232, the parts shaded obliquely were separate, there would be no difficulty in removing first the upper half of the flask, the false cores, after which the patterns would be quite free. The term *false core* is employed by the brass-founder to express the same thing as the *drawback* of the iron-founder. The former calls every loose piece of the mould not intended for holes, a false core. By such a method, however, the circular edge of a sheave would require at least three such pieces, but Fig. 153 shows a different way of accomplishing the same thing, when the pattern is made in two parts in the manner represented.

Fig. 153.

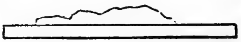


The entire model is first knocked into the side A, the sand is cut away to the inner margin of the pattern which terminates upon the dotted line *a*, and the side A, of the mould is then well dusted; a layer of sand is now thrown on, and rammed tolerably firm to form an annular core, which is made exactly level with the inner margin *b* of the pattern, and the core is well dusted; lastly, the side B is put on and rammed as usual. To extract the model, the side B is first lifted, the half pattern *b*, *b*, (which is shaded,) is removed, and the ingate is cut in the side B, to the edge of the pully; the mould is well dusted with flour and replaced.

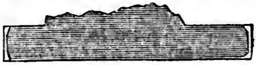
The entire mould is now turned over, A is first removed, then the remaining half pattern *a*, *a*, which must be touched very tenderly or it will break down the core; and the runner, (which divides in two branches around the core), is also scooped out in the side A, which is dusted with flour and replaced, ready for pouring. Common patterns not requiring cores are frequently divided into two parts in the above manner, so that when the mould is open the pattern may divide and remain half in each side; this lessens the risk of breaking down the mould and the attendant trouble of afterwards repairing it.

REVERSING AND FIGURE CASTING.—Supposing that an ornament, represented in section in Fig. 154 has been modeled in relief, either in clay or wax upon a flat board, from which a thin casting in brass is wanted without the tablet, the process is called reversing, and is to be accomplished in any of three ways.

First an empty flask is placed upon the board, 154, and rammed full of sand; it assumes the appearance of 155; the second part of the flask is attached to 155 and filled to make the part 156, which is called the *back-mould;* some clay is then rolled out to the intended thickness of the casting, with a cylindrical roller running on two slips of wood or on two wires, and a narrow band of this clay is placed on 156, round the figure, that it may separate 155 and 156, exactly to the required distance, ready for receiving the metal.


Figs. 154


155


156


157

By the second mode, 155 is first made, then 156, and from the latter 157 is moulded, which is a counterpart of 155. A thin sheet of clay is then pressed all over 157, into every cavity, and cut off flush with the plane surface of the mould, by which it assumes the appearance denoted by the double line in 157. After this 156 is destroyed, and made over again in 157, but so much smaller than before as the thickness of the clay *lining;* when the new back-mould, 156, is placed in contact with 155, it leaves the required space for the intended casting. This mode is only prefer able to the first, when many parts of the work are nearly perpendicular; in which case, if the first mode be adopted, a portion of the back mould 155 must be pared away at the perpendicular parts, and if incautiously performed there will be a risk of irregularity of thickness, or even of holes in the casting.

The third mode is to take a casting of 154 in plaster of Paris; when this is thoroughly dry it is oiled, and poured full of a cement of wax, grease, and red-ochre, which is poured out again when partially set, leaving a thin crust behind (as in the pewter handle). A second, a third, or more layers of wax are thus added until the whole is sufficiently thick, when the wax shell is extracted, and then moulded from in the ordinary manner; the first brass casting is finished and chased to serve as the permanent pattern. The management of the wax requires practice.

In constructing such moulds additional care is given to every part of the work; for example, the sand is sifted much finer, the parting is made with fine charcoal dust, and the facing with charcoal and rottenstone mixed together in about equal parts, the mixture being of a slaty color; sometimes the loamstone, which is found in the pits where clay for making tiles is dug, is used instead of rottenstone. The moulds are well dried in an oven, or over the mouth of the furnace, and the faces are afterwards smoked over a dull fire of cork shavings; this deposits a very fine layer of soot over the face of the mould, which greatly assists the running of the metal; when this additional care is taken the works are known as *fine-castings.*

In casting figures, such as busts, animals, and ornaments consisting of branches and foliage, considerably more skill is required: the originals are generally solid, but the moulds necessarily divide into very many parts. Most persons will have had the opportunity of judging of the complexity of these moulds, from similar works in plaster of Paris, which are frequently purchased by artists and the virtuosi before the seams of the mould are removed.

A glance at these plaster-casts, at the complex and undercut form of many of these ornamental works, and at the explanatory diagram on page 231, will convey some notion of the method to be pursued as well as of the trouble attending them. It is shown for example, by the diagram just referred to, that all figured works approaching to the circular or elliptical section, require that the mould should be divided into at least three parts, except under most favorable circumstances. In the human figure and quadrupeds, the four limbs and the trunk require at least three parts each, and often many more; it will be easily conceived therefore that such moulded works require considerable skill and patience.

Piece after piece of the mould is successively produced, just as in making the core, Fig. 153, p. 248, every piece embracing only so much of the figure, as in no part to require any core to overhang the line in which it is withdrawn. The side of the mould in which the figure is partly embedded is first dusted with charcoal, and then the first core is very carefully rammed into the nook, and pared down to the new line of division; the green or wet sand core is then dusted, and the second core is made, and afterwards dusted, when the moulder proceeds with the third core and so on; every one being carefully adapted to its neighbor, and withdrawn to see that all is right, before the succeeding core is proceeded with. The relative positions of the cores amongst themselves are readily recognized and maintained by the irregularity of their forms, as in a child's dissected map, or by making a notch or two here and there, which are faithfully copied in the succeeding piece. It is frequently necessary to thrust two or more broken needles through the green cores into the neighboring parts to connect them together, in imitation of the pins in the flasks.

All the parts of the mould are dried in the oven, and the facings are smoked over a cork fire as before explained; the perfection of the casting is augmented by pouring whilst the mould is still slightly *warm*, as otherwise on cooling it has an increased affinity for damp; but the mould when *hot* is more or less filled with aqueous vapor, which is equally prejudicial.

When a figure, such as a bust, is required to be cast hollow from a solid model, it is first moulded exactly as above. The core is now produced as follows: at the foot of the bust a large space, nearly equal in length and bulk to the bust, is cut away in the sand, to serve for fixing the core in the mould, or for the *balance*, as it is called, as the core cannot be propped up at both ends. The entire hollow, that is for the bust and the balance, is filled with a composition of about one part of plaster of Paris and two of sand or fine brick-dust, mixed with a little water and poured in fluid, a few wires being placed amidst the same for additional support.

The mould is now taken to pieces to extract the core, which is then dried, thoroughly burned, and allowed to cool slowly (which the founder calls *annealing*, from a similar method being employed in annealing or softening the metals and glass): the core is then returned to the mould, to see that it has not become distorted. If needful the fitting around the balance is made good to suit the reduced magnitude of the core, which latter is then so far pared away as to leave room for the thickness of metal; this is frequently regulated by boring holes at many parts of the core with a stop-drill, having a collar to prevent its penetrating beyond the determined depth; the surface of the core is now pared down to the bottoms of the holes, as uniformly as possible. When the mould has been faced, dried and smoked, the whole is put together for pouring, for which purpose the figure is inverted and filled from the pedestal.

Equestrian and other figures are sometimes cast in two, three, or more pieces, and joined together by solder, screws, or wires; but in all such works, the aim of the founder is to leave little or nothing for the finisher or chaser to do.

Some objects which are either exceedingly complex in their form, or soft and flexible in their substance, and which do not therefore admit of being moulded in sand, in the ordinary manner of figure casting, may be moulded for a *single copy*, provided the originals consist of substances which may be either readily melted or burned into ashes.

A cavity is made in the sand of the moulding-trough, a little larger and longer than the object, or else a wooden box of appropriate size is procured, in the midst of which the wax model may be placed; to the end of the model is added a piece to represent the runner, which will be required for introducing the metal. The composition of one-third plaster of Paris and two-thirds brick-dust, mixed with water, the same as for the core of the bust, is then poured in, entirely to surround the model. The mould is first slowly dried, it is then inverted and made warm to allow the wax to run out, after which it is annealed, or burned to redness, and lastly, when cooled, it is buried in sand and filled with metal. The method necessarily throws the chance of success upon a single trial, as the model is destroyed.

Should the face of the casting be required to be particularly smooth, a small quantity of brick-dust is washed, (in the manner practised with emery, and to be explained,) and mixed with very fine plaster: a coat of this is brushed over the model, which excludes air-bubbles, the model is quickly placed in its cavity, and the coarser mixture is poured in as before.

The above method exactly corroborates a mode long since described as being suitable to casting copies of small animals or insects, parts of vegetables and similar objects; these are to be fixed in the centre of a small box, by means of a few threads attached to any convenient parts, one or two wires being added to make air-holes, and ingates for the metal. A small quantity of river silt or mud, which had been carefully washed, was first thrown in and spread around the object by swinging the box about; and when partly dry, successive but coarser coats were thrown in, so as ultimately to fill up the box. When it had become thoroughly dry, the wires were first removed from the earthy mould; it was then burned to reduce the object to ashes, and when every particle of the model had been blown out, it was ready to be filled with metal.

FILLING THE MOULDS.—Having traced the formation of various kinds of moulds for brass work, we must now return to the furnace to see if the metal is in condition to be poured, which is indicated by the slight wasting of the zinc from its surface with a lambent flame. When this condition is observed, the large cokes are first removed from the mouth of the pot, and a long pair of crucible tongs are thrust down beside the same to embrace it securely, after which a coupler is dropped upon the handles of the tongs: the pot is now lifted out with both hands and carried to the skimming-place, where the loose dross is skimmed off with an iron rod, and the pot is rested upon the spill-trough, against or upon which the flasks are arranged.

The temperature at which the metal is poured must be proportioned to the magnitude of the works: thus large, straggling, and thin castings require the metal to be very hot, otherwise it will be chilled from coming in contact with the extended surface of sand before having entirely filled the mould; thick massive castings if filled with such hot metal would be *sand-burned*, as the long continuance of the heat would destroy the face of the mould before the metal would be solidified.

The line of policy seems therefore to be, to pour the metals at that period when they shall be sufficiently fluid to fill the moulds perfectly and produce distinct and sharp impressions, but that the metal shall become externally congealed as soon as possible afterwards.

For slight moulds the carbonaceous facings, whether meal-dust-charcoal, or soot, are good, as these substances are bad conductors, of heat, and rather aid than otherwise by their ignition; it is also proper to air these moulds for thin works, or slightly warm them before a grate containing a coke fire. But in massive works these precautions are less required; and the facing of common brick-dust, which is incombustible and more binding, succeeds better.

The founder therefore fills the moulds having the slightest works first, and gradually proceeds to the heaviest; if needful he will wait a little to cool the metal, or will effect the same purpose by stirring it with one of the ridges or waste runners, which thereby becomes partially melted. He judges of the temperature of the melted brass, principally by the eye, as when out of the furnace and very hot, the surface emits a brilliant bluish white flame, and gives off clouds of the white oxide of zinc, a considerable portion of which floats in the air like snow, the light decreases with the temperature, and but little zinc is then fumed away.

Gun-metal and pot-metal do not flare away in the manner of brass, the tin and lead being far less volatile than zinc; neither should they be poured so hot or fluid as yellow brass, or they will become sand-burned in a greater degree, or rather the tin and lead will strike to the surface, as noticed at page 212. Gun-metal and the much used alloys of copper, tin, and zinc, are sometimes mixed at the time of pouring; the alloy of lead and copper is never so treated, but always contains old metal, and copper is seldom cast alone, but a trifling portion of zinc is added to it, otherwise the work becomes nearly full of little air-bubbles throughout its surface.

When the founder is in doubt as to the quality of the metal, from its containing old metal of unknown character, or that he desires to be very exact, he will either pour a sample from the pot into an ingot mould, or extract a little with a long rod terminating in a spoon heated to redness. The lump is cooled and tried with the file, saw, hammer, or drill, to learn its quality.

The engraved cylinders for calico-printing are required to be of pure copper, and their unsoundness when cast in the usual way, was found to be so serious an evil that it gave rise to casting the metals under pressure.

Some persons judge of the heat proper for pouring, by applying the skimmer to the surface of the metal; which when very hot has a motion like that of boiling water; this dies away and becomes more languid as the metal cools. Many works are spoiled from being poured too hot, and the management of the heat is much more difficult when the quantity of metal is small.

The mixture and temperature of the metal being found to be proper, it is poured in the manner represented in Fig. 119, p. 221. the tongs are gradually lowered from the shoulder down the left arm, and the right hand is employed in keeping back the dross from the lip of the melting-pot. A crucible containing the general quantity of 40 or 50 lbs. of metal, can be very conveniently managed by one individual, but for larger quantities, sometimes amounting to one hundred weight, an assistant aids in supporting the crucible, by catching hold of the shoulder of the tongs with a *grunter*, an iron rod bent like a hook.

Whilst the mould is being filled, there is a rushing or hissing sound from the flow of the metal and the escape of the air; the effect is less violent where there are two or more passages, as in heavy pieces, and then the jet can be kept entirely full, which is desirable. Immediately after the mould is filled, there are generally small but harmless explosions of the gases, which escape through the seams of the mould; they ignite from the runners, and burn quietly; but when the metal *blows*, from the after-escape of any confined air, it makes a gurgling bubbling noise, like the boiling of water, but much louder, and it will sometimes throw the fluid metal out of the runner in three or four separate spirts: this effect, which mostly spoils the castings, is much the most likely to occur with cored works, and with such as are rammed inless judiciously hard, without being, like the moulds for fine castings, subsequently well dried.

The moulds are generally opened before the castings are cold, and the founder's duty is ended when he has sawn off the ingates or ridges, and filed away the ragged edges where the metal has entered the seams of the mould; small works are additionally cleaned in a *rumble*, or revolving cask, where they soon scrub each other clean.

Nearly all *small* brass works are poured *vertically*, and the runners must be proportioned to the size of the castings, that they may serve to fill the mould quickly, and supply at the top a mass of still fluid metal, to serve as a *head* or pressure for compressing that which is beneath, to increase the density and soundness of the casting. Most *large* works in brass, and the greater part of those in iron, are moulded and poured *horizontally*.

IRON-FOUNDERS' FLASKS, AND SAND MOULDS.—The process of moulding works in sand is essentially the same both for brass and iron castings; but the very great magnitude of many of the latter gives rise to several differences in the methods: it will suffice, however, to advert to the more important points in which the two practices differ, or to those which have not been already noticed; I shall therefore commence with a few remarks upon the flasks and the sand.

In the greater number of cases the iron-founder moulds and casts his work horizontally, with the flasks lying upon the ground; frequently the top part only is lifted; and in the largest works the lower part of the flask is altogether omitted, such pieces being moulded in the sand constituting the floor of the foundry; in these cases the position of the upper flask is denoted by driving a few iron stakes into the earth, in contact with the internal angles of the *lugs*, or projecting ears of the flasks.

The sand would drop out of such large flasks, if only supported around the margin; they are consequently made with cross-bars or wooden *stays* a few inches asunder, which, unless the entire flask is made of wood, are fixed by little fillets cast in the solid with the sides of the iron flasks. A great number of hooks in the form of the letter S, but less crooked at the ends, are driven into the bars, and both the bars and hooks are wetted with thick clay water, so that the sand becomes entangled amidst them, and is sustained when the flask is lifted. Some flasks require the force of either two or several men, who raise them up by iron pins or handles projecting from the sides of the flask; they are then placed upon one edge, and allowed to rest against any convenient support whilst they are repaired, or they are sustained by a prop.

The very heavy flasks are lifted with the crane, by means of a transverse beam and two long hangers, called *clutches*, which take hold of two gudgeons in the centres of the ends of the flask; it can be then turned round in the slings, just the same as a dressing-glass, to enable it to be repaired.

The modern iron-founder's flasks are entirely of iron, and do not require the wooden stays, as they are made full of cross ribs nearly as deep as the flask itself, and which divide its entire surface into compartments four or five inches wide, and one to two feet long. On the sides of every compartment are little fillets, sloping opposite ways, so as to lock in the small bodies of sand very effectually. When these top flasks are placed upon middle flasks without ribs, as in moulding thick objects, the two parts are *cottered* or keyed together, by transverse wedges fixed in the steady pins of the flask; lifters or *gaggers* are then placed amidst the sand; these are light **T** shaped pieces of iron, wetted and placed head downwards, the tails of which are largest at top, so as to hold themselves in the sand, the same as the key-stone of an arch is supported. The gaggers are placed at various parts to combine the sand in the two flasks, and they fulfil the same end as the iron hooks and nails driven into the wooden stays of the old-fashioned flasks.

The bottom flask or drag has sometimes plain flat cross-ribs two inches wide (like a flat bottom with square holes), that it may be turned over without a bottom board; and unless the flasks have swivels for the crane, they have two cast-iron pins at each end, and one or more large wrought-iron handles at each side, by which they may be lifted and turned over by a proportionate number of men.

The sand of the iron-founder is coarser and less adhesive than that used by the brass-founder. The parting sand is the burned sand which is scraped off the castings; it loses its sharp, crystalline character from being exposed to the red heat. The facing-sand is sometimes only about equal parts of coal-dust and charcoal-dust, ground very fine; at other times, either old or new sand is added, and for large thick works a little road-drift is introduced. All these substances get largely mixed with the sand of the floor, and lessen its binding quality, which is compensated for by occasional additions of new sand, and by using more moisture with the sand; as before extracting the patterns, the iron-founder wets the edges of the sand with a sponge, which has sometimes a nail tied to it to direct the water in a fine stream; for heavy works a watering pot is used.

The *green-sand moulds* are made, as in the brass-foundry, of the ordinary stock of old moist sand; these are often filled as soon as they have been made.

The *dry-sand moulds* are made in the same manner, but with new sand containing its full proportion of loam; these moulds are thoroughly dried in a large oven or stove, and then black-washed or painted with thin clay water containing finely ground charcoal; this facing is also thoroughly dried before the moulds are poured.

The *loam moulds*, which are much used for iron castings and somewhat also for those of brass, are made of wet loam with a little sand, ground together in a mill to the consistence of mortar; the moulds are made partly after the manner of the bricklayer and plasterer, as will be explained; the loam moulds also are thoroughly dried, black-washed, and again dried, as from their greater compactness they allow less efficient escape for the vapor or air, and therefore they must be put into the condition not to generate much vapor when they are filled.

Iron moulds are also employed for a small proportional number of works which are then called *chilled castings;* these were referred to at pages 163 and 164; and occasionally the methods of sand casting and chilling are combined, as in some axletree-boxes, which are moulded from wooden patterns in sand, and are cast upon an iron core. To form the annular recess for oil, a ring of sand, made in an appropriate core-box, is slipped upon the iron mandrel, and is left behind when the latter is driven out of the casting.

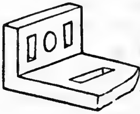
It would be a useless repetition to enter into the details of moulding ordinary iron works; but from the horizontal position of the flasks it is necessary that the part of the work which is required to be the soundest, and most free from defects, should be placed downwards, as the metal is more condensed at the lower part, and free from the scoria or *sullage* which sometimes renders the upper surface very rough and full of minute holes. As the flasks almost always lie on the ground, it is also found the most convenient to retain them in contact by placing heavy weights upon them; the foundry should in consequence have an abundant supply of these.

The flasks require to be poured through a hole in the upper half, as seen at *r*, Fig. 169, page 259, which hole is formed by placing a wooden *runner stick* in the top part A, whilst it is being rammed; and a small channel is afterwards cut sideways into the mould. Sometimes two, three, or even half-a-dozen or more runners are put to one single casting, either when it requires a great weight of metal, or when it is large but slight, as in trellis-work, in which case the metal might cool before filling the mould if only introduced at one single runner.

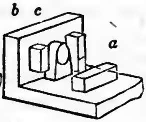
When the runners are required to be lofty, either to supply pressure to the metal, or as a reserve to fill up the space left by its contraction in cooling, iron rings of six or eight inches diameter are piled up to the required height, to support the tube of sand contained within them. Small objects that are poured from one hole, are frequently moulded with two runners, that the metal may *flow* through the mould, and that there may be a sufficient supply to meet the shrinkage, and also to supply head or pressure; another advantage also results, as it assists in carrying off the scoria or *sullage.*

The iron-founder employs all the methods of coring explained at pages 245 to 248, and also others of an entirely different kind but little required in brass-works; namely for lateral holes in the parts of the castings buried beneath the general surface of the mould, and which are explained by the Figs. 158 to 161. Thus 158 represents the finished casting, 159 the model of the same, 160 the appearance of the bottom flask or drag when the pattern is first removed, and 161 the flask and cores when closed ready for pouring; the moulds are inverted, and the same letters of reference refer to similar parts of all these figures.

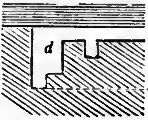
Figs. 158



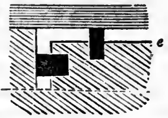
159



160



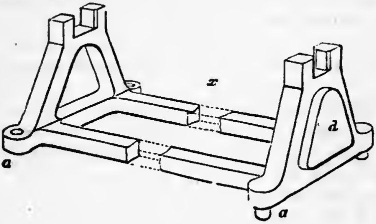
161.

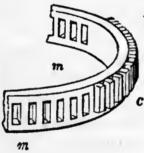


The core print *a,* would deliver from the sand and leave the cavity at *a,* Fig. 160, to be afterwards filled by the core shown black in Fig. 161, the same as formerly explained at Fig. 143, p. 245. But the core print, *b,* Fig. 159, (which has reference to the black stud *b,* Fig. 161,) would tear away the sand above it in withdrawing the pattern; therefore the print *b* should, like *d,* Fig. 159, extend to the face of the pattern, or the parting line represented by *e,* Fig. 161. This being the case, the pattern would leave the space denoted at *d,* Fig. 160; the core is put down sideways to the bottom of the recess, and extends entirely across the same; the small open space above, is made good with the general surface, as shown by the shade lines in Fig. 161, and this filling in at the same time fixes the core precisely where denoted by the print *d,* which latter has a mark to show to the moulder where the core is to end. The circular hole requires the core print shown at *c,* Fig. 159; the cores themselves are made in the core-boxes 144 and 145, before explained at page 246.

Fig. 163 represents the model and core-print, from which the finished casting shown at Fig. 162 might be made from a solid pattern in a two-part flask; it would be inverted, and the parting would be made upon the line, *x.* The prints for the four holes *a a,* would be placed in the top flask, and those for the great apertures or panels *d,* would be made in a core-box of the express form, and as thick as the pattern and core-print measured together. The core would be deposited edgeways into the core-print, and the upper corners of the mould would be made good, as explained in Fig. 161.

Figs. 162 163 164





165

By the same method, a mortise wheel, or one with spaces around its edge, as at *m m*, Fig. 164, to be filled with wooden cogs, might be made with a series of core-prints, as at *c*, brought up flush with the parting of the mould; if every print were filled with a core such as Fig. 165, made in an appropriate core-box, the matter would be accomplished with great facility and truth.

The iron-founder makes frequent use of flasks, which divide in three or four parts; this is done in many cases simply to increase the depth of the contained space; in which case when wooden flasks were employed, they admitted of being temporarily fixed together by dogs, or large iron staples, driven a little way into the neighboring flasks, but the modern iron flasks are fixed by cotters. The following examples will show the nature of some other uses to which the flasks with several partings are applied.

Fig. 166.

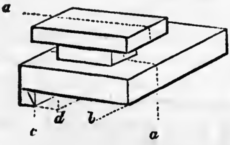
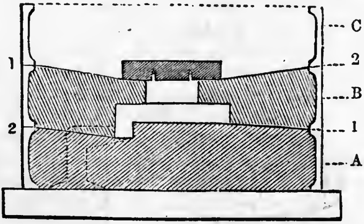


Fig. 167.



A casting, such as Fig. 166, which represents the top of a sliding-rest for a lathe, might be moulded in a very deep two-part flask, if the parting were made upon the dotted line *a, a*; but there would be very great risk of tearing down the mould in drawing out the pattern, and from the depth, there would be scarcely a possibility of repairing it, and the metal would probably be strained. It would be also possible to mould it with the joining upon the line *b*, provided several cores were employed, but the mode adopted is more convenient than either of these—when the pattern is made in two parts, and the flask in three, as in Fig. 167.

A and B are first united and partly filled with sand, the pattern is knocked in as represented, and the whole well rammed, especially in the groove, the parting being made on the line, 1, 1, and dusted. C is now put on, filled, and struck off level, a board is put above it, and A B C are all turned over together, A becoming the top.

A is now removed, and the sand is cut away to make the second parting on the line 2, 2, after which A is replaced, and the runner-stick is inserted to make the runner, *r*. On removing the pattern, the runner-stick *r* is first taken out, A, or the top part of the flask, is lifted off, and the white part of the pattern is drawn out; B, or the middle part, is then lifted, and the last or shaded piece of the pattern, is drawn out of the mould, which is now put together again, and poured through *r*; so that the top surface of the pattern, as seen in both views, becomes the *face*, from being cast downwards, or upon the lowest piece C, of the flask, called the drag.

The part *c*, Fig. 166, might be cast with a chamfer in three different ways; although, in small castings, it is more usual to cast it square and plane it out of the solid. First, the pattern might be moulded square, and the top A, after removal, might be worked to the angle by aid of the trowel and a chamfered slip of wood, used as a gage; or secondly, by the employment of a core, the print of which is represented by the dotted lines terminating at the angle *d*, Fig. 166; or thirdly, by having a loose slip on the pattern sliding on the line *c*, Fig. 166, so as to be drawn off when the top A, had been lifted. This last method is analogous to that represented in Fig. 168, also intended for a sliding-rest and which might be cast in a two part flask, if the two camfers *c c*, were fitted loosely upon slides as shown; but a three-part flask is more convenient, as explained by Fig. 169, in which the pattern is inverted.

Fig. 168.

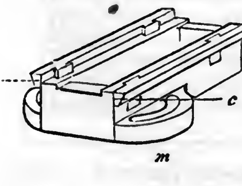
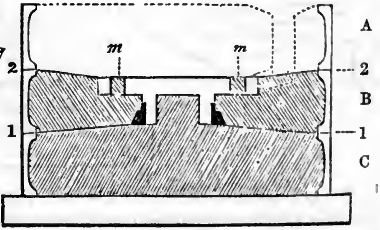


Fig. 169.



The lowest piece C, or the drag, is parted upon the line 1, 1, but its sand extends upwards between the two sides of the pattern, as shown by the shade-lines. The middle piece B, is parted through the line 2 2; and lastly A. the top, is filled up level, the runner-stick at *r* being inserted at the time, A is first lifted, and all the pattern is then removed, excepting the chamfered bars and their slides, which are represented black; this pattern delivers its own cores for the circular mortises *m m*, the sand forming them being a part of that in B, or the middle flask; lastly, B is lifted, and chamfer-slips are picked off from C. This pattern may consequently be moulded without turning over the flask, and every part of the mould is quite accessible for repair.

The pedestal of the swage-block, Fig. 95, page 141, is another good example of moulding in a three-part flask. The model is made with the upper fillet loose, also with the sides solid, or without the holes, and the object is moulded as it stands. The top part of the flask opens at the upper moulding, and which latter is then removed from the pattern; the middle flask divides at the plinth or flange, so that when this has been lifted, the pattern also may be withdrawn, leaving a square pedestal of sand, as large as the interior of the model, standing upon the bottom part or drag, as in 169. The panels are made by means of a core-box of the kind Fig. 146, p. 246, the box is exactly as thick as the metal to be cast; and the circular cores are then fixed upon the pedestal of sand by means of a few wires or nails, after which the flask is put together, ready for pouring.

If the Fig. 95, here referred to, had four fluted columns at the four angles, either with a large cap to each, or with a square entablature connecting the whole of them, the object might be also cast in one piece, if moulded in a three-part flask. After removing the top flask, the entablature and capitals would be first withdrawn, the columns being divided through their *smallest* diameters; the mould would be then turned over, and upon lifting off the drag, or bottom-piece, the remainder of the pattern could be drawn, either in one single piece, or if the pillars were loose, the five parts could be more safely extracted; the three-part mould would be put together again and reversed for pouring. In this general manner, by making either the mould, or the pattern, or both, in different pieces, and by the judicious employment of cores and drawbacks, objects apparently the most untractable are cast with very great perfection.

The iron-founders are likewise very dexterous in making castings in some respects different from the patterns from which they are moulded; thus, if the pattern be too long, or that it be temporarily desired to obliterate some few parts, the mould is made of the full size and *stopped-off*, additional sand being worked into the mould by aid of the trowel and some temporary piece of wood to represent the imagined termination of the pattern. On the other hand, any simple enlargement or addition is not always added to the pattern, but it is frequently *cut out* of the mould with the trowel, in a similar manner.

Many common works, such as plates, gratings, parts of ordinary stoves, and simple objects, are made to *written* measures, and without patterns, as a few parallel slips of wood to represent the margin of the casting, are arranged for the purpose upon a flat body of sand, which is modelled up almost entirely by hand; but for all accurate purposes and for machinery, good and well-made patterns are indispensable, and to some particulars of which a little attention will be now devoted.

REMARKS ON PATTERNS FOR IRON CASTINGS.—The construction of patterns for iron castings requires not only the observance of all the particulars conveyed on pages 238 to 240, but, in addition, the large size of the models, the peculiar methods employed in moulding them, and the nearly inflexible nature of the iron castings when produced, call for some other and important considerations,—and which should not be entirely overlooked, even in works of comparatively small size, or it may lead to failure and disappointment.

Thus, it becomes necessary to make patterns in some degree larger than the intended iron castings, to allow for their contraction in cooling, which equals from about the ninety-fifth to the ninety-eighth part of their length, or nearly one per cent. This allowance is very easily and correctly managed by the employment of a *contraction rule,* which is made like a surveyor's rod, but one-eighth of an inch longer in every foot than ordinary standard measure. By the employment of such contraction rules, every measurement of the pattern is made proportionally larger without any trouble of calculation.

When a wood pattern is made, from which an iron pattern is to be cast, the latter being intended to serve as the permanent foundry pattern, as there are two shrinkages to allow for, a *double* contraction rule is employed, or one the length of which is one-quarter of an inch in excess of every foot. These rules are particularly important in setting out alterations in, or additions to, existing machinery. The latter is measured with the common rule, and the new patterns are set out, to the same nominal measures, with a single or double contraction rule, as the case may be, the three being made in some respects dissimilar to avoid confusion in their use. The entire neglect of contraction rules incurs additional trouble and uncertainty. The contraction of brass is nearly three-sixteenths of an inch in every foot, but from the small size of brass castings the contraction rule is less required for them, as the differences may be easily allowed for without it.

Iron castings weigh about fourteen times as much as the ordinary deal and fir patterns from which they are made, that being nearly the ratio of the specific gravities of those materials.

Patterns for iron castings are much more frequently divided into several parts than those for brass. For instance, the division into two equal parts, after the manner of Fig. 153, p. 248 (but without reference to the under-cutting) is very common, as both the pattern and flask separate when the top part is lifted, and the halves of the pattern can then be drawn out from the halves of the flask with much less risk of tearing down the sand.

Referring to p. 232, Fig. 122 if small, would be moulded as represented, with false cores or drawbacks; but if it were a large fluted column, the iron-founder would employ a solid two-part flask; the shaded parts would together represent the body of sand in the drag, and the pattern would be made in *three* parts something like a boot-tree. When the top flask had been lifted, the central slice of the pattern, extending from the two upper to the two lower angles, would be withdrawn vertically, and the two outer pieces would be released sideways. The general rule is to divide the circumference of the pattern into six equal parts, and to let the central slice equal one of them in width.

The Figs. 167 and 169, representing two parts of a slide-rest, and the pedestal, 95, are some amongst many of the common examples of the division of the patterns; and with which may be associated, the numerous subdivisions of the mould instead of the pattern by the employment of cores, many applications of which have been also explained. All these matters display much interesting and ingenious contrivance, resorted to either to render possible the operation of moulding, or to facilitate its performance.

To lessen the distortion of castings from their unequal contraction in cooling, it is important that the models should be nearly symmetrical. For example, bars or rods of all the sections in Fig. 121, p. 232, may be expected to remain straight; perhaps *g* is the most uncertain, but if the lower fins of *e* and *h* were removed, their flat surfaces, then exposed to the sand, would become rounding or convex in length, from the contraction of the upper rib being unopposed by that of a similar piece on the under side. Bars and beams, the sections of which resemble the letter **I**, are of the most favorable kind for general permanence, and also for strength, and large panels may be cut out from their central plates to diminish their weight without materially reducing their stability. They are much used, not only in building, but also in the framing of machinery, which is in a great measure based upon the same general rules.

It is also of great importance, especially in castings of large size, that the *thickness* of the metal should be nearly alike throughout, so that it may cool at all parts in about the same time. Should it happen that one part is set or rigid, whilst another is semi-fluid or in the act of crystallizing, there is great risk of the one part being altogether torn from the other and producing fracture. Or should the disturbing force be insufficient to break the casting, it may strain the metal nearly to its limit of tenacity or elasticity; so that a force far below that which the casting should properly bear may break it in pieces.

An example of this is seen in wheels with very light arms and heavy rims or bosses. The arms sometimes cool so quickly as to tear themselves away from the still hot rim or nave; or when the arms are solidified without fracture, the contraction of the rim may so compress the spokes endways as to dish the wheel (in the manner of an ordinary carriage wheel), and thereby strain the casting nearly or quite to the point of fracture. The arms are sometimes curved like the letter S, instead of being straight and radial; the contraction then increases their curvature with less risk of accident than to straight arms. It appears to be often desirable to supersede the straight diagonal braces of iron castings by curved lines, which are both more ornamental and better disposed to yield to compression or extension by a slight alteration in their curvature.

A more elegant way of avoiding the mischief is by placing the spokes as *tangents* to the central boss, in which case the contraction of the rim makes a small angular change of position in the boss; for the rim, in thrusting the spokes inwards, causes the boss to twist round a little way with far less risk of fracture.

The destructive irregularity of thick and thin works is partly averted by uncovering the thick parts of the casting, or even cooling them still more hastily, by throwing on water from watering-pots. In wheels this has been done by a hose, the axis of which is concentric with the wheel, the arms being all the time surrounded by the sand to retard their cooling; but it is the most judicious in all patterns to make the substance for the metal as nearly uniform throughout as circumstances will admit, so as not to require these modes of partial treatment, which often compromise the ultimate strength of the casting.

Another mode sometimes adopted for avoiding the fracture of wheels, from the great dissimilarity of their proportions, is by inserting *wrought-iron arms* in the mould, but they do not always unite kindly with the iron of the rim and the nave. The same inconvenience occurs when iron pins are inserted in the ends of either iron or brass castings, to serve for their attachment to their respective places. In iron castings it frequently produces the effect of chill casting, so as to render the works difficult to be turned or filed at the junction, and there is risk of the casting becoming blown or unsound in either case. When the pins are heated before being placed in the mould, they become nearly cold before the metal can be poured, and they also endanger the presence of a little steam or vapor, which is detrimental; therefore they are more generally put in cold, notwithstanding the sudden check they then give to the fluid metal.

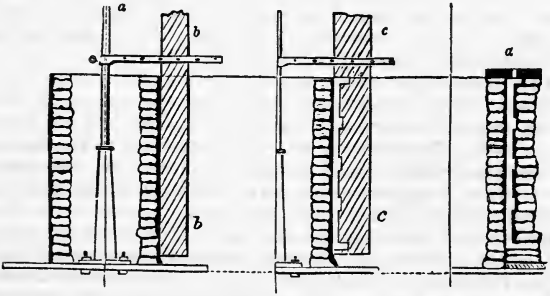
The patterns for iron castings of large size are necessarily very expensive, especially those for hollow cylinders and pans, many of which are so large that it would be impossible to find solid pieces of wood from which the patterns could be made, either with sufficient strength for present use, or with the necessary permanence of form for a subsequent period, as they would be almost sure either to break or to become distorted from the effects of unequal shrinking. Such patterns, therefore, require to be made of a great many thin layers or rings of wood, each consisting of 6, 8, or 12 pieces, like the felloes of wheels, so that in all parts the grain may be nearly in the direction of a tangent.

As they are glued up, every succeeding layer is connected with the former by glue and wooden pins or dowels, and the whole is afterwards turned to the tubular or hemispherical form, as the case may be. As the castings are generally required to be rather thin, such models are not only very expensive, but also very liable to accident; and besides, it frequently occurs that only one or two castings of a kind may be required, which makes the proportional cost of the patterns excessive.

It fortunately happens, however, that this case, which is one of the most costly and uncertain, by the employment of ordinary wood or metal patterns, becomes exceedingly manageable by a peculiar and simple application of the art of turning (the one great centre of the constructive arts, to which these pages are intended immediately and collaterally to apply); and by which process, or one branch of *loam moulding*, to be explained hereafter, patterns are not generally required.

Loam Moulding.—Figs. 170, 171, and 172, are intended to illustrate this process as regards a steam cylinder. Fig. 170 is the entire section of the mould in its first stage. Figs. 171 and 172 are the half sections of the second and third stages, preparatory to burying the mould in the pit in which it is to be filled.

Figs. 170 171 172.



The inner part of the loam mould is called the *core* when small, but the *nowel* when large; the outer is called the *case* or the *cope*. Each part is built upon an iron loam-plate, or a ring cast rough on the face, and with four ears by which it may be lifted. The mould is occasionally erected upon four shallow pedestals of bricks for the convenience of making a fire beneath it to dry the loam. At other times it is made upon a low truck, upon which it may be wheeled into the loam stove, which is heated to about the temperature of 300 to 400 degrees Fahrenheit.

A vertical axis *a*, is mounted in any convenient manner, frequently in two holes in the truck itself, or as shown in the figure, in a pedestal or socket erected upon the truck; at the other times the axis is mounted in a hole in the loam-plate, and in any bearing attached either to the building or its roof.

The first step is to fix upon the spindle, the templet *b b*, at the distance of the radius of the cylinder, either by one or two *clutches* with various binding screws. An inner cylinder of brickwork is then built up, plastered by the hands with soft loam (which is represented black in all figures), and scraped into the cylindrical form by the radius board, which is moved round on its axis by a boy. When the surface is smooth and fair it is thoroughly dried, after which it is brushed over with blackwash, and again dried. The charcoal dust in the blackwash serves as a parting, to prevent the succeeding portions of the loam-mould from adhering to the first.

The templet *c c*, Fig. 171, cut exactly to the external form of the cylinder, is now attached to the axis at the distance from the core required for the thickness of the metal: some additional loam is thrown on to form the *thickness*, which is smoothed in the same careful manner as the centre, after which the templet and spindle are dismounted, and the thickness, which is represented white in Figs. 171 and 172, is also dried and blackwashed.

The ring for the outer case or cope is now laid down, and its position is denoted either by fixed studs or by marks; and the outer case represented in Fig. 172 is built up of bricks and loam, with an inner facing of loam worked very accurately to the turned thickness. The new work or the cope, is also thoroughly dried, and afterwards lifted off very carefully by means of the crane and a cross beam with four chains. This process likewise drags off the thickness, which usually breaks in the removal; its remains are carefully picked out of the cope, both parts of the mould are repaired, and again blackwashed and dried.

When the cylinder requires *ports* at the ends, or the short tubes with flanges for attaching the steam-passages, models of the tubes are worked into the cope, and are afterwards withdrawn; the cores are made in core boxes, and are partly supported by the outer extremity, and partly upon *grains*, or two little plates of sheet iron connected by a central wire, the whole being equal to the thickness of the metal at the part. When steam-passages are wanted, either along the side, or around the cylinder, they are worked up in clay upon the thickness, and duly covered in by the cope; their cores are supported, partly by their loose ends, and partly by grains, which become entirely surrounded by, and fixed in the metal, when it is poured.

There is always some uncertainty of the sound union of the grains, or other pieces of iron, with the cast-metal. Some cast them in iron and file them quite bright, others also tin them, apparently to preserve them from rust, as the tin must be instantly dissipated by the hot metal. Grains should always present clean metallic surfaces, and when used for very thin castings to prevent them from dropping out, the wires are nicked with a file that they may be keyed in the metal. It is however better to avoid the use of grains, which may be generally done by giving the core *sand bearings*, and afterwards plugging up the holes in the casting.

The mould is now put together in a pit sunk in the floor of the foundry, and the two iron plates are screwed together; the surrounding space being rammed hard to prevent the mould from bursting open, but the inner part is left much more loose for the escape of the air. The top edges of the mould are covered over with a *loam-cake* (which has been previously made and dried), or a ring three or four inches thick, strengthened with iron bars amidst the clay, the joining being made air-tight by a little cows' hair, and by the pressure of a quantity of iron weights; the loam-cake is generally perforated with many holes as shown at *d*, for the entry of the metal and the escape of the air. But provision must always be made in casting thin cylinders, boxes, and such like forms, for the breaking up of the core as soon as the metal is set, to prevent the metal *scoring* or rending from its contraction upon a rigid unyielding centre.

To enable the mould to resist the great pressure of the lofty column of fluid metal (equal at the base to near 60 pounds on every square inch), the core is strengthened by diametrical iron bars entering slightly into the brickwork: the outer cylinder is surrounded at a small distance by iron rings piled one on the other, the interval being rammed with sand; and stays are placed in all directions from the rings to the sides of the pit, which is either lined with brick-work, or when liable to be inundated with water, it is made of iron, like a water-tight caisson.

Small cylinders are moulded in sand from wooden models, and only the cores are turned in loam; for cylinders of the smallest size the cores are made of sand in core boxes as already explained.

Large pans, and various other circular works, are moulded precisely in the same way as cylinders; except that curved templets are used, and that towards the conclusion, the apertures through which the spindle passed are filled in and worked by hand to the general surface.

Water-pipes are made much in the same mode, but the cores for these are turned upon an iron tube pierced full of holes, which is laid horizontally across two iron trestles with notches, and is kept in rotation by a winch handle at the end: there is also a shaper-board or scraper fixed parallel with the axis; this primitive apparatus is called a *founder's lathe*.

The perforated tube (serving as the mandrel) is first wound round with hay-bands, then covered with loam, and the core is turned, dried and blackwashed; the thickness is now laid on and also blackwashed, after which the object is moulded in sand. The thickness is next removed from the core, which latter is inserted in the mould, and supported therein by the two prints at the extremities, and by grains with long wires, the positions of which may be seen by the little bosses on the pipe, the metal being there made purposely thicker to avoid any accidental leakage at those parts. When pipes are cast in large quantities, they are moulded from wooden patterns in halves, so that it only becomes necessary to turn the core, and this, when made in the above manner, is sufficiently porous for the escape of the air.

The moulds for crooked pipes and branches are frequently made in halves, upon a flat iron plate. An iron bar or templet of the curve required is fixed down, and a semicircular piece of wood, called a *strickle,* is used for working and smoothing the half core; next a larger strickle is used for laying on the thickness, the two halves are then fixed together by wires, and moulded from in the sand flask; the thickness is now stripped off the core, which is fixed in the mould by its extremities, and if needful, is supported also upon grains.

By the employment of these means, although the loam work requires time for the drying, yet with ordinary care an equality of thickness may be maintained, notwithstanding the complexity of the outline, and without the necessity for wooden patterns.

Very many of the large works in brass are also moulded in loam, the management being in most respects exactly the same as for iron, except that in some ornamental works wax is more or less employed, and is melted out of the moulds before the entry of the metal; a very slight view of the methods will serve as a sequel to the subject of brass founding.

Large bells are turned in almost the same manner as iron cylinders or pans, by means of wooden templets, edged with metal and shaped to the inner and outer contour of the core and thickness. The inscription and ornaments are either impressed within the cope, the clay of which is partially softened for the purpose, or the ornaments are moulded in wax, and fixed on the clay thickness before making the cope. Less generally the whole exterior face of the bell, or indeed its entire substance, is modelled in wax, and melted out before pouring. In any case, the concluding steps in filling up the apertures where the spindle passed, are to attach a dissected wooden pattern of the central stem and of the six *cannons* or ears by which the bell is slung, which parts are moulded in soft loam; and then, the parts having been dried and replaced, and the iron ring for the clapper inserted, the whole is ready for the pouring pit. The heaviest bells are moulded within the pit the same as huge cylinders.

Brass guns are also moulded in loam, and in a somewhat peculiar manner; a taper rod of wood much longer than the gun, is wound round with a peculiar kind of soft rope, upon which the loam is put for making the rough casting model of the gun, which is turned to a templet; the work is executed over a long fire to dry it as it proceeds, and the model is made about one-third longer than the gun itself. The model when dried and blackwashed all over, is covered with a *shell* of loam, not less than three inches thick, secured by iron bands, the shell is also carefully dried; after this the taper bar is cautiously driven out from its small end, the coil of rope is pulled out, and so likewise is every piece of the clay model of the gun.

The parts for the cascable and trunnions, which should have been worked separately upon appropriate wooden models, are then attached to the shell. Should the gun have dolphins, or any other ornamental figures, now seldom the case, they are modeled in wax and fixed on the clay model before the shell is formed, and are then melted out to make the required space for the metal.

When all is ready and dried, six, eight, or more of these loam cases, or shells, are sunk perpendicularly in a pit at the mouth of the reverberatory furnace, and the earth is carefully rammed around them; at the same time a vertical runner is made to every mould, to enter either at the bottom, or not higher than the trunnion: the upper ends of the runners terminate in the bottom of a long trough or gutter, at the far end of which is a square hole, to receive the excess of metal.

In casting brass guns, tapping the furnace is rather a ceremony, and certainly an imposing sight: the middle and the end of the trough, are each stopped by a shovel or gate held across the same; and the runners are all stopped by long iron rods, held by as many men. When all is pronounced to be *ready*, the stopper of the furnace is driven inwards with a long heavy bar swung horizontally by two or three men, and the metal quickly fills the trough; on the word of command, "*number one, draw*," the metal flows into the first mould, and fills it quickly but quietly from the bottom; the mould being open at the top, no air can be accidentally enclosed. Numbers two, three, and four are successively ordered to draw. The first shovel is then removed from the great channel, and now the guns, five to eight or ten, as the case may be, are similarly poured and filled to the level of the trough; after which the last shovel is withdrawn, and the residue of the metal is allowed to run into the square bed or pit prepared for it. The flow of metal from the furnace is regulated by the tapping bar, the end of which is taper, and is thrust more or less into the mouth of the furnace as required; the trough and runners are thus kept exactly full, which is an important point in most cases of pouring, as it prevents a current of air being carried down along with the metal.

Large bells are poured much in the same manner, except that the runners are at the top, and the metal runs from the great channel, through smaller gutters to every sunk mould, the stoppers for which are successively drawn. For quantities of brass intermediate between the charge of an ordinary crucible, and such as require the reverberatory furnace, the large ladles or shanks of the iron-founder are used; the contents of four or six crucibles being poured into the shank as quickly as possible, and thence in one stream into the mould.

The author of the article Founding, in the *Encyclopedia Metropolitana,* minutely describes three ways of casting large hollow statues, which are briefly as follows:

First: a rough model of the figure is made in clay, but somewhat smaller than its intended size; it is covered over with wax, which is modeled to the required form, or the wax is worked up in separate pieces and afterwards attached: various rods or cylinders of wax to make the apertures for the runners or air holes, are fixed about the figure and led upwards. The whole is now surrounded with a coating of loam and similar materials, the inner portion of which is ground very fine and laid on with a brush like paint; and the outer part is secured with iron bands. When all has been partially dried a fire is lighted beneath the grating on which the figure is built, to cause the wax to run out through one or more apertures at the base, which are afterwards stopped, and all is thoroughly dried and secured in the pit, after which the charge of the furnace is let into the cavity left by the wax.

Secondly: the finished figure is modeled in clay, and stuck full of brass pins just flush with its surface, which surface is now scraped away as much as the thickness required in the metal; the reduced figure is now covered with wax mixed with pitch or rosin, which is worked to the original size with all the exactness possible. The other stages are the same as in the foregoing; the metal studs or pins prevent the mould and core from falling together, and they afterwards melt, becoming a part of the metal constituting the figure.

Thirdly: the finished figure is modeled in plaster, and a piece-mould is made around it, the blocks of which consist internally of a layer of sand and loam 1½ inch thick, and externally of plaster one foot thick. The mould when completed is taken to pieces, dried, and rebuilt in the casting pit; it is now poured full of a composition suitable for the core, the mould is again taken to pieces, the core is dried and scraped to leave room for the metal, and all is then put together for the last time, secured in the pit and the statue is cast.

The first plan is the most wasteful of metal, the third, the least so, although it is the most costly when the time occupied is also taken into account; but it has the advantage of saving the original work of the artist.

MELTING AND POURING IRON.—Iron is usually melted in a blast furnace, or as it is more commonly called, a cupola; although the cupola or dome leading to the chimney, from which it would appear to have derived its name, is frequently omitted, the two or three furnaces being often built side by side in the open foundry.

At the basement there is a pedestal of brickwork about 20 to 30 inches high, upon which stands a cast-iron cylinder from 30 to 40 inches diameter, and 5 to 8 feet high; this is lined with road-drift, which contracts its internal diameter to 18 or 24 inches. The furnace is open at the top for the escape of the flame and gases, and for the admission of the charge, consisting of pig-iron, waste of old metal, coke and lime, in due proportion. The lime acts as a flux, and much assists the fusion; chalk is considered to answer the best, but oyster shells are very commonly used where they are abundant.

At the back of the furnace, there are three or four holes one above the other for the blast, which is urged by bellows or by a revolving fan. No crucible is used, and as the fluid metal collects at the bottom of the furnace, the blast pipe is successively removed to a higher hole, and the lower blast hole is stopped with sand, which partly fuses and secures the blast hole very effectually.

The front aperture of the furnace through which the metal is allowed to flow into the ladles or trough, is usually made sufficiently large for the purpose of clearing or raking out rapidly the fuel and slag, as the process is most laborious owing to the excessive heat. This aperture is closed by a *guard-plate,* fixed on by staples attached to the iron-case of the furnace, in the centre of which plate the tapping hole is made: during the time the metal is fusing the tap hole is closed by sand well rammed in, and this if well done is never found to fail.

Many iron furnaces are made octangular, and in separate parts bound together by hoops, so that in the event of the charge becoming accidentally solidified in the cupola, the latter may be taken to pieces for its removal, and thus avoid the necessity of destroying the furnace. There is frequently a light framing or grating above the furnace, upon which the small cores are placed that require to be dried.

In some foundries the cupolas are built just outside the moulding shop, beneath one or more chimneys or shafts, which carry off the fumes; in such cases the fronts of the furnaces are accessible through an aperture in the foundry wall, with which they are nearly flush; when the furnaces are lofty there is a feeding stage at the back, from which the charge is thrown in.

For heavy iron castings, which sometimes amount to thirty tons and upwards in one piece, reverberatory or air furnaces are also commonly used; the ordinary charge for these is four to six tons of iron, and five or six furnaces are commonly built close together, so that they may be simultaneously tapped in the production of such enormous works.

For melting iron in the small way, good air furnaces may be used, and also some of the black-lead furnaces, which are blown with bellows, but this is one of the processes that is not successful upon a limited scale.

Considerable judgment is required in proportioning the *charge* for the iron furnace, which always consists of at least two, and often of half-a-dozen kinds of new pig-iron mixed together, and to which new iron a small proportion of old cast-iron is usually added. The kinds and qualities used are greatly influenced by local and other circumstances, so that nothing can be said beyond a few general remarks.

When the principal object is to obtain sound castings with a very smooth face, as for ornamental works not afterwards wrought, the soft kinds of iron containing most carbon, which are most fusible and flow easily, are principally used. But such metal would neither possess sufficient hardness, durability, nor strength, for many of the castings employed in the construction of edifices and machinery.

If the cupola contained a little hard pig-iron, but were in great measure filled with the old cast-iron, which had been repeatedly melted and had become successively harder from the loss of carbon at every fusion; such castings would be brittle, and sometimes so hard as scarcely to admit of being cut; these would be equally unfit for the generality of machinery from the opposite causes.

But the same mixture of iron will be found to differ very much according to the size of the objects in which it is cast. Iron which in a plate one-fourth of an inch thick may be quite brittle and hard, will mostly be of good soft and useful quality in a stout bar or plate of two or three inches thick. Thick castings are necessarily slow in cooling, and are seldom very hard unless intentionally made so.

Between the extremes (say three parts of pig-iron to one of old, or three parts of old iron to one of pig-iron), various qualities may be selected. In castings for machinery the general aim is to obtain a strong, sound, and tough iron. Mixtures of this nature which are used for iron ordnance are called gun-metal amongst the gun-founders.

The fireman, or the individual having the management of the furnace, therefore always employs the scales in mingling the different kinds of iron, according to the magnitude and character of the works to be cast; and until the sorts in use are familiarly known, it is partly a matter of trial, and requires the same attention as the making of alloys, properly so considered.

It is much to be regretted that no protection has yet been found to prevent the conversion of cast-iron into plumbago, or the carburet of iron, from long immersion in sea-water, or the water of copper mines, sewers, and other places. This, which is a most serious inconvenience in dock works, sea walls and mines, arises, says Dr. Michael Faraday, from the circumstance that the protoxide of iron, formed beneath salt water, is soluble, and becomes washed away, thus robbing the original mass of its iron; whereas the peroxide, or ordinary rust formed by exposure to the air, is insoluble, and serves partly as a defence to the metal beneath. When first raised from the sea-water the plumbágo becomes exceedingly hot from the action of the atmosphere. It may be cut with a knife like an ordinary pencil.

When enough iron is melted (the common charge being two and a half to four cwt., but sometimes above twelve tons), the cupola is tapped in front, at a hole close to the bottom, which allows the whole contents to run out, either into ladles or, in very large works, into channels leading directly to the moulds. The furnace is not unfrequently tapped whilst the charge of metal is being melted, and in such cases when the required quantity has been removed into the ladles, the fireman re-stops the tap-hole by a conical plug of clay on the end of a wooden bar. The process is called *botting*, and requires a dexterous hand, or the whole contents of the furnace may escape.

In pouring iron, the means of conveying the melted metal to the flasks differ with the quantity. One man will carry from fifty to seventy pounds in a hand-ladle; three to five men will carry from two to four cwt. in a double hand-ladle, or a *shank;* larger quantities, amounting to sometimes from three to six tons, are carried in the crane-ladle. These all possess one feature in common, namely, their handles or pivots are placed but slightly above the centre of gravity of the ladles,—they may therefore be tilted very readily, as their fluid contents in obeying the law of gravitation are almost neutral in the operation of tilting, which they scarcely assist or retard, unless by mismanagement the ladle is over-filled, and thus rendered top-heavy.

All these ladles are coated with a thin layer of loam, and every time before use they are brushed over with black wash and carefully dried. The hand-ladle has a handle three or four feet long, with a *crutch* or cross piece at the end, which is mostly held in the left hand. Frequently the contents of half-a-dozen or more hand-ladles are poured simultaneously into the same flask. The shank has a single handle on the one side, and one made in two branches at the other, and together they measure six to eight feet in length. The tilting is completely under the command of the one or two men at the double handle.

The crane-ladle is carried from the furnace to the mould by the swinging and traversing motions of the crane, which is similar to those used at the iron forges, etc. (see p. 87), and in very large foundries the plan of the building is divided into imaginary squares, with a crane in the centre of every square, so that the ladle is walked from one to the other, even to the far end of the shop, with great facility and expedition.

The *bail* or handle of the crane-ladle is fixed in its perpendicular position by the *guard*, a simple bolt, which prevents the ladle from being overset by accident until it has reached its destination. Two long handles, terminating in forked branches, are now fitted by their square sockets upon the swivels or pivots of the crane-ladle, and secured by transverse keys,—after which the guard is withdrawn; and then the two men at the ladle, two others at the crane, and one to skim the dross from the lip of the ladle, commonly suffice to manage two or three tons and upwards of fluid iron with great ease and dexterity.

It has added to the pivot of the large crane-ladle a tangent-screw and worm-wheel, by which it may be gradually tilted by one man standing directly in front at any convenient distance; and another man skims the metal by a kind of throttle-valve coated with clay, which sweeps into the lip of the ladle and keeps back the sullage: the axis of the skimmer is continued as a long rod at right angles to the first, and also terminating in a cross. By these arrangements any precise quantity of metal can be delivered, and the risk of accident scarcely exists.

The observations offered on p. 252 respecting the temperature of the metal suitable to different brass works, might be here in a great measure repeated—namely, that the smallest castings require very hot metal, and a gradually lower temperature is more suitable to works progressively heavier, to avoid their becoming sand-burned or rough on the face from the partial destruction of the mould.

When cast-iron is very hot, the metal scintillates most beautifully, far more vividly than a mass of wrought-iron raised above the welding heat; as the metal cools, the sparks become intermittent, and at last the metal remains entirely quiet, excepting a multitude of lines vibrating in all directions, as if the surface were covered with thousands of wire-worms in great activity; this effect lessens until the metal solidifies. The softest iron shows most of this play of lines, or is said to *break* the best.

Iron castings are generally much heavier than those of brass, and the melting heat of the metal being considerably higher, the quantity of gas generated is very much greater; additional care is consequently required to provide for its escape, or the explosions are much more violent. The sand is punctured at many places with a fine wire, before the removal of the patterns; sometimes also more coarsely as soon as the metal has become solidified. The gases issuing from the filled moulds are often lighted, either by the red-hot skimmer, or by a torch of straw with which the moulds are flogged: this lessens the accumulation of gas and the consequent risk of accident.

The pouring of very large objects in *open* moulds, such as plates, beams and girders, is a very beautiful and grand sight. The metal is led from the furnace through a gutter lined with sand, into a large trough or *sow,* the end of which is closed with a *shuttle;* when the sow is full, the shuttle is raised; this allows the metal to flow very quickly into the mould, but enables it to be kept back should it be unnecessarily hot; the castings made in open moulds are generally covered up with sand as soon as the metal is set.

The above, and the casting of smaller objects, such as flat plates in open moulds, may appear amongst the most certain modes of procuring sound castings; but unless the air be well *drawn* from the lower surfaces, they will become honeycombed or full of air-bubbles. This defect is avoided by making the sand-bed sufficiently porous, and pricking it with many holes just below the surface, to serve as horizontal *air*-drains.

A far greater number of works are cast in *close* moulds, and in the horizontal position; the proportionate quantity of metal is carried to them in ladles; skimmers are held to the lips of the moulds at the time of pouring, to keep back all the sullage or dross. The number, position, and height of the runners, are determined by circumstances; generally not less than two apertures are provided, the first for the entry of the metal, the second for the escape of the air, and to allow the metal to *flow through* the mould and carry off the sullage.

Sometimes in heavy castings, in addition to the runners one or more large heads or *feeds* are made at the upper part, to supply fluid iron as the metal shrinks in the act of solidifying; and in some such cases the feed is *pumped*, by moving an iron rod up and down in the feed to keep the metal in motion, so that for a time the metal may freely enter and the air escape, to increase the general soundness of the mass. The pumping should, however, be discontinued the moment the metal begins to stiffen and clog the iron rod, or in other words to crystallize, otherwise mischief instead of benefit will accrue.

Works which are required to be particularly sound, as some cylinders, pipes, shafts and plungers, are cast vertically; the moulds are sunk in the earth, and well rammed to enable them to withstand the great pressure of the fluid column, without becoming strained or bursting open. Such objects are moulded and poured with a head, or an additional portion about one-third the length of the finished casting, as mentioned in respect to brass guns.

In pouring cylinders of tolerably large size, the metal is conducted from the sow through two sunk passages with side branches, entering the mould in the direction of tangents about one-third from the bottom; these keep the metal in circulation, and assist the rise of the sullage; cylinders are also poured through holes in the loam cake, other apertures being always provided in it for the escape of the air. Beneath the iron plate upon which the mould is built, is placed a central mass of hay-bands, in order that the air may have free passage to collect, and then to escape upwards to the surface of the earth, through one, two, three, or more internal or external tubes, as the case may be. The thick cylinders for hydrostatic presses are closed at one end, and those cast with the mouth downwards, require an air tube bent at each end, to lead from the core beneath the casting to the surface of the earth; the gas drives out in a stream, and is immediately ignited like a great torch: others prefer casting them with the mouth upwards, in order that less risk may exist of locking up air within the casting.

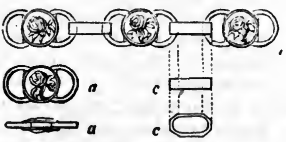
For the very heaviest works the three or four furnaces are usually tapped at the same moment, the stream from every one is conducted through a sand trough, and they all unite in one great trunk leading to the mould.

In pouring some of the largest cylinders, the trough is led entirely round the top of the loam mould, and from the circular channel, sometimes as many as thirty runners, every one of which is stopped by a shovel held by a man or a boy, descend to the mould, and as many air holes are made between the ingates. When the foreman sees that all the furnaces are in full run, and that the channels are well supplied, he gives the word, "*up shovels*;" they rise at the instant, and allow the molten stream to deposit itself in its temporary resting-place.

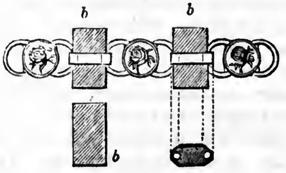
At the time the cylinder is poured, all the precautions explained, p. 266, are necessary to give the mould sufficient strength to resist the pressure of the fluid metal; but as soon as it becomes set, the conditions are altered, and this resistance must be removed from the inner surface, that the cylinder may shrink in cooling without restraint or fracture. Accordingly, after three or four hours' time, all the diametrical iron stays are knocked away by a vertical weight or monkey, and men descend by iron ladders into the cylinder, to break down the brick core. The heat is so terrific, that they can only endure it for a minute or so at a time, but still the precaution is imperative: and even in comparatively small castings of hollow objects, such as cylinders, pans, and boxes, it is desirable to break down the cores, to prevent the castings from *scoring* or breaking.

Although some iron castings employed for bridges, girders, and even for machinery, require the enormous quantities of iron referred to, on the other hand this useful metal is employed for exceedingly light and beautiful castings, abundant examples of which may be seen in the Berlin ornaments and chains. The links of most of the Berlin chains are connected with wrought-iron wire, but Figs. 173 and 174 represent a chain made entirely by the process of casting.

Figs. 173



174.



Its length is 4 feet 10 inches. It consists of about 180 links, and weighs $1\frac{3}{8}$ oz. avoirdupois. It was thus made: The larger links *a a* were first cast separately; a solid model of the chain about 8 inches long, with core prints, as in Fig. 174, was then moulded. The links *a*, previously smoked to prevent the adhesion of the metal, were first laid in the mould, and afterwards the sand cores *b b*, and a separate runner was made to every one of the small links *c c*, so as to unite the whole when poured.

The concluding duty of the iron-founder is to remove the castings from the mould and to break off the runners. After this all the loose sand (which is reserved for making the partings of future moulds) is scraped off with iron shovels and wire scratch brushes, and the seams are smoothed off with chisels and old files.

The skin or crust of a casting made in a sand mould is in general harder than that of a loam casting. This appears to occur from the former being partially chilled by the moisture of the sand. In some cases, as in the teeth of wheels, it is desirable to retain this hard sand coat on account of its greater durability; but when the crust is partially removed from thin or slight works, it constantly happens that they spring or become distorted whilst under the treatment of tools, from the general balance of strength being disturbed by the partial removal of the crust. This gives rise to continual interferences, which come however under the consideration of the mechanician rather than of the founder.

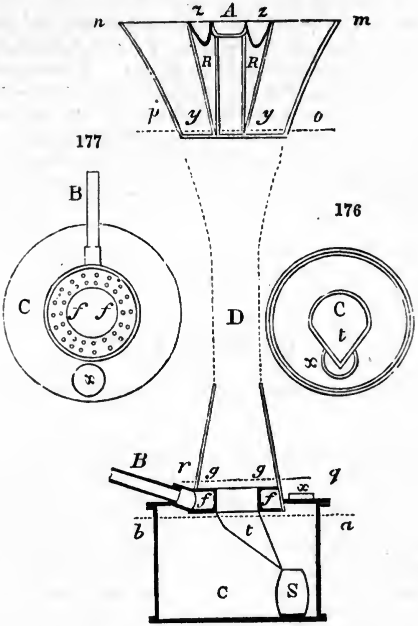
The crust of the casting, which always retains some sand, is very destructive to the tools, unless they can be sent in deep enough to penetrate to the clean metal beneath. When but little is to be removed from the casting, or that they are wrought with expensive tools and circular cutters, it is desirable to *pickle* the works, or to undermine the sand by dissolving a little of the metal with some acid.

Iron castings are pickled with sulphuric acid diluted with about twice as much water. The castings, if small, are immersed in a trough lined with lead; or else the acid is sprinkled over them. In two or three days a thin crust, like an efflorescence, may be washed off with the aid of water and slight friction.

Brass and gun-metal, when pickled, require nitric acid diluted with four to six times as much water, otherwise the rough coat should be removed with an old file or a triangular scraper, but which is less effective than the dilute acid. This acid liquor should be also kept in leaden vessels, or in those of well-glazed earthenware or glass. The yellow brass is much improved by a good but *equal* condensation with the hammer, and in fact to whatever action the metals are subjected, whether natural in the mould, or artificial under the hammer and tools, it is of primary importance that all parts should be treated as nearly alike as possible.

NEW METHOD OF MANUFACTURING DROP SHOT.—David Smith, of the house of Le Roy and Co., 263 Water Street, New York, has invented and put into practice a new mode of manufacturing drop shot. The chief feature of this invention consists in causing the fused metal to fall through an ascending current of air, which shall travel at such a velocity that the dropping metal shall come in contact with more particles of air, in a short tower, than it would in falling through the highest towers before in use. Fig. 175 is a vertical sectional elevation of a sheet metal cylinder, set up as a tower within a building, and may be about 20 inches internal diameter, and 50 feet high or less. This tower, although mentioned in Smith's patent, is now dispensed with in the middle of the height, so that only an open space remains. Fig. 176 is a

Fig. 175.



177

176

plan at the line *a b*; Fig. 177 is a plan at the line *q r*; Fig. 178 is a section at *o p*; and Fig. 179 is a section at *m n*, Fig. 175

Fig. 178.

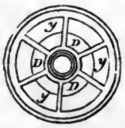
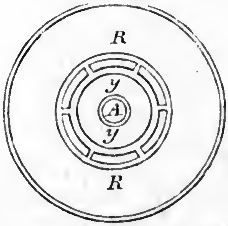


Fig. 179



C is a water-cistern beneath the tower. B is a pipe from the blowing apparatus leading into the annular chamber *f*; the upper surface *g* is perforated as shown in Fig. 177, to dispense the ascending air. The outer side of this annular ring *f* forms the base of a frustum of a cone, forming the tower D, passing the blast through the frame *y y*, Fig. 178; and in Fig. 175 is shown to support a cylindrical standard R, the upper central portion of which receives the pouring pan A. This pan is charged with each separate size of shot. Round the pouring pan A is a circular waste trough *z*. The object of this arrangement is that the fluid metal running through the pouring pan A into the ascending current of air, will be operated upon in the same manner as if it fell through stagnant air of great height The shot falls through the open centre of the ring *f* into the water cistern C, where a shoot *t* carries it into the tub S, which when full may be removed through *x*, an aperture in the cover of the cistern.

CHAPTER XVI.

WORKS IN SHEET METAL, MADE BY JOINING.

ON MALLEABILITY, ETC.; DIVISION OF THE SUBJECT.—The process of casting, which has been recently considered under so great a variety of forms, is one of the most valuable courses of preparation to which the metallic materials are submitted. In the foundry, the metals are made to assume an infinitude of the most arbitrary shapes, but which are in general more or less *thick* or *massive*. It is now proposed to consider a few of the methods and principles of a very extensive and serviceable employment of the malleable metals and alloys, which (excepting iron) are cast into thick slabs or plates, and then laminated into *thin sheets* between cylindrical rollers.

Rollers have been used for a considerable period in the manufacture of sheets of malleable iron, steel, and copper, when in the red-hot state, but most others of the metals and alloys are rolled whilst cold; and which economic application of power often nearly supersedes the use of the hammer, as it performs its function in a more uniform and gradual manner, and at the same time increases to the utmost the hardness, tenacity, elasticity and ductility of such of the metals and alloys as are submitted to this and similar courses of preparation for the arts. These processes of condensation cannot be carried to the extreme without frequent recurrence at proper intervals to the process of annealing; and in rolling the thinnest sheets of metal, several are frequently sent through the rollers at the same time; but, as in the instances of tin-foil, gold and silver leaf, and some others, the hammer is again resorted to after the metals have been rolled as thin as they will economically admit of, in this process of part-manufacture.

None of these preparations of the metals can go on without a material internal change of their substance, to which the celebrated Dr. Dalton thus refers: "Notwithstanding the hardness of solid bodies, or the difficulty of moving the particles one amongst the other, there are several that admit of such motion without fracture, by the application of proper force, especially if assisted by heat. The ductility and malleability of the metals need only be mentioned. It should seem the particles glide along each other's surface, somewhat like a piece of polished iron at the end of a magnet, without being at all weakened in their cohesion."

This gliding amongst the particles of metals is exemplified by the action of thinning them by blows of the hammer; likewise by the actions of laminating rollers and the draw-bench, in which cases the external layers of the metals are retarded or kept back as it were in a wave, whilst the central stream or substance continues its course at a somewhat quicker rate. The necessity for annealing occurs when the compression and sliding have arrived at the limit of cohesion. Beyond this the parts would tear asunder, and produce such of the internal cracks and seams, met with in sheet-metal and wire, as are not due to original flaws and air-bubbles, which have become proportionally elongated in the course of the manufacture of these materials.

A sliding or gliding of a very similar nature occurs also in every case in which the metals are bent; and this differs only in degree, whether we consider it in reference to a massive beam, a permanently flexible spring, a piece of thin sheet-metal, or a film of gold leaf. For instance, the curvature of a cast-iron beam, originally straight, is produced by the stretching or extension of the lower edge, and the shortening or compression of the upper edge, the central line remaining unaltered during the process, except it is bent. In like manner a spring derives its elasticity from the extension and compression of its opposite surfaces at every flexure; and the spring remains permanent, or endures its work without alteration of form, when the bending is not carried beyond its limit of elasticity; but when it is bent beyond a certain point, the spring either retains a permanent *set* or distortion, or it will break. In the same manner the beam, when only bent to the limit of its elasticity, returns to its original form when the load is relieved, and the constant study of the engineer is so to proportion the beam that it may never be required to exceed nor even to arrive at the limit of its elastic force. For those parts of mechanism exposed to sudden shocks and strains, he will employ wrought-iron, the cohesive strength of which is considerably greater than that of cast-iron, although less than that of steel, which is the strongest and most permanently elastic of all metallic substances.

The thin metals also possess some elasticity, but this dies away before they reach the tenuity of leaf gold, in which, however, the bending cannot be accomplished without a similar change in the arrangement of its opposite sides, although the difference is beyond the reach of our physical senses.

If we desire to wrap a piece of gold leaf around a cylinder of half an inch diameter, so small is the resistance that the least puff of breath suffices. A piece of thin tin-foil offers no more resistance than writing-paper. Thin latten-brass, or China tea-lead, is bent more easily than a card; brass and iron the thirtieth or fortieth of an inch thick, could be readily bent with a wooden-mallet; but metal of one-eighth of an inch thick would call for smart blows of a hammer, and in iron and steel the further assistance of heat would be likewise required, because in the last case a very considerable amount of the sliding motion of the metal would be called into play.

For example, the piece of metal ⅛ of an inch thick, was originally flat and of the same size on its opposite surfaces; whereas now, neglecting any alteration of thickness, the inner part would equal the circumference of a circle ½ an inch diameter, and the outer that of a circle of ¾ inch diameter; or it would become 1½ and 2¼ inches long respectively on its opposite surfaces. To produce this change of dimensions would necessarily require far greater force than the bending of the gold leaf, the internal and external measures of which, viewed as a cylinder, could be ascertained alone by calculation, and not by ordinary means. On the other hand, the sliding of the thick sheet of metal would be illustrated most distinctly, if several pieces of writing-paper, equal to the original metal individually in surface and collectively in thickness, were wrapped around the same cylinder. The inner paper would exactly meet, the outer would present an open seam ¾ inch wide. The metals possessed of the malleable property undergo a nearly equal change in their arrangement; but the unmalleable or brittle metals break.

Several of the processes of working the sheet metals are closely analogous to those employed in forging ordinary works in iron and steel,—the difference being mainly such as arise from the thin and thick states of the respective materials, and their relative degrees of rigidity or resistance. The illustrations will be selected indiscriminately from various trades in which the sheet metals are employed. It appears desirable, however, to separate the subject into two principal parts, namely, the formation of objects *some* lines of which are straight, and the formation of objects *no* lines of which are straight.

The first division comprehends all objects with plane, cylindrical or conical surfaces, such as may be produced in pasteboard by cutting out the respective sides, either separately or in clusters, and combining them in part by bending, and in part by cement. Similar works in metal are often produced by the precisely analogous means of cutting, bending, and uniting, and which call for increase of strength in the methods proportioned to the rigidity of the materials.

The second division comprehends all objects with surfaces of double curvature, including spherical, elliptical, parabolical, and arbitrary surfaces, as in reflectors, vases, and a thousand other things, none of which forms can be produced in stiff pasteboard, because this material is incapable of being extended or contracted in different parts in the manner of sheet metal. This is easily shown, by the following case, amongst others.

Terrestrial globes are covered with *thin paper,* upon which the delineation of the surface of the earth has been printed: the paper may be cut into twelve gores, or fish-shaped pieces, all including thirty degrees from pole to pole. A globe is usually covered with 26 pieces of paper, namely, 2 *pole papers,* or circles including 30° around each pole; and 24 *gores* meeting at the equator. Sometimes the gores extend from the pole to the equator; every gore has then a narrow curved central notch extending 30° from the equator. But the same gores cut out of *pasteboard* could not be applied to the surface of a globe, as pasteboard does not admit of that degree of gradual extension and contraction, required for the production of spherical and similar *raised* forms, from pieces originally flat, but will become abruptly bent and torn in the attempt.

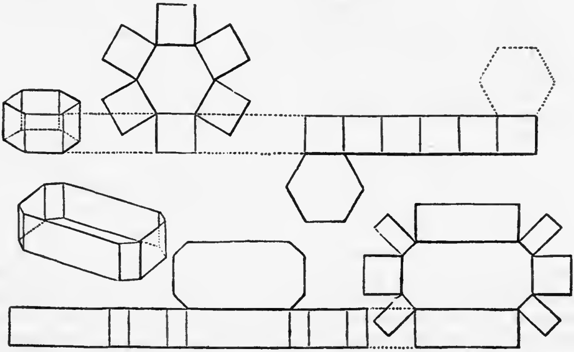
On the contrary, a round disk of metal may be beaten into a hemisphere, or nearly into a sphere; but even thin paper is only possessed of this quality in a very limited degree, for the globe could not be smoothly covered with so few as two, three, or four pieces of the *thinnest* paper without its puckering up, showing that some parts of the material are in excess. The gliding property, or that of malleability and ductility, possessed by the metals, is indispensable to adapt the flat plate to the sphere, by stretching the central portion and gathering up the marginal part, an action that admits of some comparison to the extension or compression of the slides of a telescope, except that the metal becomes *thicker* or *thinner* instead of being duplicated on itself.

WORKS IN SHEET METAL, MADE BY CUTTING, BENDING, AND JOINING.—Every one in early life has made the first step towards the acquirement of the various arts of working in sheet metal, in the simple process of making a box or tray of card; namely, by doubling up the four margins in succession to an equal width, then cutting out the small squares from the angles, and uniting the four sides of the box, either edge to edge, by paste, sealing-wax, or thread, or in similar manners by lapped or folded joints. A different mode is to make the sides of the box as a long strip, folded at all the angles but one; or lastly, the bottom and sides may be cut out entirely detached, and united in various ways.

In the above, and also in the most complicated vessels and solids, it is necessary to depict on the material the exact shape of *every* plane superficies of the work, as in the plans and elevations of the architect; and these may be arranged in any clusters which admit of being folded together, so as to constitute part of the joints by bending the material. Thus, a hexagonal box, Fig. 180, can be made by drawing first the hexagon required for the bottom, as in Fig. 181, and erecting upon every side of the same a parallelogram equal to one of the sides, which in this case are all exactly alike; otherwise the group of sides can be drawn in a line, as in Fig. 182, and bent upon the joints to the required angle, or 120 degrees. Either mode would be less troublesome than cutting out seven detached pieces and uniting them; the addition of one more hexagon, dotted in Fig. 182, would serve to complete the top of the hexagonal prism, by adding a cover or top surface.

The same mode will apply to polygonal figures of all kinds, regular or irregular; thus Fig. 183 would be produced when the group of sides in 184 were bent around the irregular octagonal base; or that the sides of 185 were separately turned up

Figs. 180 181 182

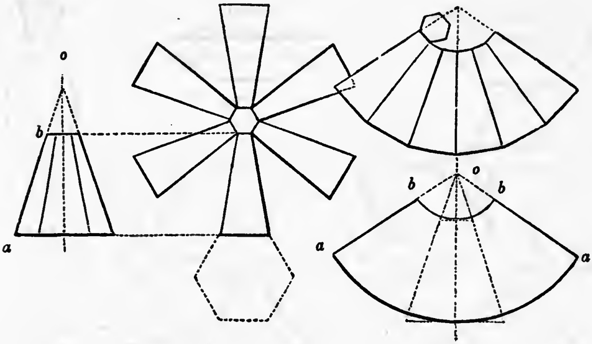


183 184 185.

The cylinder is sometimes compared with a prism of so many sides, that they melt into each other and become a continuous curve; and if the hexagon in Fig. 182 were replaced by a circle, and the group of sides were cut out of equal length with the circumference of that circle, and in width equal to the height of the vessel, any required cylinder could be produced. And in like manner any vessel of elliptical or similar forms, or those with parallel sides and curved ends, and all such combinations, could be made in the manner of Fig. 184 (provided the sides were perpendicular), by cutting out a band equal in length to the collective margin of the figure, as measured by passing a string around it; or the sides might be made of two, or several pieces, if more convenient, or if requisite from their magnitude.

All prismatic vessels require parallelograms to be erected on their respective bases; but pyramids require triangles, and frustums of pyramids require trapezoids, as will be explained by Figs. 187

and 188, which are the forms in which a single piece of metal must be cut, if required to produce Fig. 186. Every one of the group of sides, must be individually equal to one of the sides of the pyramid, whether it be regular or irregular, and 186 being an erect and equilateral figure, all the sides in 187 and 188 are required to be alike, and would be drawn from one templet: an irregular pyramid would require all its superficies to be drawn to their absolute forms and sizes.

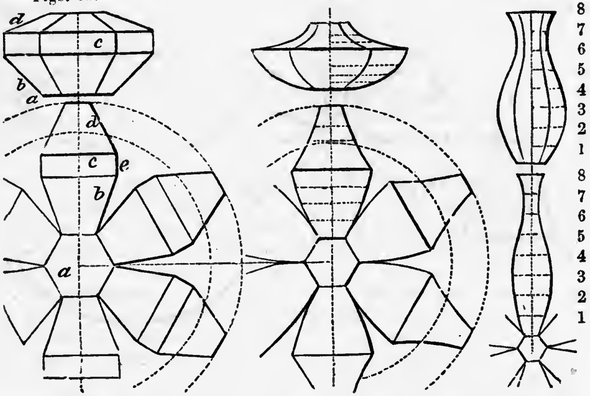

Figs. 186 187 188

189.

The cone is sometimes compared with a pyramid with exceedingly numerous sides (as the cylinder is compared with the prism), and Fig. 189, intended to make a funnel or the frustum of a cone of the same proportions as 186, illustrates this case. The sides of the cone are extended until they meet in the centre *o*, Fig. 186, and then with the slant distances *o a*, and *o b*, the two arcs *a a*, and *b b*, are drawn with the compasses, from the centre *o*; and so much of the arc *a a*, is required as equals the circumference *a*, of the cone: the margins *a b*, *a b*, are drawn as two radii. When the figure is curled up until the radial sides meet, it will exactly equal the cone, and the similitude between Figs. 188 and 189 is most explanatory, as 189 is just equal to the collective group of the sides required to form the pyramid.

It will now be easily seen that mixed polygonal figures, such as Figs. 190, 192, and 194, may be produced in a similar manner, provided their sides are radiated from the square, the hexagonal or other bases, in the manner of Figs. 191, 193, 195, but the sides of the rays not being straight, it is no longer possible to group them by their edges, as in Figs. 182, 184, and 188. The object with plane surfaces, Fig. 190, is only the meeting of two pyramids, at the ends of a prism, and when unfolded, as in Fig. 191, the centre *a*, is equal to the base *a*, of the object; the sides *b*, radiate and expand from the hexagon at the angle of the faces of the inverted or lower pyramid *b*, and their vertical height in the sheet is equal to the slant height in the vessel; the superficies *c*, are those of a prism, therefore they continue parallel, and have the vertical height of the part *c*, of the figure; lastly, the sides *d*, again contract as in the original, and at the same angle as the sides of the six upper faces; in a word, the faces *b*, *c*, *d*, are identical in the vase and in the radiated scheme.

Figs. 190 192 194



191 193 195.

Should the vessels, instead of planes, have surfaces of *single curvature*, as in Figs. 192 and 194, the method is nearly as simple. The object is drawn on paper, and around its margin are marked several distances, either equal or unequal, and horizontal lines or ordinates are drawn from all to the central line. The radiating pieces for constructing the polygonal vases are represented in Figs. 193 and 195, in which the dotted lines are parallel with the sides of the hexagons or the bases, and at a distance equal to those of the steps 1, 2, 3, to 8, around the curve of the intended vases; the lengths of these lines, or ordinates, 1 1, 2 2, 3 3, are in regular hexagonal vessels exactly the same in the radiated plans as in the respective elevations, because the side of the hexagon and the radius of its circumscribing circle are alike.

In all other regular polygonal vessels the new ordinates will be reduced for figures of 8, 10, and 12 sides, in the same proportions as the sides of these respective polygons bear to the radii of their circumscribing circles, and the ordinates for 3, 4, and 5 sided figures will be similarly increased.

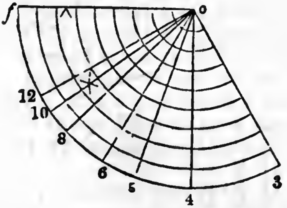
All the above cases could be accurately provided for without any calculation, by the employment of a very simple scale represented in Fig. 196, in which the angle 3 *o f*, shall contain 120 degrees, or the third of a circle; 4 *o f*, 90 degrees, or the fourth; 5 *o f*, 72, or the fifth; 6 *o f*, 60, or the sixth; and 8, 10, and 12, respectively the 8th, 10th, and 12th parts of a circle. The circular arcs are struck from the centre *o*, and may be the 6th, 8th, 10th of an inch, or any small distance apart.

To learn the altered value of any ordinate, as for constructing a vase, like the several figures 190, 192, 194, but with 10 sides; we will suppose the original ordinate to reach from *o* to × on the radius *o f*, the required measure would be the length of the arc × ×, where intersected by the line 10, or that for a decagon; but it would be more convenient to make the angle half the size, as then the new ordinate would be at once bisected, ready for being set off on each side the central line of the radiated plan. When one side had been carefully formed, a curved templet or gage would be made to the shape, by which all the other sides could be drawn.

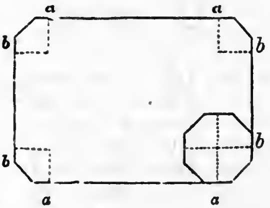
For polygonal vessels with unequal sides, such as Fig. 197, the curvatures of the edges of the rays will be identical, notwithstanding the difference of the sides. For example, the octagon drawn in the one corner shows that the figure resembles the regular octagon as far as the angles are considered; and that the regular octagon may be considered to be cut into four quarters and to be removed to the four corners, by the insertion of the two pairs of intermediate pieces *a a*, and *b b*, which latter would necessarily be parallel. In the like manner a pyramidal vessel built upon the same base, would require equal angles for all its sides.

It would have been easy to have extended these particulars to numerous other figures, such as the regular geometrical solids, oblique solids, and many others, but enough has been advanced to explain the cases of ordinary occurrence, and in the delineations of which, the tinman, coppersmith, and others are very expert.

Figs. 196.



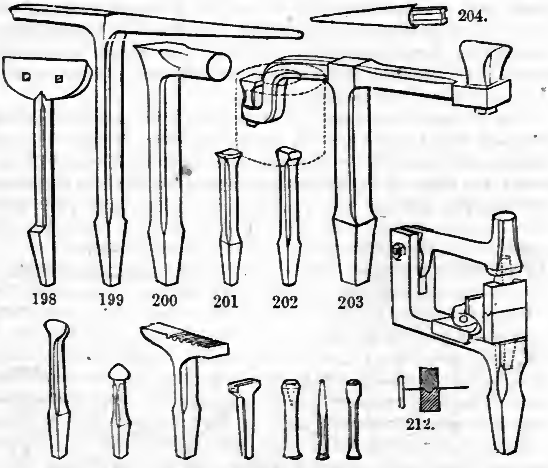
197.



Much of that which has been stated, as it will eventually appear, has been partly advanced in elucidation, on the less apparent methods practised in making similar forms out of flat plates, by the process called *raising;* this is done with the hammer alone, by stretching some parts of the metal and contracting others (the *drawing* and *upsetting* of the blacksmith), a process not required in any of the foregoing figures, the whole of which might be made in pasteboard, a material that, as before observed, does not admit of being raised or bulged into figures of double curvature.

The various works having been drawn upon the sheet of metal, the first process is to cut them out; this is almost always done with the shears; sometimes, however, for thick metal, the cold-chisel and hammer are used, the work being laid upon the bare anvil or upon a cutting-plate, as in forging; occasionally the metal is fixed in the jaws of the tail-vice, and cut off with the cold-chisel applied in contact with the vice; the edge of the chisel is placed nearly parallel with the jaws, which serve as a guide. In some cases very long vices, with a screw at each end, are used in a similar manner, for the thick iron plates employed for boilers; but the shears are the most generally convenient.

Although the tools used in working the sheet-metals are extremely various as regards their sizes and specific forms, they may, with the exception of the shears and soldering-tools, be principally resolved into numerous varieties of hammers, anvils, swage-tools, and punches. Figs. 198 to 212 represent some few of the most common of these tools, which are used alike both in bent and raised works, and their close resemblance to those for ordinary forging in iron and steel will not escape observation. The most remarkable points of difference are in their greater height and length, which enable them to be applied to the interior of large



204.

198 199 200 201 202 203

212.

205 206 207 208 209 210 211

objects, and also in their square shanks, by which they are fixed in holes in the wooden blocks and benches.

The hammers are nearly alike at both ends; many of them have circular faces, either flat or convex; others resemble the straight or cross-panes of ordinary hammers, and are also either flat or convex; and those used in finishing, are exceedingly bright, in order that they may impart their own degree of polish to the work, which process is called *planishing.*

When thin metal is struck between tools both of which are of metal, it is invariably more or less thinned; and should the blows be given partially, such parts will become stretched or cockled, and will distort the general figure. It is therefore usual, whenever admissible, to employ wooden hammers of the forms described, and also wooden blocks or anvils when metal hammers are used; reserving the employment of tools *both* of metal, either for the concluding steps, or for those cases, where from the substance of the metal and the nature of the work, the wooden hammers would be ineffective, or a greater definition of form is required than wooden tools could give.

The anvil used by the coppersmith and similar workmen is usually square, say from six to eight inches on every side; and the smaller anvils, which are called *stakes,* and also *teests,* are of progressively smaller sizes, down to half an inch square, and even less. Some of them have one edge rounded like 201; others have rounded faces as 202 and 203; a few assume the form of a rounded ridge, like Fig. 205; and many have bulbs or buttons, as if turned in the lathe, as in Fig. 206.

The *beak-irons* are also very unlike those used by the smith; they are seldom attached to the anvil, and are often exceedingly long, as in Fig. 199: some few, for more accurate purposes, are turned in the lathe to the conical form, like 204; these are held in the vice, the jaws of which enter grooves in the shank; and mandrels four to six feet long, used for making long pipes, are attached to the bench by long rectangular shanks and staples.

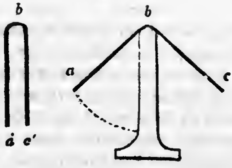
Fig. 198, the *hatchet-stake,* is from two to ten inches wide; it is very much used for bending the thin metals, in the same manner as the rectangular edge of the anvil is used for those which are thicker; a cold-chisel fixed in the vice forms a small hatchet-stake; 207 is the *creasing-tool* for making small beads and tubes; 208 is the *seam-set* for closing the seams prepared on the hatchet-stake; 209 is a hollow and 210 a solid punch; the cutting edge of the former meets at about the angle of fifty degrees, the latter is solid at the end for small holes; both are struck upon a thin plate of lead or solder laid upon the stake; 211 is a *riveting-set* or punch for the heads of rivets; and 212 is the *swage-tool,* a miniature of the tilt-hammer, to which a great variety of top and bottom tools, or *creases,* are added, which greatly economize the labor of making different mouldings and bosses; the stop is used to retain the parallelism of the mouldings with the edge of the metal, and a similar stop is also at times applied to the hatchet-stake, 198.

The sides of the vessels represented in Figs. 180 to 195, if the metal were thin, would be bent to the required angles by laying the metal horizontally upon the hatchet-stake, with the lines exactly over the edge of the same, and blows would be given with the mallet, (or with the hammer for more accurate angles), so as to indent the metal with the edge of the stake; it would be then bent down with the fingers, unless the edge were very narrow as for a seam, when the mallet would be alone used. Thicker metal is more commonly bent over the square edge of the anvil, as in Fig. 59, p. 104, a square set or hammer being held upon its upper surface; and sometimes the work is pinched fast in the vice, and it is bent over with the blows of a flat-ended punch or set, applied close in the angles, and then hammered down square with the hammer; very strong metal is seldom bent in this manner, but the sides of objects are then made separately, and united in some of the ways which will be explained.

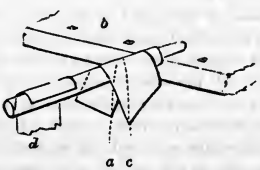
In bending thin metals either to circular or other curves, they are held on the one edge in the hand, and curled on the opposite edge over beak-irons or triblets with the mallet; when the metal is too stubborn or too narrow to be thus held in the hand (as the copper-smith scarcely ever uses tongs, except at the fire), the metal is driven into a concave tool to curl up the edges. For instance, the crease, Fig. 207, is frequently employed for making small tubes or edging; the strip of metal is laid over the appropriate groove, and an iron wire is driven down upon it with the mallet; this bends it like a wagon-tilt; the edges are then folded down upon the wire with the mallet, and it is finished by a top tool, or a punch, Fig. 208, having a groove of similar concavity or radius to that in the crease.

For half-round strips, the crease together with the round wire suffice, or they would be more quickly made in the swage-tool, 212, and which might in this manner be made to produce any particular section or moulding, and that at any distance from the edge by means of the stop or gage. Large tubes are always finished upon beak-irons, such as Fig. 199, the round ends of which serve for curvilinear, and the square ends for rectilinear works.

Figs. 213



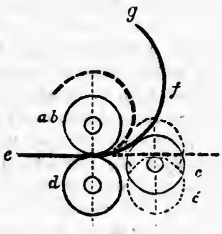
214.



All the sheet metals up to the thickest boiler plate are treated much after the same general methods; large cast-iron moulds of various sweeps are employed, the stout iron being heated to redness, and set into them with set hammers struck with the sledge. When a circular bend is wanted in the centre of a long piece, it is conveniently and accurately done by bending it over a ridge, such as a parallel plate with a rounded edge, or a triblet, the ends of the work serving for a purchase, or as levers. Thus Fig. 213 shows the common mode of bending thick plates to the form of the piece, *a′ b, c′*, for the internal flues of marine boilers; the plate; is heated to redness in the middle, and pressed down until *a c* assume the positions *a′ c′*.

In a similar manner, to bend long strips into easy curves, such as for cylindrical vessels, the tinmen use a *former*, Fig. 214, a cylindrical piece of wood from two to four inches in diameter, and two feet long, turned with a pivot at the one end; the pivot is laid upon the edge of the bench, and the man rests his chest against the other extremity of Fig. 214, to support it in the horizontal position. The tin plate is first stretched in the hands by the two corners, *a*, *c*, and rubbed over the *former* diagonally, to bend it at every part; this is repeated across the other diagonal to flatten the plate; it is afterwards folded round the stick, and rubbed forcibly down with the hand, as at *d*, to give it an easy bend approaching to the required curvature. Should the vessel require a bed at the upper edge, it is usually made by the swage tool, Fig. 212, before the plate is curled up; the work is then much more rigid, and requires additional force to bend it.

Figs. 215



216.

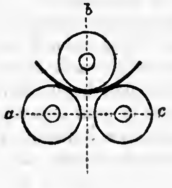


Fig. 215 is intended to explain a very simple and useful machine, first employed by the tinmen for rolling up the cylinders for spring window-blinds, the sides of culinary vessels and similar works, and now also by the boiler-makers, and others for the strongest plates. It has two cylindrical rollers, *a*, *b*, and *d*, which are connected by toothed wheels so as to travel in opposite directions, thus far exactly the same as a pair of laminating rollers for making the sheet metals; the third roller *c*, is just opposite the two, and is free to move on its pivots, as it is unconnected with *a*, *b*, and *d*; and the third roller *c*, is capable of vertical adjustment.

When, therefore, the metal is moved along by the carrying rollers *a b*, and *d*, it strikes against the edge of the bending roller *c*, and is curled up to enable it to pass *over* the same; and as this bending occurs in an equal degree at *every* point of the sheet of metal, it assumes a circular sweep, the radius of which is dependent on the place of *c*. In the central position, the sheet would assume the circle *e, f, g*; and when *c* is more raised as to the upper position, the metal would follow the dotted circle, the radius of which is much less; and when the bending roller *c*, is placed out of level, the works are thrown into the conical form.

Fig. 216 shows the application of the bending rollers to boiler plates; none of the rollers *a, b, c*, touch each other, and *b* is under adjustment for different curvatures.

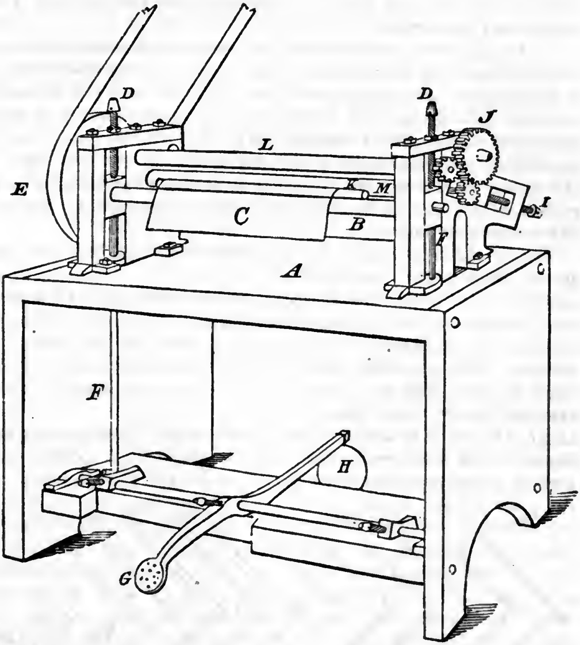
In the last four figures the same principle is employed, namely, the application of three forces as in a lever of the first order, or as in bending or breaking a stick across the knee. The school-boy's problem of "drawing a circle through three given points" is thoroughly exemplified in Fig. 216 and in 215, the one force is the grip of the plate on the line of centres of *a, b, d*; the roller *c*, curls the plate partly around the roller *a*, and the point at which the plate leaves *a b*, may be called the second force, or *b*; the third is the point of contact on *c*.

One of the most useful applications of the *bending* machines, is in *straightening* the metals, which may at first appear to be a misapplication of words, but in truth by the depression of *c*, to about the position of *c′*, it only bends the plate for the moment, just to the *limit* of its elasticity. It results that when it has been passed through twice, or with each side alternately upwards, the elastic reaction just suffices to convert the figure temporarily given, or that of the arc of an *enormous circle*, into a plane or true surface; and as this is done without any blows, which produce partial condensation at such spots, the plate is less subject to after changes than if it had been hammered flat; as by the rollers, *every part* of the plate is bent exactly to the limit of its permanent elasticity. In the tinmen's bending rollers, *d, c*, Fig. 215, are often turned with half round grooves, to receive the thickened edge which contains the wire employed to stiffen the tops of the vessels; sometimes also the rollers are used for preparing the seam to contain the wire. Grooved-rollers (similar to those shown on page 81) are very extensively employed, likewise, in other works in the arts besides the manufacture of iron, to which they are there more immediately referred.

The use of the plain cylindrical roller at *h*, page 81, is so simple as to be immediately apparent; rollers with curvilinear edges, such as at *i*, have been long employed for bending the steel and brass plates for fenders; similar rollers on a smaller scale and of numerous patterns, many of them chased and ornamented, are used in making jewelry, as for producing mouldings, beadings, and matted, checkered or other works

Improved Machine for Rolling up Sheet Metal Pipe.—This Machine is the invention of Mr. William Ostrander, of New York, and is patented by Ostrander and Webster. It consists of three rollers, L M B (the same as ordinary stovepipe rollers); J is an independent pinion which mashes in the smaller ones fastened to the rollers, L and M, which gives them both the same line of motion; the roller, B, is raised or lowered by the treadle, G, in connection with F F, upon which rest the boxes of B. D D are set screws to adjust the height and pressure of B; I is a set screw, which raises or lowers M, which regulates the space between L, M, and B. K is a mandril constructed of wood, upon which the pipe is formed; it is covered with the same material that is desired to be rolled or formed up by the machine, the seam or joint left unsoldered, in which the sheet C is placed, and there held while being formed between the three rollers. E is the pulley and belt; A is the bench; H is the weight which is used only when the machine is worked by a crank. The operation by steam is as follows: the

Fig. 217.



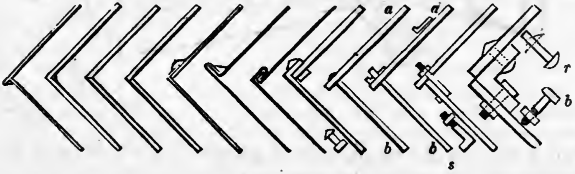
rollers, L and M, are in constant motion, the mandril, K, is taken out from the three rollers, and the edge of the sheet, C, to be formed, is slipped between the mandril and its covering; it is then laid in the space it occupies as represented in the engraving; the foot is applied to G, which raises the roller, B, until the mandril, K, is brought in contact with L and M; the three rollers, together with the mandril, are revolved, and the sheet C, is drawn in and formed closely about the mandril; the foot is then removed from G, which allows the roller, B, to drop down, and permits the mandril, K, to be taken out and the newly-formed pipe to be slipped off, whose edge, in nearly every instance, will be "laid" close enough for soldering: should the metal be so stiff and hard as to prevent its edge being laid in the first rolling, it will be perfectly so when rolled a second time on the bare wooden mandril. This roller is capable of forming from three to five thousand feet of pipe per 10 hours, in 20 inch joints, by a boy. It does not require the use of mallets to lay the edges. It can be made as long as any sheet of metal requires, inasmuch as the rollers can be braced from the outside without being interfered with. It can be used in the old way for stovepipe, etc., by removing the pinion, J, up out of the way, and bringing the rollers, L M, close together.

This machine is now in practical use by Woolcock and Ostrander, No. 57 Ann Street, N. Y., who make large quantities of speaking and other pipes with it.

ANGLE AND SURFACE JOINTS.—The next steps to be considered, appear to be the methods of uniting the edges of the vessels after they have been cut and bent to meet in angles, curves, or plane surfaces. The principal modes of accomplishing this are represented in Figs. 218 to 240, which are grouped together for the convenience of comparison.

Figs. 218 and 219 are for the thinnest metals, such as tin, which require a film of soft-solder on one or other side. Sheet-lead is similarly joined, and both are usually soldered from within.

Figs. 218 219 220 221 222 223 224 225 226 227 228 229.



Figs. 220 and 221 are the *mitre* and *butt*-joints used for thicker metals with hard solders. Sometimes 221 is dovetailed together, the edges being filled to correspond coarsely; they are also partly riveted before being soldered from within. These joints are very weak when united with soft solder.

Fig. 222 is the *lap*-joint; the metal is creased over the hatchet stake. Tin-plate requires an external layer of solder; spelter solder runs through the crevice, and need not project.

Fig. 223 is folded by means of the hatchet-stake, the two are then hammered together, but require a film of solder to prevent them from sliding asunder.

Fig. 224 is the *folded angle-joint,* used for fire-proof deed boxes, and other strong works in which solder would be inadmissible. It is common in tin and copper works, but less so in iron and zinc, which do not bend so readily.

Fig. 225 is a *riveted* joint, which is very commonly used in strong iron plate and copper works, as in boilers, etc.; generally a rivet is inserted at each end, then the other holes are punched through the two thicknesses with the punch 210, on a block of lead. The head of the rivet is put within, the metal is flattened around it, by placing the small hole of the riveting set 211 over the pin of the rivet, and giving a blow; the rivet is then clinched, and it is finished to a circular form by the concave hollow in another riveting set. When the works cannot be laid upon an anvil or stake, a heavy hammer is held against the head of the rivet to receive the blow; in larger works the holes are all punched before riveting, and the heads are left from the hammer.

Figs. 226 and 227; the plates *a a,* are punched with long mortises, then *b b,* are formed into tenons, which are inserted and riveted; but in 227 the tenons have transverse keys to enable the parts to be separated.

Fig. 228, the one plate makes a butt-joint with the other, and is fixed by **L** formed rivets or screw-bolts *s*; the short ends are generally riveted to the one plate, even when screwed nuts are used. This mode is very common for cast-iron plates, as in stove work.

Fig. 229 is the mode universally adopted for very strong vessels, as for steam-boilers, in which the detached wrought-iron plates are connected by angle-iron, rolled expressly for the purpose, (see *f*, Fig. 27, p. 81). The rivet holes are punched in all the four edges, by powerful punching engines furnished with traveling stages and racks, which insure the holes being in line, and equidistant, so that the several parts when brought together may exactly correspond. The rivet *r*, which may be compared to a short stout nail is made red-hot, and handed by a boy to the man within the boiler, who drives it in the hole; he then holds a heavy hammer against its head, whilst two men quickly clench or burr it up from without: between the hammering, and the contracting of the metal in cooling, the edges are brought together into most intimate and powerful contact. Bolts and nuts *b*, may be used to allow the removal of any part, as the man-hole of the boiler.

For the curved parts of the boilers, the angle iron is bent into corresponding sweeps, and for the corners of square boilers, the angle iron is welded together to form the three tails for the respective angles or edges which constitute the solid corner: this when well done, is no mean specimen of welding.

It frequently happens that several plates are required to be joined together to extend their dimensions, or that the edges of one plate are united as in forming a tube; these joints are arranged in the figures 230 to 240, similarly to those for angles previously shown, from which they differ in several respects.

Fig. 230 is the *lap*-joint, employed with solder for tin plates, sheet lead, etc., and for tubes bent up in these materials.

Fig. 231, the *butt*-joint, is used for plates and small tubes of the various metals; united with the hard solders they are moderately strong, but with tin solder the junctions are very weak from the limited measures of the surfaces.

Figs.

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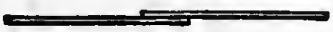

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Fig. 232 is the *cramp*-joint: the edges are thinned with the hammer, the one is left plain, the other is notched obliquely with shears, from one-eighth to three-eighths of an inch deep; each alternate cramp is bent up, the others down for the insertion of the plain edge; they are next hammered together and brazed, after which they may be made nearly flat by the hammer, and quite so by the file. The cramp-joint is used for thin works requiring *strength*, and amongst numerous others for the parts of musical instruments. Sometimes also 230 is feather-edged; this improves it, but it is still inferior to the cramp-joint in strength.

Fig. 233 is the lap-joint without solder, for tin, copper, iron, etc.; it is set down flat with a seam-set, Fig. 209, and used for smoke-pipes, and numerous works not required to be steam or water-tight.

Fig. 234 is used for zinc works and others; it saves the double bend of 233.

Fig. 235 is the *roll-joint* employed for lead roofs, the metal is folded over a wooden rib, and requires no solder; the water will not pass through this joint until it exceeds the elevation of the wood. The roll-joint is less bent when used for zinc, as that material is rather brittle; the laps merely extend up the straight sides of the wooden roll, and their edges are covered by a half-round strip of zinc nailed to the wood.

Fig. 236 is a hollow crease used for vessels and chambers for making sulphuric acid; the metal is scraped perfectly clean, filled with lead heated nearly to redness, and the whole are united by *burning*, with an iron heated also to redness. Solder which contains *tin* would be acted upon by the acid. whereas until the acid is very concentrated, the lead is not injured; this method is however now superseded by the mode of autogenous soldering. The concentration of sulphuric acid and some other chemical preparations, is performed in vessels made of platinum.

Figs. 237 and 238 are very commonly employed either with rivets or screw-bolts; the latter joint is common in boilers, both of copper and iron, and also in tubes; copper works are frequently tinned all over the rivets and joints, to stop any minute fissures. Fig. 237 is the flange-joint for pipes.

Fig. 239, with rivets, is the common mode of uniting plates of marine boilers, and other works required to be flush externally.

Fig. 240 is a similar mode, used of late years for constructing the largest iron steam-ships; the ribs of the vessels are made of **T** iron, varying from about four to eight inches wide, which is bent to the curve by the employment of very large surface-plates cast full of holes, upon which the wood model of the rib is laid down, and a chalk mark is made around its edge. Dogs or pins are wedged at short intervals in all those holes which intersect the curve; the rib, heated to redness in a reverberatory furnace, is wedged fast at one end, and bent round the pins by sets and sledge-hammers, and as it grows or yields to the curve, every part is secured by wedges until the whole is completed.

The following method of constructing metallic boats, invented by Mr. Francis, of the Novelty Works, New York, is taken from Harper's New Monthly Magazine.

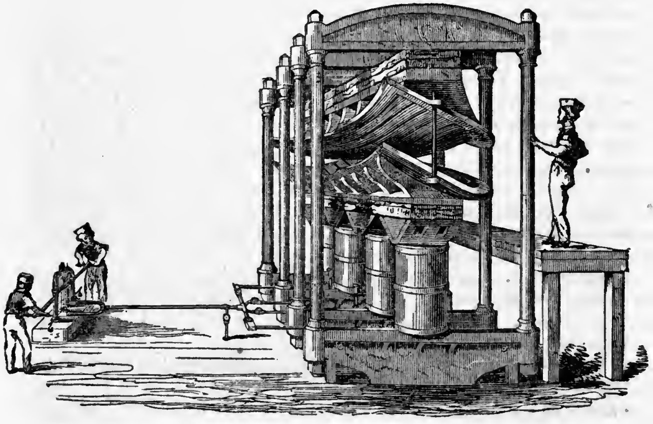
In many cases of distress and disaster befalling ships on the coast, it is not necessary to use the car, the state of the sea being such that it is possible to go out in a boat, to furnish the necessary succor. The boats, however, which are destined to this service must be of a peculiar construction, for no ordinary boat can live a moment in the surf which rolls in, in storms, upon shelving or rocky shores. A great many different modes have been adopted for the construction of surf-boats, each liable to its own peculiar objections. The principle on which Mr. Francis relies in his life and surf-boats, is to give them an extreme lightness and buoyancy, so as to keep them always upon the *top* of the sea. Formerly it was expected that a boat in such a service, must necessarily take in great quantities of water, and the object of all the contrivances for securing its safety, was to expel the water after it was admitted. In the plan now adopted the design is to exclude the water altogether, by making the structure so light and forming it on such a model that it shall always rise above the wave, and thus glide safely over it. This result is obtained partly by means of the model of the boat, and partly by the lightness of the material of which it is composed. The reader may perhaps be surprised to hear, after this, that the material is *iron.*

Iron—or copper, which in this respect possesses the same properties as iron—though *absolutely* heavier than wood, is, in fact, much lighter as a material for the construction of receptacles of all kinds.

on account of its great strength and tenacity, which allows of its being used in plates so thin that the quantity of the material employed is diminished much more than the specific gravity is increased by using the metal. There has been, however, hitherto a great practical difficulty in the way of using iron for such a purpose, namely, that of giving to these metal plates a sufficient stiffness. A sheet of tin, for example, though stronger than a board, that is, requiring a greater force to break or rupture it, is still very *flexible*, while the board is stiff. In other words, in the case of a thin plate of metal, the parts yield readily to any *slight* force, so far as to bend under the pressure, but it requires a very great force to separate them entirely; whereas in the case of wood, the slight force is at first resisted, but on a moderate increase of it, the structure breaks down altogether. The great thing to be desired therefore, in a material for the construction of boats, is to secure the stiffness of wood in conjunction with the thinness and tenacity of iron. This object is attained in the manufacture of Mr. Francis's boats by *plaiting* or *corrugating* the sheets of metal of which the sides of the boat are to be made. A familiar illustration of the principle on which this stiffening is effected is furnished by the common table waiter, which is made usually, of a thin plate of tinned iron, stiffened by being turned up at the edges all around—the upturned part serving also at the same time the purpose of forming a margin.

The platings or corrugations of the metal in these iron boats pass along the sheets, in lines, instead of being, as in the case of the waiter, confined to the margin. The idea of thus corrugating or

Fig. 241.



plaiting the metal was a very simple one; the main difficulty in the invention came, after getting the idea, in devising the ways and means by which such a corrugation could be made. It is a curious circumstance in the history of modern inventions that it often requires much more ingenuity and effort to contrive a way to *make* the article when invented, than it did to invent the article itself. It was, for instance, much easier, doubtless, to invent pins, than to invent the machinery for *making* pins.

The machine for making the corrugations in the sides of these metallic boats consists of a hydraulic press and a set of enormous dies. These dies are grooved to fit each other, and shut together; and the plate of iron which is to be corrugated being placed between them, is pressed into the requisite form, with all the force of the hydraulic piston—the greatest force, altogether, that is ever employed in the service of man.

The machinery referred to will be easily understood by the above engraving. On the left are the pumps, worked, as represented in the engraving, by two men, though four or more are often required. By alternately raising and depressing the break or handle, they work two small but very solid pistons which play within cylinders of corresponding bore, in the manner of any common forcing-pump.

By means of these pistons the water is driven in small quantities, but with prodigious force, along through the horizontal tube seen passing across, in the middle of the picture, from the forcing-pump to the great cylinders on the right hand. Here the water presses upward upon the under surface of pistons working within the great cylinders, with a force proportional to the ratio of those pistons compared with that of one of the pistons in the pump. Now the piston in the force-pump is about one inch in diameter. Those in the great cylinders are about twelve inches in diameter, and as there are four of the great cylinders the ratio is as 1 to 576. Areas being as the squares of homologous lines, the ratio would be, mathematically expressed, $1^2 : 4 \times 12^2 = 1 : 4 \times 144 = 1 : 576$. This is a great multiplication, and it is found that the force which the men can exert upon the piston within the small cylinder, by the aid of the long lever with which they work it, is so great, that when multiplied by 576, as it is by being expanded over the surface of the large pistons, an upward pressure results of about eight hundred tons. This is a force ten times as great in *intensity* as that exerted by steam in the most powerful sea-going engines. It would be sufficient to lift a block of granite five or six feet square at the base, and as high as the Bunker Hill Monument.

Superior, however, as this force is, in one point of view, to that of steam, it is very inferior to it in other respects. It is great, so to speak, in *intensity*, but it is very small in *extent* and *amount*. It is capable indeed of lifting a very great weight, but it can raise it only an exceedingly little way. Were the force of such an engine to be brought into action beneath such a block of granite as we have described, the enormous burden would rise, but it would rise by a motion almost inconceivably slow, and after going up perhaps as high as the thickness of a sheet of paper, the force would be spent, and no further effect would be produced without a new exertion of the motive power. In other words, the whole amount of the force of a hydraulic engine, vastly concentrated as it is, and irresistible, within the narrow limits within which it works, is but the force of four or five men after all; while the power of the engines of a Collins' steamer is equal to that of four or five thousand men. The steam-engine can do an *abundance* of *great* work; while, on the other hand, what the hydraulic press can do is very little in *amount*, and only great in view of its extremely concentrated intensity.

Hydraulic presses, before the introduction of D. Dick's anti-friction press, were often used, in such cases and for such purposes as require a great force within very narrow limits. The indentations made by the type in printing the pages of Harper's Magazine, are taken out, and the sheet rendered smooth again, by hydraulic presses exerting a force of *twelve* hundred tons. This would make it necessary for us to carry up our imaginary block of granite *a hundred feet higher* than the Bunker Hill Monument to get a load for them.

There are nine of these presses in the printing-rooms of Harper and Brothers, all constantly employed in smoothing sheets of paper after the printing. The sheets of paper to be pressed are placed between sheets of very smooth and thin, but *hard* pasteboard, until a pile is made several feet high, and containing sometimes two thousand sheets of paper, and then the hydraulic pressure is applied. These presses cost, each, from twelve to fifteen hundred dollars.

In Mr. Francis's presses, the dies between which the sheet of iron or copper are pressed, are directly above the four cylinders which we have described, as will be seen by referring once more to the drawing. The upper die is fixed—being firmly attached to the top of the frame, and held securely down by the rows of iron pillars on the two sides, and by the massive iron caps, called platens, which may be seen passing across at the top, from pillar to pillar. These caps are held by large iron nuts which are screwed down over the ends of the pillars above. The lower die is movable. It is attached by massive iron work to the ends of the piston-rods, and of course it rises when the pistons are driven upward by the pressure of the water. The plate of metal, when the dies approach each other, is bent and drawn into the intended shape by the force of the pressure, receiving not only the corrugations which are designed to stiffen it, but also the general shaping necessary, in respect to swell and curvature, to give it the proper form for the side, or the portion of a side, of a boat.

It is obviously necessary that the dies should fit each other in a very accurate manner, so as to compress the iron equally in every part. To make them fit thus exactly, massive as they are in magnitude. and irregular in form, is a work of immense labor. They are first cast as nearly as possible to the form intended, but as such castings always warp more or less in cooling, there is a great deal of fitting afterwards required, to make them come rightly together. This could easily be done by machinery if the surfaces were square or cylindrical, or of any other mathematical form to which the working of machinery could be adapted. But the curved and winding surfaces which form the hull of a boat or vessel, smooth and flowing as they are, and controlled, too, by established and well-known laws, bid defiance to all the attempts of mere mechanical motion to follow them. The superfluous iron, therefore, of these dies, must all be cut away by chisels driven by a hammer held in the hand; and so great is the labor required to fit and smooth and polish them, that a pair of them costs several thousand dollars before they are completed and ready to fulfil their function.

The superiority of metallic boats whether of copper or iron, made in the manner above described, over those of any other construction, is growing every year more and more apparent. They are more light and more easily managed, they require far less repair from year to year, and are very much longer lived. When iron is used for this purpose, a preparation is employed that is called *galvanized* iron. This manufacture consists of plates of iron of the requisite thickness, coated on each side, first with tin, and then with zinc; the tin being used simply as a solder, to unite the other metals. The plate presents, therefore, to the water, only a surface of *zinc*, which resists all action, so that the boats thus made are subject to no species of decay. They can be injured or destroyed only by violence, and even violence acts at a very great disadvantage in attacking them. The stroke of a shot, or a concussion of any kind that would split or shiver a wooden boat so as to damage it past repair, would only indent, or at most perforate, an iron one. And a perforation even, when made, is very easily repaired, even by the navigators themselves, under circumstances however unfavorable. With a smooth and heavy stone placed upon the outside for an anvil, and another used on the inside as a hammer, the protrusion is easily beaten down, the opening is closed, the continuity of surface is restored, and the damaged boat becomes, excepting, perhaps, in the imagination of the navigator, as good once more as ever.

Metallic boats of this character were employed by the party under Lieut. Lynch, of the U. S. Navy, now a traitor to his country, in making their voyage to the Dead Sea. The navigation of the stream was difficult and perilous in the highest degree. The boats were subject to the severest possible tests and trials. They were impelled against rocks, they were dragged over shoals, they were swept down cataracts and cascades. There was one *wooden* boat in the little squadron; but this was soon so strained and battered that it could no longer be kept afloat, and it was abandoned. The metallic boats, however, lived through the whole, and finally floated in peace on the heavy waters of the Dead Sea, in nearly as good a condition as when they first came from Mr. Francis's dies.

The seams of a metallic boat will never open by exposure to the sun and rain, when lying long upon the deck of a ship, or hauled up upon a shore. Nor will such boats burn. If a ship take fire at sea, the boats if of iron, can never be injured by the conflagation. Nor can they be sunk. For they are provided with air chambers in various parts, each separate from the others, so that if the boat were bruised and jammed by violent concussions, up to her utmost capacity of receiving injury, the shapeless mass would still float upon the sea, and hold up with unconquerable buoyancy as many as could cling to her.

The principle on which these life-boats are made is found equally advantageous in its application to boats intended for other purposes. For a gentleman's pleasure-grounds, for example, how great the convenience of having a boat which is always stanch and tight—which no exposure to the sun can make leaky, which no wet can rot, and no neglect impair. And so in all other cases where boats are required for situations or used where they will be exposed to hard usage of any kind, whether from natural causes or the neglect or inattention of those in charge of them. this material seems far superior to any other.

CHAPTER XVII.

WORKS IN SHEET METAL, MADE BY RAISING; AND THE FLATTENING OF THIN PLATES OF METAL.

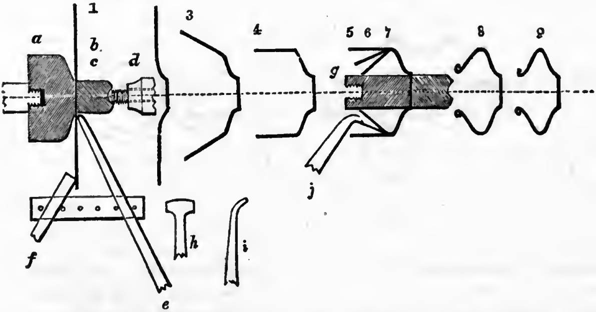
Circular Works Spun in the Lathe.—The former examples have only called into action so small an amount of the malleable or gliding property of the metals, that all the forms referred to could be produced in pasteboard, a material nearly incapable of extension or compression. The raised works now to be considered, call for much of this gliding or malleable action which may be compared with the plastic nature of clay as an opposite extreme. Thus a lump of clay is thrown on the potter's horizontal lathe, a touch of the fingers shapes it into a solid round lump, the potter thrusts his clenched hand into the centre, and it raises in form something like a basin; by applying the other hand outside to prevent the material from spreading, it will rise as an irregular hollow cylinder, and a gentle pressure from without, and a sustaining pressure from within, will gather up or contract the clay into the narrow mouth suited to a bottle, and which is made somewhat in this manner almost by the fingers alone.

A similar and parallel application, due to the *malleability* of the metals, and one which also requires the turning-lathe, is very extensively practised: namely, the art of "*spinning or burnishing to form*" thin circular works in several of the ductile metals and alloys, as for teapots, plated candlesticks, the covers of cups and vessels, the bell mouths of musical instruments, and numerous other objects required in great numbers, and of *thin* metals. Plated candlesticks are thus formed of several parts soldered together, or retained in position by the fittings of their edges, the whole being strengthened by a central wire, and by filling the entire cavity with a resinous cement. The Figs. 242 and 243 are intended to show the mode of spinning the body of a Britannia metal teapot from one unperforated disk of metal.

The wooden mould or chuck *a*, Fig. 242, is turned to the form of the lower part of the teapot, and a disk of metal *b*, is pinched tight between the flat surfaces of *a* and *c*, by the fixed centre screw *d* of the lathe, so that *a*, *b*, and *c*, revolve with the mandrel: and now by means of a burnisher *e*, which is rested against a pin in the lathe rest, as a fulcrum, and applied near the centre of the metal; and a wooden stick *f*, held on the opposite side to support the edge, the metal is rapidly bent or swaged through the successive forms 1, 2, 3, to 4, so as to fit close against the curved face of the block and to extend up its cylindrical edge.

The mould *a* is next replaced by *g*, Fig. 243, a plain cylindrical block of the diameter of the intended aperture. One of various forms of burnishers (*h*, *i*, some bent, others T form, and so on, the surfaces of which are slightly greased) are used, together with the hooked stick or rubber *j*, first to force the metal inwards, as shown at 5, 6, 7, and also to curl up the hollow bead which stiffens the mouth of the finished vessel, 9. Sometimes the moulds are made of the entire form of the inside of the work, but of several pieces, each smaller than the mouth; so that when the central block is first removed the others may be successively taken out of the finished vessel, like the parts of a hat-block or of a boot-tree.

Figs. 242 243.



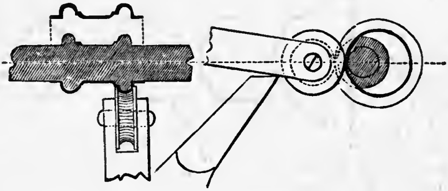
It is of importance during the whole process to keep the edge exactly concentric and free from the slightest notches, for which purpose it is occasionally touched with the turning tool during the process of spinning. The operation is very pretty and expeditious, and resembles the manipulation of the potter who forms a bottle or vase with a close mouth in a manner completely analogous, although the yielding nature of his material requires the fingers alone, and neither the mould, stick, nor burnisher.

Fig. 244.

The lenses of optical instruments are often fixed in their cells by similar means; *a*, Fig. 244, shows in excess the form of the metal when turned, and *b* the thin edge when curled over the glass by means of a burnisher applied whilst the ring revolves in the lathe.

Much of the cheap Birmingham jewelry is also spun in the lathe, but in a different manner. For instance, to make such an object as the ring represented black in Fig. 245, a steel mandrel is turned upon a lathe to the same form as the ring, but less in diameter. The metal is prepared as a thin tube, it is soldered and cut into short pieces, each to serve for one ring, and these are spun into shape almost in an instant, between the arbor and the milling tool or roller, as seen in the front view, Fig. 246. It is clear that unless the arbor were smaller than the work, the latter from being undercut could not be released. Sometimes only one broad milling tool is employed, at other times two or more narrow ones. This process is most distinctly a modification of two rollers, which travel by surface-contact instead of by toothed wheels, and differs but little from the embossing or matting rollers employed by jewelers and others for long strips instead of rings. Extending the same application to the milling-tool upon a solid body, such as milled nut, the interior metal supplies the resistance given by the arbor, in the last figure.

Fig. 245 246.



WORKS RAISED BY THE HAMMER.—In raising the metals by the hammer, we have to produce similar effects to those in the spinning process; not however by the gradual and continued pressure of a burnisher, on one *circle* at a time, but by *circles of blows*, applied much in the same order, and as far as possible with the same regularity of effect.

The art consists, therefore, of two principal points. First, so to proportion the original size and thickness of the metal disks that it shall exactly suffice for the production of the required object—neither with excess of metal, which would have to be cut off with shears and thrown aside, wasting a part both of the metal and labor, nor with deficiency of metal, which would be nearly a total loss. Secondly, that the work shall be produced with the *smallest possible number of blows,* which sometimes tend to thin, and at other times to thicken the metal; whereas the finished works should present a uniform thickness throughout, and which is, in many cases, just that of the original metal when in the sheet.

For instance, a hollow ball six inches diameter is made of two circular pieces of copper, each seven and a half inches diameter. Now, calling the original circumference of the disk twenty-two and a half inches, this line eventually becomes contracted to eighteen inches, or the circumference of the ball,—although, at the same time, the original diameter of the disk, namely, a line of seven and a half inches, has become stretched to that of nine inches or the girth of the hemisphere.

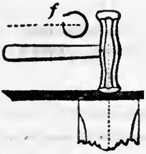
This double change of dimensions, accomplished by the malleability or gliding of the metal, occurs in a still more striking manner in the illustration of spinning the tea-pot, in which the disk, originally about one foot diameter, becomes contracted to two or three inches only at the mouth. The precise nature of the change is seen on inspecting Figs. 190 and 192 in connection with the radiated pieces 191 and 193 required for the formation of such polygonal vases, when bent up and soldered at their edges.

The same vases wrought to the circular figure from round plates, either by spinning or by the hammer, would not require disks of metal so large as the boundary circles in Figs. 191 and 193; as the pieces between the rays would be entirely in excess, they would cause the vessels to rise beyond their intended sizes, and would require to be pared off. But the original disks for making the vases should be of about the diameters of the inner circles, as then the *pieces d,* beyond the inner circles, would be nearly equal to the *spaces e,* within these circles, which would leave the vessel of uniform thickness throughout, and without deficiency or excess of metal, supposing the conversion to be performed with mathematical truth.

The first and most important notion to be conveyed in reference to raising works with the hammer, is the difference between those which may be called *opposed,* or *solid* blows, that have the effect of stretching or thinning the metal; and those which may be called *unopposed,* or *hollow* blows, that have less effect in thinning than in bending the metal; in fact, it often becomes thickened by hollow blows, as will be shown.

For example, the hammer in Fig. 247 is directly opposed to the face of the anvil, or meets it face to face, and would be said to give a solid blow; one which would not jar the hand grasping the plate, were the latter ever so thick or rigid: and this blow would thin the metal by its sudden compression between two hard surfaces, the face of the hammer being represented at *f*.

Figs. 247



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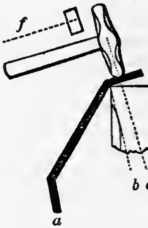
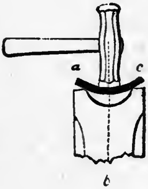


249.

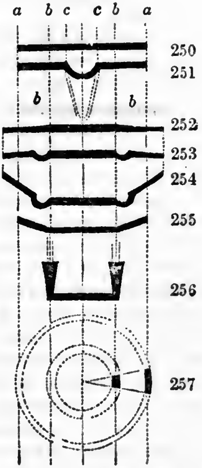


The hammer in Fig. 248 is not directly opposed to the anvil, or rather to that point of it which sustains the work, consequently this would be called a hollow blow, one which would jar the hand were the plate thick and rigid; and it would bend the plate partly to the form of the supporting edge, by a similar exhibition of the forces *a*, *b*, *c*, referred to in the diagrams, Figs. 213 to 216; not, however, by the quiet pressure therein employed, but by impact, or by driving blows. The hand situated at *a*, Fig. 248, would be insufficient to withstand the blows of the hammer at *c*, but for the great distance of *a b*, compared with *b c*, and the thin flexible nature of the material.

From these reasons the coppersmith and others never require tongs for holding the metal, the same as the blacksmith, except at the fire, as in annealing and soldering; in hammering thin works, a constant change of position is required, and which can be in no way so readily accomplished as by the exquisite mechanism given us by nature, the unassisted hand. When, however, the works are too rigid or too small to be thus held, the anvil is made to supply the two points *a*, *c*, as in Fig. 249, and the blow of the hammer is directed between them.

We will now trace the effects of *solid* and *hollow* blows given partially on a disk of metal *a a*, Fig. 250, supposed to be twelve inches diameter; first within a central circle *c c*, of three inches diameter; and then around the margin *a b*, to the width of three inches, leaving the other portions untouched in each case; the thickness of the metal is greatly exaggerated to facilitate the explanation.

The *solid* blows within the circle *c c*, would thin and stretch that part of the metal, and make it of greater superficial extent; but the broad band of metal *a c*, would prevent it from expanding beyond its original diameter, and therefore the blows would make a central concavity, as in a cymbal, or like Fig. 251. And the more blows that were given; either inside the bulge upon a flat anvil, or outside the bulge upon an anvil or head of a globular form, the more would the metal be raised, from its being thinned and extended; and thus it might be thrown into the shape of a lofty cone or sugar-loaf.



The *hollow* blows given within the same limited circle would also stretch the metal and drive it into the hollow tools employed, such as Fig. 249; thus producing the same effect as in 251, but by stretching the metal as we should the parchment of a drum, by the pressure of the hand in the centre, or by a blow of the drum-stick.

The *solid* blows around the three-inch margin, would thin the metal and cause it to increase externally in diameter; but the plate would only continue flat, as in Fig. 252, if every part of the ring were stretched proportionally to its increased distance from its first position. Were the inner edge towards *b*, thinned beyond its due amount, its expansion, if resisted by the strength of the outer ring *a*, would throw part of the work into a curve, and depress the metal, not as in the cymbal, but in the form of a gutter as in Fig. 253; it would however more probably happen, that the inner edge alone of the marginal ring would be expanded, leaving the outer edge undisturbed, and producing the coned figure, 254.

The *hollow* blows given around the edge, as in Fig. 248, would have the effect of curling up or raising the edge, first as a saucer 255, and then into a cylindrical form 256; provided that by the skilful management of the hammering, the metal could be made to slide upon itself without puckering, so as to contract the original boundary circle of the disk or twelve inches, into six inches, or the measure of the edge of the cylinder resulting from the drawing in of the three-inch margin.

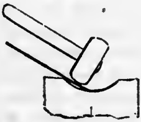
In this process the metal would become proportionally thickened at the upper edge, because each little piece of the great circle, Fig. 257, when compressed into a circle of half the diameter, would only occupy half its original length, as it could not be altogether lost; and the metal would therefore increase in thickness in a proportional degree. The remainder of the circle serves for the time as effectually to compress the metal in the direction of the tangent, as if the radii were the sides of an unyielding angular groove dotted in Fig. 257: this contraction produces in fact the same effect as the *jumping* or *upsetting* by endlong blows in smith's-work.

Theoretically, the thickness of the upper edge of the cylinder would be doubled, and the lower edge would retain its original thickness, as in 256; whereas in extending the margin of the disk by *solid* blows as in Fig. 252, the thinned edge would be found to taper away, also in a straight line, from the full thickness even to a feather edge if sufficiently continued, but neither of these cases would be admissible, as the general object is to retain a uniform substance.

In equalizing the thickness of the cylindrical tube, Fig. 256, the solid blows would thin the metal, but at the same time throw it into a larger circle, it would then require to be again driven inwards, which would again slightly thicken it. So that in reducing the metal to uniformity, two distinct and opposite actions are going on; and upon the due alteration, combination, or proportioning of which, will entirely depend the ultimate form: that is, whether the metal be allowed to continue as a cylinder; to expand or to contract, either as a cone or as a simple curve; or to serpentine in in any arbitrary manner, according as the one or other action is allowed to predominate with the gradual development. The treatment of such works with the hammer, is unlike spinning the teapot, at those parts of the work where the metal is folded down in close contact with the solid revolving mould therein employed; but in completing the upper part on the small block, Fig. 243, the burnisher and the rubber may be considered equivalent to the two antagonist forces, which lead the hammered vessel inwards, or outwards at the will of the operator.

This subject is too wide to enable any thing more to be offered than a few general features, and I shall therefore proceed to trace briefly the practice in some examples.

Figs. 258



259.

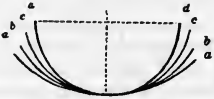
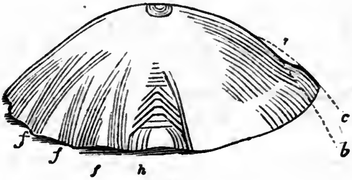


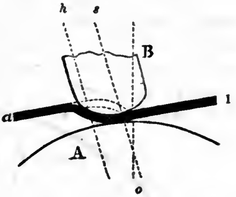
Fig. 258 represents the first stage of making the half of a copper ball; the metal is first driven with a mallet into a concave bed, generally of wood, in which it is hastily gathered up to a sweep of about the third part of a sphere, as *a, a,* Fig. 259; but this puckers up the edge like a piece of fluted silk, or the serpentine margin of many shells, in the manner represented at *f f f,* Fig. 260, which is of twice the size of 259.

The next step is to remove the flutes or puckers by means of blows of the raising hammer, applied externally as indicated by the black lines at *h,* Fig. 260; and in Fig. 261 are represented, on a still more enlarged scale, the relative positions of the hammer, anvil, and work. Thus A represents the globular face of the anvil, B the rounded edge of the raising hammer, which like the pane of an ordinary hammer, stands at right angles to the handle, and *a* 1, shows the work, *a* being the edge, and 1 the point of the flute. The blows of the hammer are made to fall nearly on the centre *o*, of the anvil, and at a small angle with the perpendicular, the hand being on the side *a*. A few blows are given as tangents, or directly across the point of the flute, and when it exceeds the width of the hammer, oblique blows are given to restore the pointed character, to be followed by other blows parallel with the first, as shown at *h*, Fig. 260. These hollow blows cause the sides of the flutes to slide into one another, almost as when two packs of cards, placed like the ridge of a house, penetrate into each other and sink down flat: in a manner somewhat resembling that by which the original and extreme margin in Fig. 257, becomes, by the successive blows, contracted to the inner circle; but in the present case the plait slides down to the general curve of the spherical dish.

Figs. 260



261.



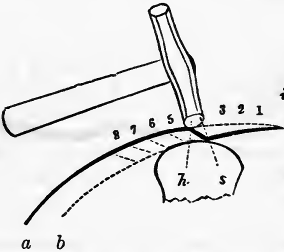
If, however, the puckers of a large globe were entirely removed by hollow blows, the central lines of the flutes would become thickened, and therefore solid blows are mingled with them, or rather the one blow partakes of the two natures. Thus from the curvature and oblique position of the hammer, Fig. 261, its face is solid at *s*, to that part immediately below it, but towards *h*, it rather bends than thins; the flatter the curves of the two surfaces, the greater the extent of the solid or thinning blows. The plaits are not, however, entirely gathered up, as the dish *a*, *a*, Fig. 259, always opens a little, from the metal becoming stretched under the treatment for removing the flutes.

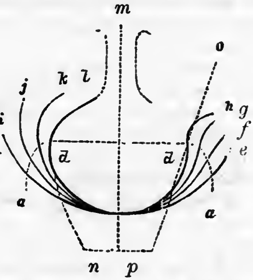
Throwing the works into flutes as described is not imperative, for the hemisphere might be entirely raised, as in the succeeding step, by blows on the outer surface upon a convex tool or head, but the flutes quicken the process, and speedily give a concavity which is convenient, as it makes the work hang better on the rounded face of the anvil.

The outer curve *a a*, Fig. 259, p. 306, which represents the copper dish when the puckers have been removed, will not be sent into the hemispherical form, or the inner line *d d*, at one process, but will progressively assume the curvatures *b b*, *c c*, and sometimes many others; neither will the work be changed from the curve *a a*, to that of *b b*, at one sweep, or as with the burnisher in spinning even by one consecutive ring or wave. The hammer must necessarily operate by successive blows arranged in circles, the proximity of which circles will at length include within their range the entire sweep *a a*, or *b b*, each of which is called a *course:* and before proceeding from one course or sweep to the next, the metal requires to be annealed.

Figs. 261 and 262 explain the transition or conversion from the first sweep *a*, to the second sweep *b*; the black lines represent the metal after a circles of blows have been given. Fig. 262 shows the narrow edge of the raising-hammer, in the act of descending upon the centre of the head or stake, and as a tangent to the circle; it first throws in a little rim at 1, which connects the new and old sweeps by a curve or ogee: then another little circle 2, will be similarly gathered in, then 3, 4, 5, and so on, up to the edge. Now the artifice consists in making the intervals both of the great sweeps, *a*, *b*, *c*, Fig. 259, and of the little waves 1, 2, 3, of Fig. 262, as large as practicable, provided they do not cause the exterior metal to pucker or become in plaits, as this would endanger its ultimately cracking at those places, where the metal might have become plaited.

Figs. 262 263.





In thus *raising-in* the metal, it necessarily becomes thickened from its contraction in diameter, but as in Fig. 261 the hammer at *h*, gives a hollow blow and bends, whilst the part *s*, gives a solid blow and thins, the two effects are thus combined; and when they are duly proportioned, by a hammer more or less round, and blows more or less oblique, the true thickness as well as the desired change of figure are both obtained.

It is easier to get the hemisphere by a little excess of thinning, or by a superfluity of blows: so that the less skilful workman will use a piece of copper of seven inches diameter, with additional blows, for a six inch hemisphere; but the more skilful will take a piece of seven and a half inches diameter, and obtain the work with less labor. Occasionally, when the work is common and thin, from three to six hemispheres or other pieces are hollowed together, the outer piece is cut as a hexagon or octagon, and its angles are bent over to embrace the inner pieces, before the process of hollowing is begun, and which scarcely consumes more time than for one only. This is a general practice in hollowing tin-works, such as the covers of sauce-pans, as the number of thicknesses divide the strength of the blows; the several pieces are then twisted round at intervals, so as to arrange them in a different order, which mixes the little imperfections, and tends to their mutual correction: the raising process represented in Fig. 262 is also performed upon two or three pieces at a time, when they are sufficiently thin to permit it.

One of the most conspicuous and remarkable examples of raised works is the ball and cross of St. Paul's Cathedral, London. The old ball consisted of sixteen pieces riveted together; the present, also 6 feet in diameter and $\frac{1}{8}$ inch thick, was raised in *two* pieces only, and may therefore be considered to mark the improvement in the coppersmith's art in making large works, such as sugar-pans, stills, etc.

The metal was first thinned and partly formed under the tilt-hammer at the copper-mills, or sunk in a concave bed; the raising was effected precisely as explained in Fig. 262, and with hammers but a little larger than usual; the two parts were riveted together in their place, and the joint is concealed by the ornamental band.

All the work is modern, and is mostly hammered up, except the cast gun-metal consoles beneath the ball, which formed part of the original metallic edifice; a name to which it is justly entitled, the height being 29 feet, and the weight of copper 3$\frac{1}{4}$ tons. The new ball and cross are strengthened by a most judicious inner framing of copper and wrought-iron bars, stays, bolts, and nuts, extending through the arms and downwards into the building; thus adding about 2 tons of iron to the load of copper, and to the 38 ounces of gold used in its decoration.

Having conveyed the full particulars for raising a hemispherical shape, the modifications of treatment required for various other forms will be sufficiently apparent. Thus, below the dotted lines *a d*, in Fig. 263 the sweeps are exactly the same as in Fig. 259, but the metal rises higher from having been originally larger; in the courses *g h*, it is first kept rather thicker on the edge, and towards the conclusion, it is thinned on the edge to the common substance, and curled over by hollow blows from within, although the whole figure might be produced by external blows, but which would be a more tedious method.

On the other hand, by the continuance of the *raising in*, explained by diagram 262, the metal would be gathered into a smaller diameter through the steps *i*, *j*, *k*, *l*, in the latter of which the metal would become thickened, unless the solid or thinning blows were allowed to predominate. If enough metal had been given in the first instance, when the mouth had been contracted as to the form of a teapot, it might be extended upwards as a cylindrical neck, in the manner explained in Fig. 256, and curled over at the top, as on the opposite side of Fig. 263, at *h*.

To lessen the labor of raising works from a single flat plate, soldering is sometimes resorted to; thus the teapots, Figs. 190 and 192, page 284, might be made in two dished pieces, and soldered at the largest diameter; the lofty vase or coffeepot, Fig. 194, could be made from a cylinder of midway diameter soldered up the side, the bulge being set-out by thinning the metal, and the contraction above being drawn-in by hollow blows.

Vases in the shape of an earthen oil jar, or of the line *l d n*, Fig. 263, could be made from a cone such as *o p*, with a bottom soldered in; these preparations would save the work of the hammer, although such forms, and others far more difficult, could be raised entirely by the hammer from a flat piece of metal.

Should any of the above vessels require a solid thickened edge or lip, beyond that which would result from the drawing-in of the metal, it would be necessary to select a piece of metal of smaller diameter but thicker, and to retain the margin of the full thickness by directing all the blows within the same; sometimes, on the other hand, works require to be thinned on the edge; these are then cut out proportionally smaller than their intended sizes, as illustrated by the following example, which is considered the most difficult of its kind.

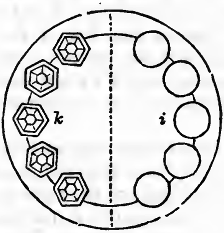
The bell of a French horn, together with the first coil of the tube, are made of a flat strip of metal about 4 feet long and 2 inches wide; for making the bell of the instrument, there is an enlargement at one end of the strip, in the form of the funnel piece 189, and of the width of 16 to 22 inches, the smaller piece being adopted when the bell is required to be very thin. The narrower piece of metal, when first bent up, much resembles the butt end of a musket, terminating in a small tube; the metal is united and soldered down the edge with a cramp or dovetail joint, Fig. 232; it is next thrown into a conical form of about five inches diameter, and expanded from within, first with blows of a wooden mallet upon a wooden block, and then with those of a hammer on iron stakes.

When nearly finished, or about one foot diameter, it is hammered very accurately upon a cast-iron mould turned exactly to the form of the bell, which is thus rendered much thinner than the general substance, and remarkably exact; the band containing the wire for stiffening the edge of the bell is attached by dexterous hammering, and without solder. To bend the tube to the curve without disturbing its circular section, it is filled with a cement, principally pitch, which allows the tube to be bent to the scroll of the instrument, without suffering the metal to be puckered or disturbed from its true circular section; and in bending similar tubes to smaller curves, they are filled with lead. These materials serve as flexible and fusible supports, which are easily removed when no longer required.

Should any of the raised works have ornamental details, such as concave or convex flutes, or other mouldings, they would be mostly overlooked until the general forms had been given; and then every little part would be proceeded with upon the same principles of solid and hollow blows. Each of the series of flutes would be first slightly developed all around the object, then more fully, and so on until the completion; when, however, the details are so large, as to form what may be considered integral parts, it is necessary to prepare for them at an earlier stage.

Thus, to take an excellent familiar example, let Fig. 264 represent plans, 265 sections, and 266 elevations of jelly moulds, many of which require the greatest skill of the coppersmith. The general outline is that of a cylinder *a b c d*, upon a larger cylinder *e f g h*, as a base. The twelve large and deeply indented flutes or finials, rise perpendicularly to a great height from the plane surfaces *a c* and *e b*, and yet the whole is hammered out of one flat plate.

Figs. 264



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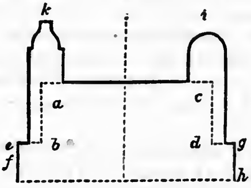
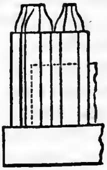


266.

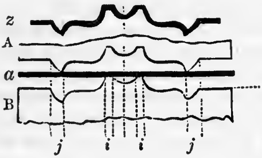


The first step is to raise the summits of the flutes *i* or *k*, preparatory to the general formation of the upper cylinder *a b c d*, and then the two are worked up together, leaving for a time the expanded base *e f g h*, but ultimately the whole receive a general attention in common. If the flutes were polygonal, and terminated in ornaments like spires or finials, as at *k*, they would be first treated as if for the more simple or generic form *i*, and the details would be subsequently produced.

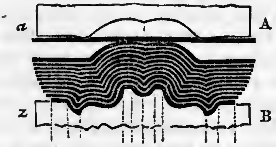
The skill called for in such works is greatly enhanced by the attention which is required to preserve a nearly uniform thickness in the metal, notwithstanding the apparent torture to which it is submitted; and this is only endured in consequence of a frequent recurrence to the process of annealing, which reinstates the malleable property.

In cases of extensive repetition, or where large numbers of any specific shape are required, expensive dies of the exact forms are employed; but these are only applicable to objects in small relief, and to those in which the parts are not quite perpendicular. Dies would be entirely inapplicable to objects such as the jelly moulds, Fig. 265, although a common notion exists that they are rapidly made by that method, but which is in general utterly impossible when such objects are made in one piece. In all such cases the metal has to undergo the same bendings and stretchings between the dies as if worked by the hammer, and which unless gradually brought about are sure to cut and rend the metal. The production of many such forms with dies is therefore altogether impracticable.

Figs. 267



268.



For example, the pattern or moulding, *z*, Fig. 267, is only in small relief, and yet the flat piece of metal *a* would be cut in two or more parts if suddenly compressed between the dies A B, as the edges *i j* would first abruptly bend and then cut the metal, without giving it the requisite time to draw in, or to ply itself gradually to the die, beginning at the centre as in the process of hammering.

In Fig. 268 the successive thicknesses obliterate the effect of the acute edges of the bottom die B; the face and back of every thickness differ, as although parallel they are not alike, but they become gradually less defined, so that in Fig. 268 the top die A requires nothing more than a flowing line with slight undulations. Therefore, when two or three dozen plates are inserted between the dies A B, the transition from *a* to *z* is so gradual that the metal can safely proceed from *a* to *b*, from *b* to *c*, and so on, and it will be progressively drawn in and raised without injury. When one or two pieces alone are required, they are *blocked-down* to fit the mould by laying above them a thick piece of lead, which latter is struck with the mallet or hammer. By the yielding resistance the lead opposes, the thin metal is drawn into the die with much less risk of accident than if it were subjected to the blows without the intervention of the lead.

In producing many pieces, however, one piece, *a*, is added at the top, between every blow, and one piece, *z*, is also removed from the bottom. Occasionally, two, three or more are thus added and removed at one time, and generally, as the concluding step, every piece is struck singly between the dies, such as Fig. 267, which exactly correspond. In general the process of annealing must be also resorted to once or more frequently during the transition from *a* to *z*. For the best works the bottom die is mostly of hardened steel, sometimes of cast-iron or hard brass. The top die is also of hardened steel in the best works, but in very numerous cases lead is used, from the readiness with which it adapts itself to the shape required.

Stamping is very common for many works in brass, but which would be inapplicable if the pieces had perpendicular and lofty sides, as in Fig. 265, page 311. Such lines, although rounded by the successive thicknesses of metal, would still present perpendicular sides, and therefore render this mode of treatment with dies impracticable, without reference to cost. Thimbles are raised at five or six blows, between as many pairs of *conical* dies successively higher, but the metal requires to be annealed every time.

PECULIARITIES IN THE TOOLS AND METHODS.—Before concluding the remarks on raised works, it may be desirable to revert to some of the principal and distinguishing features of the tools employed in these arts. As a general rule, it will be observed that all these manifold shapes are the more quickly obtained the more nearly the various tools assimilate to the works to be wrought. For instance, the several dies and swage tools quickly and accurately produce mouldings of the specific forms of the several pairs of dies; but it is utterly impossible to extend this method to all cases, and the *progressive* changes required, from the flat disk, the cylinder or cone, as the case may be, to the finished object; and therefore certain ordinary forms of tools can alone be employed, and they are continually changed as the work proceeds.

For hollow works with contracted mouths, the inner tools are required gradually to decrease in bulk and to increase in length, in order to enter the cavities; but they can be rarely the exact counterparts of the transient forms of the works, nor is it always desirable they should be so. The tools are often required to be bent at the end, to extend within a shoulder or gorge. The small stake in the tool, Fig. 203, is an example of this; the dotted line represents the work, such as the perforated cover of a cylinder, or the top of a teakettle. The strong wrought-iron arm or *horse*, Fig. 203, carries the small steel tools, and which latter may be also fixed by their shanks either in the bench or vice, according to circumstances.

There are many curious circumstances respecting the modification of the *materials* for, as well as the forms of, the hammers and anvils, if the use of these terms may be extended to the various contrivances, by the action and re-action of which thin metal works are produced; and the concluding examples are advanced to bring some of these peculiarities of method into notice.

The plated metals have so thin a coating of silver, that they require more expert hammering than similar works in solid silver, otherwise the removal of the bruises left by the hammer, by scraping and polishing, might wear through the silver and show the copper beneath. The bruises are therefore driven to the copper side, by hammering upon the silver or the face, with a very smooth planishing hammer, and covering the anvil or bottom tool with *cloth*. On account of the elasticity thus given, the blows become so far hollow that all the little bruises descend to the copper side, or that which is exposed to the cloth, and the face becomes perfectly smooth.

When the inside of a vessel is required to be smooth, it is the hammer that is covered with cloth, stretched over it by an iron ring, and the polished stake or head within the vessel is left uncovered; and in those cases in which the work is required to be good on both sides, the faces both of the hammer and anvil are each muffled; this gives them some of the elasticity of wooden tools, but with superior definition of figure.

Plated works are generally furnished with an additional thickness of silver at the part to be engraved with a crest or cipher, in order that the lines may not penetrate to the copper; should it, however, be requisite to remove the engraved lines for the substitution of others, the following mode is resorted to.

The object is laid upon the anvil over a piece of sheet lead and it is struck with a bare hammer *upon the engraved lines;* these latter are therefore *hollow* as regards the face of the hammer; in consequence of which, the re-action of the lead causes it to rise in ridges corresponding with the engraved lines, and to drive the thin plated metal before it. The device is thus in great measure obliterated from the silver face and thrown to the copper side, so as to leave much less to be polished out; this ingenious method is appropriately called *reversing.*

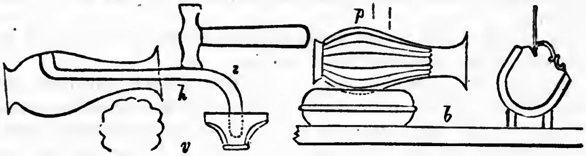
In making vases, such as Figs. 192 and 194, page 284, the metal is first driven into concave *wooden* blocks with a wooden mallet, as in Fig. 258, in order to gather up the metal into the fluted concave 260, but without making any sensible alteration in its thickness. In the next stage of the work, *metal* tools are alone employed, whether the object be made by raising-in with hollow blows, or by setting-out with solid blows, as adverted to; and the sizes and curvatures of the tools require to be accommodated to the changes of the work.

Supposing the vases to have either concave or convex flutes, ornamental details are now sketched with the compasses upon the plain surface of the vase; and if from the shape of the works swage tools similar to Fig. 212, cannot be employed for raising the projecting parts, they are *snarled-up,* by the method represented in Fig. 269.

Thus at *v* are the jaws of the tail vice, in which the *snarling-iron s,* is securely fixed: the extremity *b,* which is turned up, must be sufficiently long to reach any part of the interior of the vessel, but yet small enough to enter its mouth. The work is held firmly in the two hands, with the part to be raised or set out exactly over the end *b*; and when the snarling-iron is struck with a hammer at *h,* the re-action gives a blow within the vessel, which throw the metal out in the form of the end of the tool, whether angular, cylindrical, or globular: except in small works, two individuals are required, one to hold and the other to strike.

Figure 270 shows the last stage of the work prior to polishing; thus in finishing the flutes and other ornaments after they are snarled-up, the object is filled with a melted composition of pitch and brick-dust—sometimes the pitch is used alone, or common resin is added—the ornaments are now corrected with punches or chasing tools of the counterpart forms of the several parts; some portions of the metal are thus driven inwards, whilst those around rise up from the displacement and reaction of the pitch. To avoid injuring the lower surface of the work it is supported upon a sand-bag *b*, like those used by engravers, and the perpendicular lines *p*, denote the usual position of the chasing tool.

Figs. 269 270 271.



Works in copper and brass are sometimes filled with lead at the time of their being chased, but the silversmiths and goldsmiths are studious to avoid the use of this metal, as, if it gets into the fire along with their works, it is very destructive to them.

Pitch and mixtures of similar kind, are constantly used in the art of chasing in its more common acceptation; from its adhesive and yielding nature it is a most appropriate support, as it leaves both hands at liberty, the left to hold the punch, the right for the small hammer used in striking it.

The pitch-block, Fig. 271, is employed to afford the utmost choice of position for works from the smallest size to those of six or eight inches long. The lower part is exactly hemispherical, and it is placed upon a stout metal ring or collar of corresponding shape, covered with leather. The mass of metal makes a firm solid bed to sustain the blows, and the ball and socket contact, allows the work to assume every obliquity, and to be twisted round to place any part towards the artist.

Large flat works in high relief are frequently sketched out and commenced from the reverse face, the prominent parts of the subject being sunk into the pitch, which after a short time must be melted away to allow the metal to be annealed; and this is frequently required when the works are much raised. In the concluding steps the artist works from the face side.

Many of the chased works are cast in sand moulds from metal models, which have been previously chased nearly to the required forms; the castings are first pickled to remove the sand coat, and in such cases, chisels and gravers are somewhat used in removing the useless and undercut parts.

Many ancient specimens of armor, gold and silver plate, vases and ornaments, are excellent examples of raised, chased, and inlaid and engraved works, both as regards design and execution. In our own times, the Hungarian silversmith, Szentepeteri, has produced a very remarkable alto-relievo in copper, taken from Le Brun's picture of the battle of Arbela, in which some of the legs of the horses stand out and are entirely in relief from the background.

The art of chasing may be considered as the sequal to that of forging (that is, setting aside the employment of the red-heat), but the various hammers and swage tools now dwindle into the most diminutive sizes, and are required of as many shapes as may nearly correspond with every minute detail of the most complex works. Some of them are grooved and checkered at the ends, and others are polished as carefully as the planishing hammers, that they may impart their own degree of perfection and finish to the works; in a similar manner that the polish and excellence of coins and medals are entirely due to that of the dies from which they are struck, the chasing process being as it were a minute subdivision of the action of the die itself.

THE PRINCIPLES AND PRACTICE OF FLATTENING THIN PLATES OF METALS WITH THE HAMMER.—I have purposely reserved this subject to be distinct, on account of its great general importance in the arts, and have placed it last, in order that the various applications of the hammer might have been rendered comparatively familiar; for, although the plane surface may appear to be of more easy attainment than many of the complex forms which have been adverted to, such is by no means the case.

The methods employed are entirely different from that explained at page 153, in reference to flattening *thick* rigid plates, which are corrected by *enlarging the concave side*, with blows of the sharp rectangular edge of the hack-hammer, applied *within* the concavity. A method which bears some analogy to that employed by the joiner in straightening a board which is curved in its width, namely, the *contraction of its convex side* by exposure to heat. In thin metal plates neither of these modes is available, as the near proximity of the two sides causes both to be influenced in an almost equal degree by any mode of treatment.

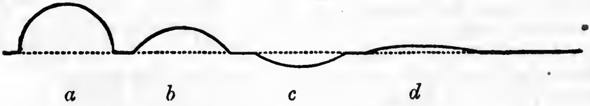
Thin plates are flattened by means of solid and hollow blows, which have been recently explained, but they require to be given with considerable judgment; and a successful result is only to be obtained by a nice discrimination and considerable practice. All therefore that can be here attempted is an examination of the principle concerned, and of the general practice pursued; as the process being confessedly one of a most difficult nature, success is only to be expected or attained by a strict and persevering regard to principle.

As respects thin works, no figure is so easily distorted as the true plane, and this arises from the very minute difference which exists between the span or chord of a very flat arch, and its length measured around the curve. For example, imagining the span of an arch to be one inch, and the height of the same to be one-twentieth of an inch, the curve would be only about one 200th of an inch longer than the span: and therefore, if any spot of one inch diameter were stretched until, if unrestrained, it would become one inch and one 200th in diameter, such spot would raise up as a bulge one-twentieth of an inch high. This trivial change of magnitude would be accomplished with very few blows of the hammer, and much less than this would probably distort the whole plate.

In general, however, there would be not one error only, but several, the relationship of which would be more or less altered with nearly every blow of the hammer; thence arises the difficulty, as the plane surface cannot exist so long as any part of the plate is extended beyond its just and proportional size, and which it is a very critical point to arrive at.

There is another test of the unequal condition of flat works besides that of form, namely, their equal or unequal states of elasticity, and which is an important point of observation to the workman. For instance, if we suppose a plate of metal to be exactly uniform in its condition, it will bend with equal facility at *every* point, so that bending a long spring, or saw, will cause it to assume a true and easy curve; but supposing one part to be weaker than the remainder, the saw will bend more at the weak part, and the blade will become as it were two curves moving on a hinge. When such objects are held by the one extremity and vibrated, the perfect will feel as a uniformly elastic cane; the imperfect, as a cane having a slight flaw, which renders it weak at one spot; and in this manner we partly judge of the truth of a hand-saw, as in shaking it violently by the handle, it will, if irregularly elastic, lean towards the character of the injured cane, a distinction easily appreciated.

Fig. 272.



A thin *plate* of metal can only be perfectly elastic, when it is either a true plane or a true curve, so that every point is under the same circumstances as to strength. Thus a hemisphere, as at *a*, 272, possesses very great strength and rigidity owing to its convexity, but as the figure becomes less convex it decreases gradually in strength, and when it slides down to the plane surface, as at *f*, the metal assumes its weakest form.

A nearly plane surface will necessarily consist of a multitude of convexities or bulges varying in size and strength, connected by intermediate portions, which may be supposed to be plane surfaces; the whole may be considered as greatly exaggerated in the figure. The bulged parts are stronger than the plane flat parts, it follows that the bending will occur in preference at the plane or weak parts of the plate, precisely as in the injured cane.

When the bulges are large but shallow, they flap from side to side with a noise at every bending, as their very existence shows that they cannot rest upon the neutral or straight line; such parts are said to be buckled, their ready change of position renders them flaccid and yielding under the pressure of the fingers, and they are therefore called *loose* parts, but at the same time it is certain that they are too large.

On the contrary, those parts which are intermediate between the bulges, feel *tight* and tense under the fingers, because they are stretched in their positions and rendered comparatively straight, by the strong edges of the bulged or convex parts: the flat portions are the hinges upon which the bulged parts move, and such flat parts are sensibly too small for their respective localities, the others being too large.

Now, therefore, in prescribing the rule for the *avoidance* of these errors, it is simply *to treat every part alike,* so that none may be stretched beyond its proper size so as to become bulged, and thereby to distort the whole plate. When the mischief has occurred, the *remedy* is to *extend all the too-small parts,* or the hinges of the bulges to their true size, so as to put every part of the plate into equal tension, by allowing the bulged or too-large parts room to expand. Uniform blows should be therefore directed upon all the straight or too-small parts of the plate, the force and number of the blows being determined by the respective magnitudes of the errors, and the rigidity of the plate.

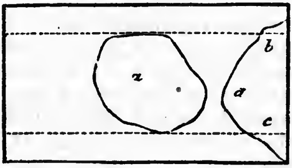
In flattening plates, the greater part of the work is done with solid blows upon a true and nearly flat anvil; the face of the hammer is slightly round, and its weight and the force of the blows are determined by the strength of the plate, the slighter plate requiring more delicate blows, and being more difficult to manage. In the commencement, the rectangular plate is hammered all over with great regularity in parallel lines beginning from one edge; it is generally turned over and similarly treated on the other side. Circular plates are hammered in circular lines beginning from the centre, that is supposing the plates of metal to be soft, and in about the ordinary condition in which they are left by the laminating rollers; as the equable hammering gives a general rigidity, which serves as a foundation for the correctional treatment finally pursued. With a steel plate hardened in the fire, and which is already far more rigid than the soft plate, it is necessary to begin at once upon the reduction of the errors and distortions, which usually occur in the hardening and tempering.

The hammer should be made to fall on one spot with the uniformity of a tilt-hammer, the work being moved about beneath it.

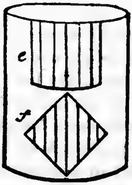
As, however, the regularity of a machine is not to be expected from the hand, it is scarcely to be looked for that the work shall be at once flat. Whilst the errors are tolerably conspicuous or considerable, the man accustomed to the work will still keep the hammer in constant motion, and will so shift the work, as to bring *the tight parts alone* beneath its blows, hammering with little apparent concern just around the margins of the loose parts, or at the foot of every rise. As the plate becomes more nearly flat, it is necessary to proceed more cautiously, and to hold the plate occasionally between the eye and the light to learn the exact parts to be enlarged; the straight-edge is also then resorted to.

In many works, especially in saws which require very great truth, the elasticity is also examined; this is frequently done by holding the opposite edges of the plate between the fingers and thumbs, and bending them at various parts. As previously explained, all the portions which are technically called tight, or those lines upon which the loose enlarged parts appear to move as on hinges, are strictly the parts to be extended by gentle hammering. For instance, supposing that in the plate, Fig. 273, there were only one central buckle *a*, the whole exterior portion would require to be stretched, beginning from the base of the bulge: but it must be remembered the extreme edges of the plate will yield with greater facility than the more central parts, and therefore require somewhat fewer blows, as the blows are all given as nearly as possible of the same intensity, and the number of them is the source of variation.

Figs. 273



274.

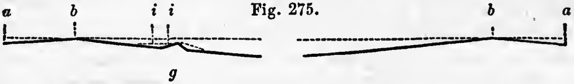


If, as it is more to be expected, there are two or more loose parts, such as *a*, and *b c*, the more quiescent part between them must be first hammered, as working upon any loose or bulged part only magnifies the evil. Where the intermediate space is narrow, as at *d*, less blows will be needed, and such tight parts will soon, and sometimes very suddenly, become loose from the two bulges melting into one. It should be rather the general aim to throw the several small errors into a large one, by getting the plate into one regular sweep; dealing the blows principally between the dotted lines, not carelessly so as to increase the general departure from the plane surface, but with an acute discrimination to lead all the defects in the *same direction*, by making the plate as it were a part of a very great cylinder, as at *e* or *f*, Fig. 274, but with as little curvature as possible.

When this is accomplished, and that the work is free from loose parts, it is hammered on the *rounding* side, in lines parallel with the axis of the imaginary cylinder; so that in *e* the lines would be parallel with the edge from which the rise commences, and in *f*, or the plate which is bent diagonally, the lines of blows would be necessarily oblique, although as regards the curvature, the same as in *e*. The reason why any reduction of curvature should at all result from this treatment (action and reaction being alike) is due to the greater roundness of the hammer than the anvil; the rounder hammer effects the change more rapidly, but also the more indents the work.

In a circular saw, the general aim is first to throw the minor errors into one regular concavity, which may be supposed to extend to *b b* in the imaginary section, Fig. 275, and then the margin *a b* would be hammered in a proportional degree, to enlarge it until it just allowed the interior sufficient room to expand to the plane surface.

Fig. 275.



It may happen in the course of the hammering that from *b* to *b* becomes loose, whilst the extreme edge *a a* is also loose, and that the intermediate part towards *b* requires to be stretched. These minor differences cannot be told alone by bending the plate with the fingers, as errors frequently exist which are too minute to yield to their pressure, and then the eye and straight-edge are conjointly employed in the examination.

In a saw, the general aim is to leave the edge rather tight or small, as then the small amount of expansion it acquires when at work, from heat and friction, will enlarge the edge just sufficiently to bring the saw into a state of uniform tension. Otherwise, if before the saw is set to work the edge is fully large enough, when expanded by the heat it is almost sure to become loose on the edge, and to vibrate from side to side, without proper stability, so as to produce a wide irregular cut, and make a flanking whip-like noise, arising from the violent vibration of the buckled parts of the plate in passing through the saw kerf; the sides of the wood will then exhibit ridges like the ripple-marks on the sandy shore.

In hammering all plates, preference should in the like manner be given to keeping the edge rather small or stiff, to serve as a margin or frame to the more loose parts within. It gives a degree of stability somewhat as if the object had a thickened rim, and when a rim really exists, the process of flattening is comparatively easy.

If by undue stretching the edge is made too loose, the whole piece becomes flaccid and very mobile, and we seem to lose the governing power, or those retaining points by which the changes of the plate are both influenced and rendered apparent. The edge should be therefore *always* kept somewhat tight, from being proportionally less hammered, especially as the edge more easily admits of expansion than the inner part.

As a general rule, it may be said, that every part of the plate which is straight and tense, whilst others are curved and flaccid, denotes that every straight part is under restraint; and that its straightness is due to its being, as it were, stretched, either lengthways or around its edges, by the other parts, which are too loose, and therefore arched and also strong. In such cases, the straight lines require to be extended in length, to allow sufficient room for the curves to expand to their proportional sizes. This refers not only to small local errors towards the inner part of the plate, as explained by diagram, Fig. 273, p. 319; but should the one edge of a plate be tolerably straight, whilst the opposite is loose and flaccid, the rule also applies with equal truth, and the straighter side must be hammered. In this case the curved side is as it were a great bulge cut in two parts.

Should a circular saw have a sudden dent, such as at *g*, Fig. 275, on the last page, standing the reverse way, and which may result from its having rested upon a small lump of coke whilst in the fire, the first blows will be given on the *hollow* side, between the lines *i i*, to lessen the abruptness of the margin by stretching it to the dotted curve, and then it will be driven downwards by violent blows, to form a part of the general sweep or concavity. A little time is gained by these driving blows over the mode of stretching by the hammer.

The foregoing descriptions have all referred to *solid* blows, upon the face of the hard anvil, but to expedite the process recurrence is often had to *blocking*, which is only one application amongst many others of a wooden anvil or block with a narrow flat-faced hammer, such as Fig. 248. In this case the blows are to a certain extent *hollow*, as the wood immediately beneath the hammer-face yields to the blow, whereas the margin around the same does not. Such blows are therefore unquestionably hollow, and *bend* with very little stretching.

The blocking is considerably employed in saw-making *after* the loose parts have been entirely removed, as the hollow blows correct any slight errors of figure, by bending alone, and with little risk of *stretching* the plates, if the work be delicately performed.

Towards the conclusion, however, all the different modes of work are required to be used in combination, as the true condition of the plate is only the exact balancing of all the forces, or of the tension of the several parts; and it constantly happens that attention to one error causes a partial change and fluctuation throughout the whole. It therefore requires great tact to know when to leave the anvil for the block, and when to return to the anvil, and so on alternately; and also which side of the plate should be upwards for the time, which particular points should be struck, and the required force of the blows.

Of course, within certain limits, a thick plate is easier to hammer than a thin one, as the latter is difficult from its excessive mobility; also a soft plate of iron is more difficult than a hard plate of steel, although the latter requires more blows to produce the same effect; but when the works are very thick they become laborious, and the difficulty always increases rapidly with the size of the plate.

Those who may desire to practise this art should therefore commence with a plate some 4, 6, or 8 inches square, and moderately stout, and subsequently proceed to pieces larger and thinner. They will also find some advantage in raising the anvil to within about a foot of the eye, as the alterations can be then more easily seen whilst the work lies on the anvil, and the effect of any predetermined blows can be the better watched. One other observance is essential, namely, *patience;* as, although, the process is thoroughly reducible to system, and no blow should be struck in vain, the beginner will frequently find it necessary to pause, examine, and consider, especially as the errors decrease; whereas the accustomed eye will follow the fluctuations of the plate almost without intermission of the blows, and will also accomplish the task with the fewest possible number of blows, which is the great object.

Indeed it may happen from hammering some parts of a plate excessively and improperly, that it is rendered so hard and rigid, as to make its correction very tedious, or indeed nearly impossible without previous annealing, as the plate might *burst* or crack from the extension being carried beyond the safe limit of malleability. As in raised works, the annealing is mostly done by a gentle red heat; but in hardened steel plates, a slight increase of temperature barely sufficient to discolor the plate, will make a perceptible difference; and this latter process is always the last step in making a saw, in order to restore, by a gentle heat, the proper elasticity which has been mysteriously lost in the grinding, polishing, and hammering required in its manufacture.

CHPTER XVIII.

PROCESSES DEPENDENT ON DUCTILITY.

DRAWING WIRES, ETC.—The ductility of many of the metals and alloys, or the quality which allows them to be drawn into wires, is applied to a variety of curious uses in the manufacturing arts, and the process may be viewed as the sequel to the use of grooved and figured rollers; but the ductile metals submit to this process with various degrees of perfection.

In drawing wire, the metal is first prepared to the cylindrical form, either directly by casting, or between rollers with semicircular grooves; and the process is completed by pulling the metal through a series of holes gradually less and less, made in a metallic plate, by which the wire becomes gradually reduced in size, and elongated; but, as in rolling, the process of annealing must be resorted to at proper intervals.

In general, the draw-plates are made of hardened steel, and they are formed upon the same principle, whether for round, square, or complex sections, either solid as wires, or hollow as tubes; the substance of the metal is partly kept back, as in a wave, by a narrow ridge within the draw-plate, acting as a burnisher.

The plates are generally made of hardened steel, or else of alloys of partly similar nature, which allow the holes to be contracted and repaired, by closing them with blows of a pointed hammer or punch around the hole.

The holes for round wires are sometimes ground out from both sides upon the same brass cone or grinder, the sides of which vary in obliquity from 10 to 30 degrees, according to the metal to be drawn; for the sake of strength the ridge is mostly nearer to the side on which the metal enters, and the sharp edge is also removed, either by wriggling the plate upon the grinder in order to round the inside, or in any other manner.

The end of the wire is pointed, to enable it to be passed through the hole, and it is then caught by a pair of nippers, themselves at the extremity either of a chain, rope, toothed rack, or screw, by which the wire is drawn through by rectilinear motion. The nippers or *dogs* resemble very strong carpenters' pincers or pliers, the handles of which diverge at an angle; they are sometimes closed by a sliding ring at the end of the strap or chain, which slides down the handles of the nippers; there are some other modifications, all acting upon the same principle, of compressing the nippers the more forcibly upon the wire the greater the draught. It requires a proportionally strong support to resist the strain; and to avoid the fracture of the hardened steel draw-plate, it is usually placed against a strong perforated plate of wrought-iron. In manufactories where large quantities of wire are made, the wire is more usually attached to the circumference of a reel, which is made to revolve by steam or other power.

It is necessary often to anneal the wire, but no general rule can be stated in respect to its recurrence; and before resuming the drawing process, the wire is invariably immersed in some acid liquor or pickle, to remove the slight coating of oxide, which would otherwise rapidly destroy the plates (as many of these metallic oxides are used in polishing), in general some lubricating matter is applied to reduce the friction, as beer-grounds, starch-water or oil; and for gold and silver, wax is generally used.

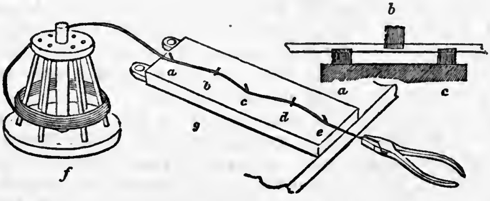
Most of the wire is drawn upon reels, and is therefore met with in circular coils, and it is necessary, in almost every case, to straighten it before use. The soft annealed wires, such as the copper wire used for bell-hanging, the soft iron *binding-wire* used in soldering, and others, are stretched and straightened by fixing the one end, and pulling the other with a pair of pliers; or short pieces of soft wire may be straightened by rolling them between two flat boards.

So steel wire for making needles is straightened by rolling or *rubbing:* it is cut up in lengths of 4 or 5 inches, and arranged in cylindrical bundles, within iron hoops of 4 inches diameter; the rubber is a bar of cast-iron, about two feet long, narrow enough to lie between the rings.

The hard-drawn and unannealed wires, used for making pins, bird-cages, blinds, and numerous other wire-works, are too elastic to yield to the above methods, and Fig. 276 represents the mode employed *to take the spring out of them,* or in other words, to straighten these hard wires. The coil of wire on the reel *f,* which revolves on a pin, is drawn through the *riddle g,* by the pliers. The riddle is a piece of wood or metal with sloping pins, which lean alternately opposite ways, so as to keep the wire close down on the board, and yet to compel it to pursue a slightly zigzag, or rather serpentine course, which is considerably magnified in the figure.

In practice, the riddle is made wider than represented, so as to contain about half a dozen rows of pins suitable to as many sizes of wire; between every set of pins, and fixed close down to the board, is a straight wire about three times the diameter of one to be straightened: very great importance is attached to this latter or central wire; being itself straight, it serves as a metallic bed for the small wire to run upon, and it thereby gets worn into furrows crossing it obliquely from pin to pin. The board is retained by two staples at the far end, which fit loosely on two studs or nails driven into the work-bench.

Figs. 276 277.



The pins are equivalent to the three forces *a, b, c,* of the bending-machine, page 289, several times referred to. Were the first three pins *critically placed,* they would suffice to bend the wire to the limit of its permanently elastic force, and would leave it perfectly straight; commonly, however, five pins are used, and sometimes seven or nine. The same riddle will not serve for wires differing in diameter; and were this simple tool more expensive, so as to render it desirable, a universal riddle might be made by placing the pins *b* and *d*, under a simple screw-adjustment; but in practice, a tap of the hammer is found sufficient to correct their positions.

It is necessary to be very particular in pulling the wire through, not to allow it to lean sensibly against either of the last two pins, or it will assume a curve; and in this manner, by drawing the wire designedly at different angles, it may be thrown into any required circular arc, instead of the right line.

Cylindrical shafts may be viewed as large wires, and when they are turned with ordinary care, in a slide-lathe with a back-stay, it becomes pretty certain that the shafts are circular, and of true diameters; but they are frequently more or less crooked or bent when they leave the lathe.

In straightening the axes or shafts intended for the *Calculating Machine*, which were of steel, about 6 to 10 feet long and $\frac{5}{8}$ to 1 inch diameter, three half-round dies, Fig. 277, *a*, *c*, fixed to the bed of a fly-press, and *b*, to the screw of the same, which was so adjusted that *b* could only bend the portion of the shaft between *a*, *c*, to the limit of its elasticity; and therefore, by keeping the press constantly at work, drawing the rod through, and twisting it round so as to bend it at *every point* of its length, every shaft was made perfectly straight.

The straightening of black wrought-iron shafts *previous* to turning, is now accomplished by three equidistant rollers, say a foot diameter and twelve feet long, similar to Fig. 216, p. 289. The shaft is heated to redness, and the centre roller is raised at the moment of its introduction, and then a few turns are given to the whole; this straightens the shaft, and retains it so until partially cooled; the other end of the shaft, should it exceed the length of the rollers, is then heated, and treated in the same manner.

All these modes are highly useful, as they operate upon the materials without partially condensing any point, from which unequal treatment a loss of figure would be almost certain to occur, when any such condensed point is partially removed by the turning-tool or otherwise; as it appears to be quite impossible to prevent all sorts of perplexities, when, by any mode of operation, the one point of a material receives a different treatment from the remainder.

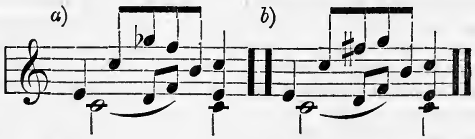
The great bulk of wire is cylindrical, but draw-plates are also made of various other forms, as oval, half round, square, and triangular, for the wires Figs. 278; and also of more complex forms, as for the production of steel of the sections of Figs. 279, known as pinion wire, the whole of the illustration being printed from the wires themselves. The largest of 279, serves for the pinions of clocks, and the smallest for those of watches; in these cases the entire arbor (which carries one of the toothed wheels) is made of pinion wire, but the teeth are removed from every part, excepting that which works into the adjoining wheel of the train. The plates for pinion wire are exactly the same as the others in principle, and exhibit a remarkable degree of perfection in their construction, as for every size there must be a series of many holes gradually assuming the form of a circular foliated Gothic window, with six, seven, eight or more foils.

Figs. 278

279

280

281.

Fig. 282.

Some of the printed calicoes and muslins are also curious examples of the wire-drawing process; the pattern Fig. 280, consists of no less than 205 different pieces of copper wire of various forms, fixed into a wood block; the surface of the wires, when filed smooth, are printed from after the manner of printers' types; the few detached pieces, Fig. 281, show some of the sections of such wires, and which may be combined in endless variety. In the same manner the specimen of music, Fig. 282, is printed from the surfaces of detached wires and slips of copper fixed in a wooden block; this is only one amongst the many ingenious processes for printing music by letter-press or surface printing.

Figs. 283

284

285

286.

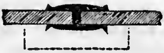


Fig. 283 represents the *double-plates* or *swage-bits* used for some of the pieces in Figs. 280 and 282; the dies are fitted into a small frame or *cramp* with a side screw (much the same as dies for cutting screws), so that the metal may be gradually reduced by one pair of swage-bits. This method is very much employed by the silversmith and goldsmith for mouldings, the tools being much cheaper than rollers: the piece 284 was thus prepared for the edging of silver and gold boxes; it is bent round to the form of the box or cover, whether square, circular or oval, and the rebate on the straight side of the band serves for receiving the flat plate to constitute the cover.

The most perfect example of this application of the drawing process is in the British Mint: two fixed rollers are employed after the manner of a draw-plate, and the long strip of gold or silver, when rolled very nearly to the thickness, is drawn through the *stationary* rollers, by dogs attached to one of the links of an endless chain, which is in continual motion from the steam-engine. It was found barely possible to make the surfaces of *revolving* rollers so truly concentric that the equality of thickness in the metal could be obtained with the rigorous exactness required, so as to dispense entirely with the necessity of scraping every piece individually, a mode still practised in some of the Continental mints.

The metal, when drawn, is tested by punching out one blank at each end; these are carefully weighed, and if found correct, the whole strip is punched into blanks; and such is the accuracy of the drawing and punching processes, that without the smallest after-adjustment, any fifty or one hundred blanks weigh alike to the fraction of a grain.

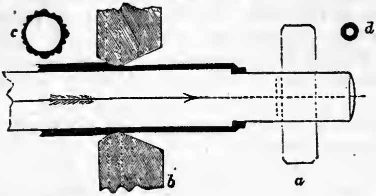
The window lead, shown in section in Fig. 285, does not admit of being drawn in the ordinary manner, from the softness of the material, nor of being rolled, because of its undercut section; the two principles are, therefore, curiously combined in the *glazier's vice.* It may be conceived that the shade lines of 286, represent parts of two narrow rollers with roughened edges (equal in thickness to the glass), which indent the bottom of the groove, and thereby carry the lead between the figured side-pieces, one only shown. In some cases cutting is combined with drawing, cutters are then fixed to the draw plate; this method has been adapted to making rules and similar rods; and in perfecting the flattened wire for the *reeds* used in looms, the edges are rounded by reeling the wire beneath a forked cutter, a process intermediate between turning and planing.

The process of wire-drawing is seldom practised by the general mechanician, and still less by the amateur; but when it is necessary to produce a wire either of some unusual section not prepared by the manufacturer, or that the equality of size requires more than usual exactness, the process may be accomplished in the small way, by fixing the draw-plate in the tail-vice and drawing the wire through with the pliers or a hand vice, or by a reel moved by a winch handle.

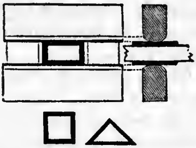
DRAWING METAL TUBES.—The perfection of tubes is mainly dependent on the drawing process, conducted in a manner similar to that employed for drawing wire. Many of the brass tubes for common purposes, when they have been bent up and soldered edge to edge, as in Fig. 231, page 294, are only drawn through a hole which makes them tolerably round and smooth externally, but leaves the interior of the tubes in the condition in which they left the fire after they were soldered, and nearly as soft as at first.

The sliding tubes for telescopes, and many similar works, are "*drawn inside and out*," and rendered very hard and elastic, by the method represented in Fig. 287, the form of the plate *b* being exaggerated to explain the shape. For example, the tube when soldered is forced upon an accurate steel cylinder or triblet, in doing which it is rounded tolerably to the form with a wooden mallet, so as to touch the mandrel in places; the end is set down with the hammer around the shoulder or reduction of the triblet, and on the drawing tube and triblet, by means of the loose key or transverse piece *a*, through the draw-plate *b*, the tube becomes elongated, and contracted close upon the triblet at every part, as the metal is squeezed between the mandrel and plate. The fluted tubes for pencil-cases, such as *c*, are drawn in this manner through ornamental plates, the triblets being in general cylindrical. Some of the drawn tube called joint-wire, is much smaller than *d*, and is used by silversmiths for hinges and joints. It is drawn upon a piece of steel wire, which being too small to admit the shoulder for holding on the tube, the latter is tapered off with a file, and the tube and wire are grasped together within the dogs, and drawn like a piece of solid wire. A semicircular channel is filed half-way in both the parts to be hinged, and short pieces of the joint-wire are soldered in each alternately.

Figs. 287



288.



Triangular, square, and rectangular brass tubes are in common use in France for sliding rules and measures. These are made in draw-plates with movable dies, Fig. 288, which admit of adjustment for size. The dies are rounded on their inner edges, and are contained in a square frame with adjusting screws, and the whole lies against a solid perforated plate.

In the general way, tubes of small diameters are completed at two draughts—sometimes three are used—and by this time the tube has received its maximum amount of hardness; therefore the first thickness of the metal and the diameter of the plates require a nice adjustment. The tube, when finished, is drawn off the triblet by putting the key through the opposite extremity of the same, and drawing the triblet through a brass collar which exactly fits it; this thrusts off the tube, which will in general be almost perfectly cylindrical and straight, except a trifling waste at each end.

It requires a very considerable assortment of truly cylindrical triblets to suit all works; and when the tubes are used in pairs, or to slide within one another, as in telescopes, it calls for a nice correspondence or strict equality of size between the aperture of the last draw-plate and the diameter of the triblet for the size next larger; and as these holes are continually wearing, it requires good management to keep the succession in due order, by making new plates for the last draught and adapting the old ones to the prior stages. Sometimes, for an occasional purpose, the triblet is enlarged by leaving a tube upon it and drawing the work thereupon; but this is not so well as the turned and ground surface of the steel triblet.

Tubes from $\frac{1}{10}$ inch internal diameter and 8 or 10 inches long, up to those of 2 or 3 inches diameter and 4 or 5 feet long, are drawn vertically by means of a strong chain wound on a barrel by wheels and pinions, as in a crane. In Donkin's enormous tube-drawing machine, which is applicable to making tubes, or rather cylinders, for paper-making and other machinery, as large as 26½ inches diameter and 6½ feet long, a vertical screw is used, the nut of which is turned round by toothed wheels driven by six men at a windlass.

All the tubes previously referred to are made of sheet-metals turned up and soldered edge to edge, but lead and thin pipes for water and other fluids have for a long period been cast as thick tubes, some 20 to 30 inches long, and extended to the length of 10, 12, or 15 feet on triblets, which require to be very exactly cylindrical or they cannot be withdrawn from the pipes.

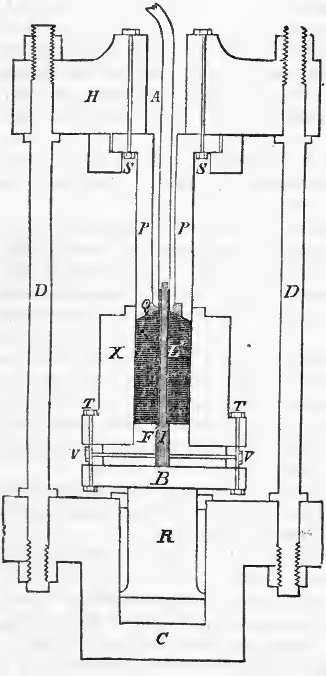
The brass tubes for the boilers of locomotive engines are now similarly made by casting and drawing without being soldered, and some of these are drawn taper in their thickness.

The ductility of tin is very great. It is from the ordinary tin tube of commerce (which is cast about 2 feet long, ½ inch thick, and drawn out to about 10 feet), out of which is made the collapsable vessels for artists' oils and colors. Pieces 3 inches long were extended to 36 inches by drawing them through ten draw-plates, which are sometimes placed in immediate succession, the one to commence just as the other had finished. The tube seemed to grow under the operation, and it was thus reduced, without annealing, from half an inch thick, as cast, to the 170th of an inch thick, and it was stretched fully sixty times in length. This mode of making the tubes of collapsable vessels, has been superseded by another, presenting far greater ingenuity, and described hereafter.

Some of the smallest tin tube of commerce, when removed from the ten-foot triblet, is drawn through smaller plates without any triblet being used. This reduces the diameter, with little change of thickness, so that the half-inch tube becomes a nearly solid wire, measuring about ¼ inch diameter externally, which is known as beading, and used to form the raised ledges around tables and counters covered with pewter.

The accompanying sectional view gives the hydraulic press, and an arrangement for manufacturing lead pipe. The principle is claimed by Tetham, Cornell, Burr, and others. *C* is the hydraulic cylinder, and *R* the ram rising from it. A cross-head is attached to the hydraulic cylinder, and connected with the upper cross-head *H* by rods *D D*. On the top of the ram a head-block *B* is placed. A foot-block *F* is attached to the bottom of the lead cylinder *L*, and the head-block, the foot-block, and the lead cylinder are secured firmly together by bolts *T T*. By this arrangement the lead "plug" or cylinder *L* is moved upwards by the ram *R* of the hydraulic press. To the upper cross-head *H* the hollow piston *P* is attached by bolts *S S*. The die *Q*, placed at the lower end of the piston, hollow throughout, communicates with the aperture *A* in the upper cross-head. The movable core *I*, when in use, is firmly fixed to the head-block of the ram and extends upwards through the centre of the lead cylinder, and a little above it, so that it is inserted through the die *Q* at the end of the hollow piston *P*. The position of the core is regulated by means of the set-screws *V V*, which move the core and set it centrally to the die. When all the parts are thus arranged the lead cylinder is raised up to the lower end of the piston, the end of the core passing through the die.

Fig. 289.



The ram is forced upwards, carrying the cylinder X that contains the plug of lead L; this cylinder X passes over the hollow piston P. The pipe is formed at the point of pressure Q, it then passes through the hollow piston and out through the aperture A.

CHAPTER XIX.

SOLDERING.

General Remarks and Tabular View.—Soldering is the process of uniting the edges or surfaces of similar or dissimilar metals and alloys by partial fusion. In general, alloys or solders of various and greater degrees of fusibility than the metals to be joined, are placed between them, and the solder when fused unites the three parts into a solid mass. Less frequently the surfaces or edges are simply melted together with an additional portion of the same metal.

The chemical circumstances to be considered in respect to soldering are, for the most part, set forth in the section on the fusibility of alloys, pages 217 to 220, to which the reader is referred. It is there explained that the solders must be necessarily somewhat more fusible than the metals to be united; and that it is of primary importance that the metallic oxides and any foreign matters be carefully removed, for which purpose the edges of the metals are made chemically clean, or quite bright, before the application of the solders and heat; and as during this period their affinity for oxygen is violent, they are covered with some flux which defends them from the air, as with a varnish, and tends to reduce any portion of oxide accidentally existing.

The solders are broadly distinguished as *hard solders* and *soft solders;* the former only fuse at the red heat, and are consequently suitable alone to metals and alloys which will endure that temperature; the soft solders melt at very low degrees of heat, and may be used for nearly all the metals.

The attachment is in every case the stronger the more nearly the metals and solders respectively agree in hardness and malleability. Thus, if two pieces of brass or copper, or one of each, are brazed together, or united with spelter-solder, an alloy nearly as tough as the brass, the work may be hammered, bent and rolled almost as freely as the same metals when not soldered, because of the nearly equal cohesive strength of the three parts.

Lead, tin, or pewter, united with soft solder, are also malleable from the near agreement of these substances; whereas when copper, brass and iron are soft-soldered, a blow of the hammer, or any accidental violence, is almost certain to break the joint asunder, so long as the joint is weaker than the metal generally; and therefore the joint is only safe when the surrounding metal, from its *thinness*, is no stronger than the solder, so that the two may yield in common to any disturbing cause.

The forms of soldered joints in the thin metals have been figured and explained in pages 293 to 296; and soldered joints in thicker works resemble the several attachments employed in construction generally. When the spaces between the works to be joined are wide and coarse, the fluid solder will probably fall out, simply from the effect of gravity; but when the crevices are fine and close, the solder will be as it were sucked up by capillary attraction. All soldered works should be kept under motionless restraint for a period, as any movement of the parts during the transition of the solder from the fluid to the solid state disturbs its crystallization and the strict unity of the several parts.

In hard-soldering, it is frequently necessary to bind the works together in their respective positions; this is done with soft iron *binding-wire*, which for delicate jewelry work is exceedingly fine, and for stronger works is the twentieth or thirtieth of an inch in diameter; it is passed around the work in loops, the ends of which are twisted together with the pliers.

In soft soldering, the binding wire is scarcely ever used, as from the moderate and local application of the heat, the hands may in general be freely used in retaining most thin works in position during the process. Thick works are handled with pliers or tongs whilst being soft-soldered, and they are often treated much like glue joints, if we conceive the wood to be replaced by metal, and the glue by solder, as the two surfaces are frequently coated or tinned whilst separated, and then rubbed together to distribute and exclude the greater part of the solder.

The succeeding "Tabular View of the Processes of Soldering" may be considered as the index, which refers to the ordinary methods of soldering most metals.

TABULAR VIEW

OF THE PROCESSES OF SOLDERING.

Note.—To avoid continual repetition, references are made to the pages of this volume which illustrate the respective subjects, and also to the lists on the opposite page, in which some of the solders, fluxes. and modes of applying heat are enumerated.

HARD-SOLDERING. 339.

Applicable to nearly all metals less fusible than the solders; the modes of treatment are nearly similar throughout.

The hard solders most commonly used are the spelter solders, and silver solders. The general flux is borax, marked A, *on page* 334; *and the modes of heating are the naked fire, the furnace or muffle, and the blowpipe marked* a. b. g.

Note.—The examples commence with the solders (the least fusible first), followed by the metals for which they are commonly employed.

Fine Gold, laminated and cut into shreds, is used as the solder for joining chemical vessels made of platinum.

Silver is by many considered as much the best solder for German silver.

Copper in shreds, is sometimes similarly used for iron.

Gold solders laminated, are used for gold alloys. See 191–193 and 341.

Spelter solders granulated whilst hot, are used for iron, copper, brass, gun-metal, German silver, etc., 184, 339–341.

Silver solders laminated, are employed for all silver works and for common gold work, also for German silver, gilding metal, iron, steel, brass, gun-metal, etc., when greater neatness is required than is obtained with spelter-solder. 199 and 341.

White or button solders granulated, are employed for the white alloys called button metals; they were introduced as cheap substitutes for silver-solder. 188.

SOFT-SOLDERING. 341.

Applicable to nearly all the metals; the modes of treatment very different.

The soft-solder mostly used, is 2 *parts tin and* 1 *part lead; sometimes from motives of economy much more lead is employed, and* 1½ *tin to* 1 *lead is the most fusible of the group unless bismuth is used. The fluxes* B *to* G, *and the modes of heating* a *to* i, *are all used with the soft-solders.*

Note.—The examples commence with the metals to be soldered. Thus in the list Zinc, 8, C, *f*, implies, that zinc is soldered with No. 8 alloy, by the aid of the muriate or chloride of zinc, and the copper bit. Lead, 4 to 8, F, *d, e,* implies that lead is soldered with alloys varying from No. 4 to 8, and that it is fluxed with tallow, the heat being applied by pouring on melted solder, and the subsequent use of the heated iron not tinned; but in general one only of the modes of heating is selected, according to circumstances.

Iron, cast-iron and steel, 8, B, D, if thick heated by *a*, *b*, or *c*, and also by *g*. 344.

Tinned iron, 8, C, D, *f*. 342–3.

Silver and Gold are soldered with pure tin or else with 8, E, *a*, *g*, or *h*.

Copper and many of its alloys, namely, brass, gilding metal, gun-metal, etc., 8, B, C, D; when thick heated by *a*, *b*, *c*, *e*, or *g*, and when thin by *f*, or *g*. 343–5.

Speculum metal, 8, B, C, D, the heat should be most cautiously applied, the sand-bath is perhaps the best mode.

Zinc, 8, C, *f*. 344.

Lead and lead pipes, or ordinary plumbers' work, 4 to 8, F, *d*, or *e*, 342.

Lead and tin pipes, 8, D & G mixed, *g*, and also *f*. 345.

Brittannia metal, 8, C, D, *g*.

Pewters, the solders must vary in fusibility according to the fusibility of the metal; generally G and *i* are used, sometimes also G and *g*, or *f*. 345–6.

Tinning the metals, and washing them with lead, zinc, etc. 346-.7

SOLDERING PER SE, OR BURNING TOGETHER. 347.

Applicable to some few of the metals only, and which in general require no flux.

Iron and brass, etc., are sometimes burned, or united by partial fusion, by pouring very hot metal over or around them, *d*. 347–9.

Lead is united without solder, by pouring on red-hot lead, and employing a red-hot iron, *d*, *e*, 347, and also by the autogenous process, page 350.

ALLOYS AND THEIR MELTING HEATS.*

No. 1.	1 Tin,	25 Lead	. . .	558	Fahr.
2.	1 —	10 —	. . .	541	—
3.	1 —	5 —	. . .	511	—
4.	1 —	3 —	. . .	482	—
5.	1 —	2 —	. . .	441	—
6.	1 —	1 —	. . .	370	—
7.	1½ —	1 —	. . .	334	—
8.	2 —	1 —	. . .	340	—
9.	3 —	1 —	. . .	356	—
10.	4 —	1 —	. . .	365	—
11.	5 —	1 —	. . .	378	—
12.	6 —	1 —	. . .	381	—
13.	4 Lead,	4 Tin,	1 Bismuth	320	—
14.	3 —	3 —	1 —	310	—
15.	2 —	2 —	1 —	292	—
16.	1 —	1 —	1 —	254	—
17.	2 —	1 —	2 —	236	—
18.	3 —	5 —	2 —	202	—

Note.—By the addition of 3 parts of mercury to No. 18 it melts at 122° F., and may be used for anatomical injections, and for stopping teeth.

FLUXES.

A. Borax. 339.
B. Sal-ammoniac, or mur. of ammo'a. 343–4.
C. Muriate, or chloride of zinc. 344.
D. Common resin.
E. Venice turpentine.
F. Tallow. 342.
G. Gallipoli oil, a common sweet oil. 346.

MODES OF APPLYING HEAT.

a. Naked fire. 335–6.
b. Hollow furnace or muffle. 335.
c. Immersion in melted solder. 344.
d. Melted solder or metal poured on. 341–7.
e. Heated iron not tinned. 342.
f. Heated copper tool, tinned. 342–9.
g. Blowpipe flame 336 to 339, 341, 345, 350.
h. Flame alone, generally alcohol.
i. Stream of heated air. 346.

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* The table by H. GAULTHIER DE CLAUBRY, from which the present extract is

THE MODES OF APPLYING HEAT IN SOLDERING.—The modes of heating works for soldering are extremely varied, and depend jointly upon the magnitude of the objects, the general or local manner in which they are to be soldered, and the fusibility of the solders. It appears to be now desirable to advert to such of the modes of applying heat enumerated in the tabular view, as are of more general application, leaving the modes specifically employed in heating works to their respective sections.

In hard-soldered works, the fires bear a general resemblance to those employed in forging iron and steel, and already described; in fact, the blacksmith's forge is frequently used for brazing, although the process is injurious to the fuel as regards its ordinary use. Coppersmiths, silversmiths, and others, use a similar hearth, but which stands further away from the upright wall, so as to allow of the central parts of large objects being soldered; the blows are always worked by the foot, either by a treadle, as in Fig. 42, p. 93, or more commonly by a chain from the rocking-staff terminating in a stirrup.

Some parts of the remarks on forging iron and steel, p. 86 to 94, and also of those on hardening and tempering steel, 147 and 152, refer to similar applications of heat to those required in soldering.

The brazier's hearth for large and long works, is a flat plate of iron, about four feet by three, which stands in the middle of the shop upon four legs: the surface of the plate serves for the support of long tubes and works over the central aperture in the plate which contains the fuel, and measures about two feet by one, and five or six inches deep. The revolving fan is commonly used for the blast, and the tuyere irons, which have larger apertures than usual, are fitted loosely into grooves at the ends, to admit of easy renewal, as they are destroyed rather quickly. The fire is sometimes used of the full length of the hearth, but is more generally contracted by a loose iron plate; occasionally two separate fires are made, or the two-blast pipes are used upon one. The hood is suspended from the ceiling, with counterpoise weights, so as to be raised or depressed according to the magnitude of the works; and it has large sliding tubes for conducting the smoke to the chimney.

Furnaces are occasionally used in soldering, or the common fire is temporarily converted into the condition of a furnace from being built hollow, or by the insertion of iron tubes or muffles, amidst the ignited fuel, as already explained in reference to forging and hardening. For want of any of these means, the amateur may use the ordinary grate, or it is better to employ a brazier or chaf-

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derived, enumerates 102 different alloys intended to be used for the safety plugs of steam boilers, in order that the fusion of the plug, and the consequent escape of the water, may occur when the steam exceeds any predetermined pressure, dependent on thermometric temperature. See *Le Dictionnaire de l'Industrie Manufacturière, Commerciale, et Agricole, par A. Baudrimont, Blanqui aîné et autres.* Paris, 1833. Vol. I., p. 326.

ing dish containing charcoal, and urged with hand-bellows blown by an assistant, as then both hands are at liberty to manage the work and fuel.

Fresh coals are highly improper for soldering, on account of the sulphur they always contain; the best fuel is charcoal, but in general coke or cinders are used. Lead is equally as prejudicial to the fire in soldering, as it is in welding iron and steel, or in forging gold, silver, or copper; as the lead readily oxidizes and attaches itself to the metals that are being soldered or welded, preventing the union of the parts, and in almost all cases rendering the metals brittle and unserviceable.

There are many purposes in the arts which require the application of heat, having the intensity of the forge fire or of the furnace, but with the power of observation, guidance, and definition of the artist's pencil. These conditions are most efficiently obtained by the blowpipe, an instrument by which a stream of air is driven forcibly through a flame, so as to direct it either as a well-defined cone, or as a broad jet of flame, against the object to be heated, which is in many cases supported upon charcoal, by way of concentrating the heat.

The blowpipe is largely used—namely, in soldering, in hardening and tempering small tools, in glass-blowing for philosophical instruments and toys, in glass-pinching with metal moulds made like pliers, in enameling, and by the chemist and mineralogist, as an important means of analysis; the instrument has consequently received very great attention both from artisans and distinguished philosophers.

Most of the blowpipes are supplied with common air, and generally by the respiratory organs of the operator; sometimes by bellows moved with the foot, by vessels in which the air is condensed by a syringe, or by pneumatic apparatus with water pressure. In some few cases oxygen or hydrogen, or the same gases when mixed are employed; they are little used in the arts.

The ordinary blowpipe is a light conical brass tube, about 10 or 12 inches long, from one-half to one-fourth of an inch diameter at the end for the mouth, and from one-sixteenth to one-fiftieth at the aperture or jet; the end is bent as a quadrant, that the flame may be immediately under observation.

Fig. 290 represents the same instrument when fitted with a ball for collecting the condensed vapor from the lungs; it is seen by the enlarged section, Fig. 291, that the tube is discontinuous, and any moisture within it, proceeding in the direction of the arrow, is arrested in the ball. There are several other blowpipes for the mouth, with various contrivances, such as a series of apertures of different diameters, joints for portability, and for placing the jet at different angles, and projecting parts to support the instrument upon the table; but none of these are in common use.

The lungs may be used for the blowpipe with much more effect than might be expected, and with a little practice a constant stream may be maintained for many minutes, if the cheeks are kept fully distended with wind, so that their elasticity alone shall serve to impel a part of the air, whilst the ordinary breathing is carried on through the nostrils for a fresh supply.

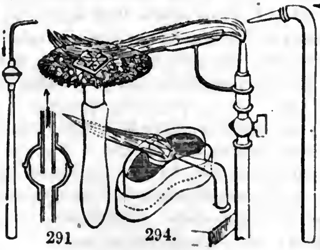
The most intense heat of the common blowpipe is that of the pointed flame; with a thick wax candle, and a blowpipe with a small aperture placed slightly within the flame, the mineralogist succeeds in melting small fragments of all the metals, when they are supported upon charcoal and exposed to the extreme point of the inner or blue cone, which is the hottest part of the flame; that is, fragments of all metals which do not require the oxhydrogen blowpipe invented by Dr. Hare of Philadelphia.

Larger particles, requiring less heat, are brought somewhat nearer to the candle, so as to receive a greater portion of the flame; and when a very mild degree of heat is needed, the object is removed further away, sometimes, as in melting the fluxes preparatory to soldering, even to the stream of hot air beyond the point of the external yellowish flame.

The first, or the silent pointed flame, is used by the chemist and mineralogist for reducing the metallic oxides to the metallic state, and is called the *deoxidizing* flame; the second, or the noisy brush-like flame, is less intense, and is called the *oxidizing* flame.

The artizan employs in soldering a much larger flame than the chemist, namely, that of a lamp the wick of which is from a quarter to one inch diameter; this must be plentifully supplied with oil; the blowpipe in such cases is selected with a large aperture; it is blown vigorously, and held a little distant from the flame, so as to spread it in a broad stream of light, extending over a large surface of the work, which is in most cases supported upon charcoal. When any minute portion alone is to be heated, the pointed flame is used with a milder blast of air and a decreased distance.

Figs. 290 292 293



291 294.

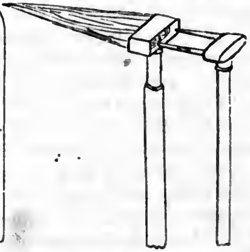


Fig. 292 is an arrangement, the use of which is attended with no fatigue to the operator. A stream of air from a pair of bellows directs a gas flame through a trough or shoot, the third of a cylindrical tube placed at a small angle below the flame. Instead of a charcoal support, they employ a wooden handle, upon which is fixed a flat disk of sheet-iron, about three or four inches diameter, covered with a matting of waste fragments of binding wire, entangled together and beaten into a sheet, about three-eighths or half an inch thick; some few of the larger pieces of wire extend round the edge of the disk to attach the remainder. The work to be soldered is placed upon the wire, which becomes partially red-hot from the flame, and retains the heat somewhat as the charcoal, but without the inconvenience of burning away, so that the broad level surface is always maintained. Small cinders are frequently placed upon the tool, either instead of, or upon the wire.

Sometimes, as in Fig. 293, the gas pipe is surmounted by a square hood, open at both ends, and two blast-pipes are directed through it; the latter arrangement is used by the makers of glass toys and seals; these are pinched in moulds something like bullet-moulds; the devices on the seals are produced by inserting in the moulds dried casts, made in plaster of Paris.

Makers of thermometers and other philosophical instruments generally use a table blowpipe, with a shallow oval, or rather a kidney-shaped lamp, Fig. 294, with a loop placed lengthways upon the short diameter for holding the cotton, which is sometimes an inch long and half an inch wide. The wick is plentifully supplied with tallow or hog's lard, and a furrow is made through it with a wire to afford a free passage for the blast from the fixed nozzle, by the size of which, and its distance from the flame, the latter is made to assume the pointed or brush-like character. This lamp is more cleanly, and emits less smell than those supplied with oil; any overflow of the tallow is caught in the outer vessel or tray, and when cold, the fat solidifies. The forge, Fig. 42, page 93, has also a blowpipe and lamp to enable it to be applied to the arts in a similar manner, and a very cheap table blowpipe is described by Dr. Michael Faraday, in his "Chemical Manipulation," page 120–169.

Many blowpipes have been invented for the employment of oxygen and hydrogen; the mixed gases were first used by Dr. Hare, of Philadelphia, who has been followed in various ways by many others. The construction and management of nearly all the blowpipes are described in Dr. Faraday's "Chemical Manipulation," 1830, pages 107 to 123. Also in "A Practical Treatise on the Use of the Blowpipe," by his talented countryman, Dr. Sheridan Muspratt, now of Liverpool, but formerly of Dublin. Two subsequent modifications of gas blowpipes which have been invented for the workshop, will alone be here described, namely, the Workshop Blowpipe, intended for soldering, hardening, and other purposes; and the Count de Richemont's Airo-hydrogen Blowpipe.

The general form of the "workshop blowpipe" is that of a tube open at the one end, and supported on trunnions in a wooden pedestal, so that it may be pointed vertically, horizontally, or at any angle as desired. Common street gas is supplied through the one hollow trunnion, and it escapes through an *annular* opening; whilst oxygen gas, or more usually common air, is admitted through the other trunnion which is also hollow, and is discharged in the centre of the hydrogen through a central conical tube; the magnitude and intensity of the flame being determined by the relative quantities of gas and air, and by the greater or less protrusion of the inner cone, by which the annular space for the hydrogen is contracted in any required degree.

From amongst numerous other small applications of heat, a portable blowpipe furnace may be noticed; it consists of a lump of pumice-stone three or four inches diameter, scooped out like a pan or crucible, and filled with small fragments of charcoal; sometimes a conical perforated cover is added: the inside may be intensely ignited, whilst the slow conducting power of the pumice-stone guards the hand from inconvenient heat.

EXAMPLES OF HARD SOLDERING.—It was mentioned in the tabular view that the several works united with hard-solders receive nearly the same treatment; a few examples will therefore serve to convey a general idea of hard-soldering; a process commonly attended with some risk of partially melting the works, because the fusing points of the metals and their respective solders often approach very nearly together.

Several of the hard solders contain zinc, which appears to be useful in different ways: first it increases their fusibility; in cases where the solder cannot be seen it serves as an index to denote the completion of the process, for when the solder is melted the zinc volatilizes, and burns with the well-known blue flame; and as at this moment some of the zinc is consumed, the alloy left behind becomes tougher, and more nearly approaches to the condition of the metal which it is desired to unite. The zinc may be therefore considered to act as a flux, and so likewise does the arsenic occasionally introduced into the gold and silver solders, as the arsenic is for the most part lost, between the processes of making and using the solders; but this metal being of a noxious quality, it is but little resorted to, and besides, it renders the other metals very brittle.

In every case of soldering, a general regard to cleanliness in the manipulation is important, and for the most part the edges of the metals are filed or scraped prior to their being soldered, as before observed; in those cases in which the red-heat is employed, filing or scraping are less imperative, as any greasy or combustible matters are burned away, and the borax has the property of combining with nearly all the metallic oxides and earthy bases, thereby cleansing the edges of the metals should that proceeding have been previously omitted.

The works in copper, iron, brass, etc., having been prepared for *brazing* (or soldering with a fusible brass), and the joints secured in position by binding wire where needful, the granulated spelter and pounded borax are mixed in a cup with a very little water, and spread along the joint by a slip of sheet metal or a small spoon.

The work, if sufficiently large, is now placed above the clear fire, first at a small distance so as gradually to evaporate the moisture, and likewise to drive off the water of crystallization of the borax; during this process the latter boils up with the appearance of froth or snow, and if hastily heated it sometimes displaces the solder. The heat is now increased, and when the metal becomes faintly red, the borax fuses quietly like a glass; shortly after, that is at a bright red, the solder also fuses, the indication of which is a small blue flame from the ignition of the zinc. Just at this time some works are tapped slightly with the poker to put the whole in vibration, and cause the solder to run through the joint to the lower surface, but generally the solder *flushes*, or is absorbed in the joint, and nearly disappears without the necessity for tapping the work.

It is of course necessary to apply the heat as uniformly as possible, by moving the work about so as to avoid melting the object as well as the solder; the work is withdrawn from the fire as soon as the solder has flushed, and when the latter is set, the work may be cooled in water without mischief.

Tubes are generally secured by loops of binding wire twisted together with the pliers; and those soldered upon the open fire are almost always soldered from within, as otherwise the heat would have to be transmitted across the tube with greater risk of melting the work, air being a bad conductor of heat; it is necessary to look *through* the tube to watch for the melting of the solder. Long tubes are rested upon the flat plate of the brazier's hearth, and portions equal to the extent of the fire are soldered in succession. The common tubes for gas-works, bedsteads, and numerous other purposes, are soldered from the outside; but this is done in short furnaces open at both ends and level with the floor, by which the heat is applied more uniformly around the tubes.

Works in iron require much less precaution in point of the heat, as there is little or no risk of fusion; thus in soldering the spiral wires to form the internal screw within the boxes of ordinary tail vices, the work is coated with loam, and strips of sheet brass are used as solder; the fire is urged until the blue flame appears at the end of the tube, when the fusion is complete; the work is withdrawn from the fire and rolled backwards and forwards on the ground to distribute the solder equally at every part. Other common works in iron, such as locks, are in like manner covered with loam to prevent the iron from scaling off.

Sheet iron may be soldered by filings of soft cast-iron, applied in the usual way of soldering with borax, which has been gradually dried in a crucible and powdered, and a solution of sal-ammoniac.

The finer works in iron and steel, those in the light-colored metals generally, and also the works in brass which are required to be very neatly done, are soldered with silver-solder. From the superior fusibility of silver-solder, and from its combining so well with the different metals without, "*gnawing them or eating them* *away*," or wasting part of the edges of the joints, silver-solder is very desirable for a great many cases; and from the more careful and sparing manner in which it is used, many objects require but little or no finishing subsequently to the soldering, so that the more expensive solder is not only better, but likewise in reality more economical.

The practice of silver-soldering is essentially the same as brazing. The joint is first moistened with borax and water; the solder (which is generally laminated and cut into little squares with the shears) is then placed on the joint with forceps. In heating the work additional care is given not to displace the solder; and for which reason some persons *boil* the borax, or drive off its water of crystallization at the red heat, then pulverize it and apply it in the dry state along with the solder; others fuse the borax upon the joint before putting on the solder.

Numerous small works united with the hard-solders, such as mathematical and drawing instruments, buttons, and jewelry, are soldered with the blowpipe; in almost all cases the work is supported upon charcoal, and sometimes for the greater concentration of the heat it is also covered with charcoal. The management of the blowpipe having been explained, it is only necessary to add that the magnitude and shape of the flame are proportioned to those of the works.

In soldering gold and silver, the borax is rubbed with water upon a slate to the consistence of cream, and is laid upon the work with a camel's-hair pencil, and the solders, although generally laminated, are also drawn into wire, or filed into dust; but it will be remembered the more minute the particles of the granulated metals, the greater is the degree of heat required in fusing them.

In many of the jewelry works the solder is so delicately applied that it is not necessary to file or scrape off any portion, none being in excess, and the borax is removed by immersing the works in the various pickling and coloring preparations to be adverted to.

EXAMPLES OF SOFT-SOLDERING.—The plumbers' sealed-solder, 2 parts lead and 1 of tin, melts at about 440° F.; the usual or fine tin-solder, 2 parts tin and 1 of lead, melts at 340°; and the bismuth-solders at from 250° to 270°: the modes of applying the heat consequently differ very much, as will be shown.

The soft-solders are prepared in different forms suited to the nature of the various works; No. 5, p. 334, the plumbers'-solder, is cast in iron moulds into triangular ingots measuring from 1 to 6 superficial inches in the section. No. 8, the fine tin solder, is cast in cakes about 4 by 6 inches, and ¼ to ½ inch thick; and this and the more fusible kinds, are trailed from the ladle upon an iron plate or flat stone, to make slight bars, ribbons, and even threads, that the magnitude of the solder may be always proportioned to the magnitude and circumstances of the work.

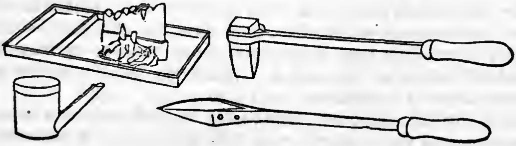
It is very essential that all soft-soldered joints should be particularly clean and free from metallic oxides; and, except where oil is exclusively used as the flux, greasy matters should be avoided, as they prevent the ready attachment of the aqueous fluxes. It is therefore usual with all the metals, except clean tinned plate, and clean tin alloys, to scrape the edges immediately before the process, so far as the solder is desired to adhere.

Lead works are first smeared or soiled around the intended joints, with a mixture of size and lamp-black, called *soil*, to prevent the adhesion of the melted solder; next the parts intended to receive the solder are scraped quite clean with the *shave-hook* (a triangular disk of steel riveted on a wire stem), and the clean metal is then rubbed over with tallow. Some joints are *wiped*, without the employment of the soldering iron: that is, the solder is heated rather beyond its melting point, and poured somewhat plentifully upon the joint to heat it; the solder is then smoothed with the cloth, or several folds of thick bed-tick well greased, with which the superfluous solder is finally removed.

Other lead joints are *striped*, or left in ridges, from the bulbous end of the plumber's crooked soldering-iron, which is heated nearly to redness, and not tinned; the iron and cloth are jointly used at the commencement, for moulding the solder and heating the joint. In this case less solder is poured on, and a smaller quantity remains upon the work; and although the striped-joints are less neat in appearance, they are by many considered sounder from the solder having been left undisturbed in the act of cooling. The vertical joints, and those for pipes, whether finished with the cloth or iron, require the cloth to support the fluid solder when it is poured on the lead.

Slight works in lead, such as lattices, requiring more neatness than ordinary plumbing, are soldered with the *copper-bit* or *copper-bolt* represented in Figs. 297 and 298; they are pieces of copper weighing from three or four ounces to as many pounds, riveted into iron shanks and fitted with wooden handles. All the works in tinned iron, sheet zinc, and many of those in copper and other thin metals, are soldered with this tool, frequently misnamed a soldering-*iron*, which in general suffices to convey all the heat required to melt the more fusible solders now employed.

Figs. 295 **297**



296 **298.**

If the copper-bit have not been previously tinned, it is heated in a small charcoal stove or otherwise to a dull red, and hastily filed to a clean metallic surface; it is then rubbed immediately, first upon a lump of sal-ammoniac, and next upon a copper or tin plate, upon which a few drops of solder have been placed; this will completely coat the tool; it is then wiped clean with a piece of tow, and is ready for use.

In soldering coarse works, when their edges are brought together, they are slightly strewed with powdered resin contained in the box, Fig. 296, or it is spread on the work with a small spoon; the copper-bit is held in the right hand, the cake of solder in the left, and a few drops of the latter are melted along the joint at short intervals. The iron is then used to heat the edges of the metal, both to fuse and to distribute the solder along the joint, so as to entirely fill up the interval between the two parts; only a short portion of the joint, rarely exceeding six or eight inches, is done at once. Sometimes the parts are held in contact with a broad chisel-formed tool, or a hatchet-stake, whilst the solder is melted and cooled, or a few distant parts are first *tacked* together or united by a drop of solder but mostly the hands alone suffice, without the tacking.

Two soldering tools are generally used, so that whilst the one is in the hand, the other may be reheating in the stove; the temperature of the bit is very important; if it be not hot enough to raise the edges of the metal to the melting heat of the solder, it must be returned to the fire; but, unless by mismanagement it is made too hot and the coating is burned off, the process of tinning the bit need not be repeated, it is simply wiped on tow, on removal from the fire. If the tool be overheated, it will make the solder unnecessarily fluid, and entirely prevent the main purpose of the *copper*-bit, which is intended to act both as a heating tool, and as a *brush*, first to pick up a small quantity or drop from the cake of solder which is fixed upright in the tray, Fig. 295, and then to distribute it along the edge of the joint.

The tool is sometimes passed only *once* slowly along the work, being guided in contact with the fold or ledge of the metal. This supposes the operator to possess that dexterity of hand, which is abundantly exhibited in many of the best tin wares; in these the line of solder is very fine and regular. The soldering-tool is then thin and keen on the edge, and the flux, instead of being resin, is mostly the muriate of zinc, with which the joint is moistened by means of a small wire or a stick prior to the application of the heated tool; sometimes the workman cools the part just finished, by blowing upon it as the bit proceeds in its course; and the iron, if overheated, is cooled upon a moistened rag placed in the empty space of the tray containing the solder.

Copper works are more commonly fluxed with powdered sal-ammoniac, and so is likewise sheet-iron, although some mix powdered resin and sal-ammoniac, others moisten the edges of the work with a saturated solution of sal-ammoniac, using a piece of cane the end of which is split into filaments to make a stubby brush, and they subsequently apply resin; each method has its advocates, but so long as the metals are well defended from oxidation any mode will suffice, and in general management the processes are the same.

Zinc is more difficult to solder than the other metals, and the joints are not generally so neatly executed; the zinc seems to remove the coating of tin from the copper soldering-tool; this probably arises from the superior affinity of copper for zinc than for tin. The flux sometimes used for zinc is sal-ammoniac, but the muriate of zinc, made by dissolving fragments of zinc in muriatic acid diluted with about an equal quantity of water, is much superior; and the muriate of zinc serves admirably likewise for all the other metals, without such strict necessity for clean surfaces as when the other fluxes are used.

The copper tool is only applicable to *thin* metals, because it requires such a degree of heat as will allow it to raise the temperature of the work to be joined, to the melting point of the solder; and the excess of heat thus required for *stout* metals, is apt, either to burn off the coating of solder, or to cause it to be absorbed as a process of superficial alloying. It requires some tact to keep the heat of the tool within proper limits by means of the charcoal or cinder fire, but with the airo-hydrogen blowpipe, explained at page 350–2, it is easy to maintain any required temperature for an indefinite period.

Thicker pieces of metal, such as the parts of philosophical apparatus, gas-fittings, and others which cannot be conveniently managed with the copper-bit, are first prepared by filling or turning, and each piece is then separately tinned in one of the following ways. Small pieces, immediately after being cleaned with the file or other tool, and without being touched with the fingers, are dipped into a ladle containing melted solder, which is covered with a little powdered sal-ammoniac. The flux meets the work before it is subjected to the heat, and the tinning is then readily done; sometimes the work is in the first instance sprinkled with resin, or rubbed over with sal-ammoniac water; the latter is rather a dangerous practice, as the moisture is apt to drive the melted metal in the face of the operator.

Thin pieces of brass or of copper alloys, if submitted to this method, must be quickly dipped, or there is risk of their being attacked and partly dissolved by the solder. There is some little uncertainty as to iron, and especially as to steel, being well coated by dipping; sometimes a forcible jar or a hard rub will remove most of the tin, and it is therefore safer to rub these works with a piece of heated copper shaped like a file, immediately on their removal from the melted solder, which makes the adhesion more certain.

Larger pieces of metal, or those it is inconvenient to dip into the ladle, are first moistened with sal-ammoniac water, or dusted with the dry powder or resin, and heated on a clear fire either of charcoal, coke, or cinders, until the strip of solder held against them is melted and adheres; as the lowest heat should be always used.

Another cleanly way of applying the heat, and which is also employed in tempering tools, varnishing, and cementing, is to make red-hot a few inches of the end of a flat iron bar about two feet long, to pinch it in the vice by the cold part, and to lay the work upon that spot which is at a suitable temperature; the work can be thus very conveniently managed, especially as it may be likewise placed in a good light.

Until the two parts of the work are thoroughly tinned, they must be well defended from the air by the flux to prevent oxidation; they are next made a trifle hotter than is required for tinning, and placed in contact whilst the solder is quite fluid, and a little additional solder is also used; when practicable, the two surfaces are rubbed together to perfect the tinning and spread the alloy evenly through the joint; the work is then allowed to cool under pressure applied by the hammer handle, the blunt end of a tool, the tail-vice, or in any convenient manner. The stages of this practice are similar to those of the carpenter, who having brushed the glue over the two pieces of wood, rubs them together and fixes them with the hand screws until cold, as before adverted to.

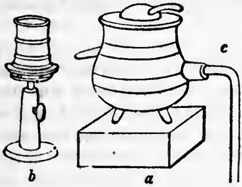
Small works are sometimes united by cleaning the respective surfaces, moistening them with sal-ammoniac water, or applying the dry powder or resin, then placing between the pieces a slip of tin-foil, previously cleaned with emory-paper, and pinching the whole between a pair of heated tongs to melt the foil; or, other similar modifications combining heat and pressure are used.

Many workmen who are accustomed to the blowpipe, as jewelers, mathematical instrument makers, and others, apply the blowpipe with great success in soft-soldering; but as the methods are in other respects similar to those given, they do not require particular notice, except that in some cases there is no choice but to tie the works together with binding-wire as in hard-soldering; but the preference is always given to detached tinning and rubbing together.

The modern gas-fitters are remarkably expert in joining tin and lead pipes with the blowpipe; they do not employ the method of the plumbers and pewterers, or the *spigot* and *faucet* joint surrounded by a bulb of solder, but they cut off the ends of the pipes with a saw, and file the surfaces to meet in butt joints, in mitres, or in T form joints as required. In confined situations they apply the heat from one side only with the blowpipe and rushes; they employ a rich tin solder, with oil and resin mixed in equal parts as the flux; the work looks like carpentry rather than soldering.

The pewterers employ a very peculiar modification of the blowpipe, which may be called the *hot-air blast,* and the names for which apparatus are no less peculiar; *a,* Fig. 299, being called the *hod,* and *b,* the *gentleman.* The first is a common cast-iron pot with a close cover, containing ignited charcoal; two nozzles leading respectively into and from it, to allow the passage of a stream of air, through the pipe *c*, from bellows worked by the foot. The pewter wares, many of which are circular, are placed on the *gentleman*, or a revolving pedestal, which may be adjusted by the side screw to any height: the workmen dip the strip of solder in a little pot of oil, and apply it to the joint with the right hand, whilst they slowly revolve the work with the left. This, which is a very controllable application of heat, includes in its range a moderately large extent of the pewterer's work, and answers the purpose extremely well: by some, the rushes and mouth blowpipe are used for circular as well as for other articles in pewter.

Fig. 299.



The pewters bear nearly the proportion of the alloys Nos. 8 to 12, page 334: for the less fusible containing most tin, the solder No. 8, or 2 tin 1 lead, is used; for the more fusible containing most lead, the bismuth solders, 2 tin 1 lead 1 bismuth, and others of similar low degrees of fusibility, are employed. The first solder is called by the pewterers *hard-pale*, the last *soft-pale*, and to suit the pewters of intermediate degrees of fusibility, the two are mixed in variable proportions and called *middling-pale;* but the table on page 334, and especially the original from which the 18 terms there given are extracted, would enable the solders to be definitely proportioned to their respective metals.

The flux always used by the pewterers is Gallipoli oil; it is a second rate olive oil, of peculiar quality, rather thick, green, and unfit for the table; but its selection requires judgment.

Iron, copper, and alloys of the latter metal, are frequently coated with tin, and occasionally with lead and zinc, to present surfaces less subject to oxidation; gilding and silvering are partly adopted from similar motives. As regards iron, the method of making the tinned plate is strictly a manufacturing process, which has been slightly noticed at page 200, and that of covering iron with zinc, so that it principally remains to describe the ordinary method of tinning vessels and other objects of copper, brass, and iron, after they have been manufactured, and which is in general thus performed.

Copper and brass vessels are first pickled with sulphuric acid, mostly diluted with about three times its bulk of water; they are then scrubbed with sand and water, washed clean and dried; they are next sprinkled with dry sal-ammoniac in powder, and heated slightly over the fire; then a small quantity of melted block-tin is thrown in, the vessel is swung and twisted about to apply the tin on all sides, and when it has well adhered the portion in excess is returned to the ladle, and the object is cooled in water. When cleverly performed very little tin is taken up, and the surface looks almost as bright as silver; some objects require to be dipped into a ladle full of tin.

Iron presents rather more difficulty, the affinity of the tin being less strong for iron than for copper; but the treatment is in general nearly the same. Old works require that the grease should be removed with concentrated muriatic acid, before the other processes are commenced; and in cast-iron vessels the grease often penetrates so deeply, owing to the porous nature of the metal, that the re-tinning is sometimes scarcely possible, and it is often more economical to obtain a new vessel.

An alloy of nickel, iron, and tin, has been introduced as an improvement in tinning the metals. The nickel and tin compound is harder than tin, and endures a much longer time: it is less fusible, and will not run or melt at a heat that would cause the ordinary tinning of pans to forsake the sides and lie in a mass at the bottom. Also that as an experiment to show the tenacity of the nickel, a piece of cast-iron tinned with the compound, had been subjected for a few minutes to the white heat under a blast, and although the tin was consumed, the nickel remained as a permanent coating upon the iron.

The proportions of nickel and iron mixed with the tin in order to produce the best tinning, are ten ounces of the best nickel, and seven ounces of sheet-iron, to ten pounds of tin. These metals are mixed in a crucible, and, to prevent the oxidation of the tin by the high temperature necessary for the fusion of the nickel, the metals are covered with one ounce of borax and three ounces of pounded glass. The fusion is completed in about half an hour, when the composition is run off through a hole made in the flux. In tinning metals with this composition the workman proceeds in the ordinary manner. The process was discovered by M. Budie, of the firm of Blaise and Co., Paris.

There is also another method, that of *cold-tinning*, by aid of the amalgam of mercury, described at page 217; but this process when applied to utensils employed for preparing or receiving food, appears questionable both as regards effectiveness, and wholesomeness, and the activity of the muriatic acid must not be forgotten; it should be therefore washed carefully off with water. The tin adheres, however, sufficiently well to allow other pieces of metal to be afterwards attached by the ordinary copper soldering-bit.

SOLDERING PER SE, OR BURNING TOGETHER.—This principally differs from ordinary soldering, in the circumstances that the uniting or intermediate metal is the same as those to be joined, and that in general no fluxes are employed.

The method of burning together, although it only admits of limited application, is in many cases of great importance, as when successfully performed the works assume the condition of greatest strength, from all parts being alike. There is no dissimilarity between the several parts as when ordinary solders are used, which are open to an objection, that the solders expand and contract by heat either more or less than the metals to which they are attached. There is another objection of far greater moment; the solders *oxidize* either more or less freely than the metals, and upon which circumstances hinge some galvanic or electrical phenomena; and thence the soldered joints constitute galvanic circuits, which in some cases cause the more oxidizable of the two metals to waste with the greater rapidity, especially when heat, moisture, or acids are present.

In chemical works this is a most serious inconvenience, and therefore, leaden vessels and chambers for sulphuric acid must not be soldered with tin-solder, the tin being so much more freely dissolved than the lead. Such works were formerly burned together by pouring red-hot lead on the joint, and fusing the parts into one mass, by means of a red-hot soldering-iron, as noticed at page 294; this is troublesome and tedious, and it is now replaced by the autogenous soldering, to be explained.

Pewter is sometimes burned together at the external angles of works, simply that no difference of color may exist; the one edge is allowed to stand a little above the other, as in Fig. 213, page 292, a strip of the same pewter is laid in the angle, and the whole are melted together, with a large copper-bit, Fig. 297, page 342, heated almost to redness; the superfluous metal is then filed off, leaving a well-defined angle without any visible joint.

Brass is likewise burned together; for instance the rims of large mural circles for observatories, that are five, six or seven feet diameter, are sometimes cast in six or more segments, and attached by burning. The ends of the segments are filed clean, two pieces are fixed vertically in a sand mould in their relative positions, a shallow space is left round the joint, and the entire charge of a crucible, say thirty or forty pounds of the melted brass a little hotter than usual, is then poured on the joint to heat it to the melting point. The metal overflows the shallow chamber or hole, and runs into a pit prepared for it in the sand; but the last quantity of metal that remains solidifies with the ends of the segments, and forms a joint almost or quite as perfect as the general substance of the metal; the process is repeated for every joint of the circle.

The compensation balance of the chronometer and superior watches is an interesting example of natural soldering. The balance is a small fly-wheel made of one piece of steel, covered with a hoop of brass. The rim, consisting of the two metals, is divided at the two extremities of the one diametrical arm of the balance, so that the increase of temperature which weakens the balance-spring contracts in a proportionate degree the diameter of the balance, leaving the spring less resistance to overcome. This occurs from the brass expanding much more by heat than steel, and it therefore curls the semicircular arcs inwards, an action that will be immediately understood if we conceive the compound bar of brass and steel to be straight, as the heat would render the brass side longer and convex, and in the balance it renders it more curved.

In the compensation balance the two metals are thus united: the disk of steel when turned and pierced with a central hole, is fixed by a little screw-bolt and nut at the bottom of a small crucible with a central elevation, smaller than the disk; the brass is now melted, and the whole allowed to cool. The crucible is broken, the excess of brass is turned off in the lathe, the arms are made with the file as usual, the rim is tapped to receive the compensation screws or weights, and lastly the hoop is divided in two places, at opposite ends of its diametrical arm.

A little black lead is generally introduced between the steel and the crucible; and other but less exact modes of combining the metals are also employed.

Cast-iron is likewise united by burning, as will be explained by the following example: To add a flange to an iron pipe, a sand mould is made from a wood model of the required pipe, but the gusset or chamfered band between the flange and tube is made rather fuller than usual to afford a little extra base for the flange. The mould is furnished with an ingate, entering exactly on the horizontal parting of the mould at the end of the flange, and with a waste head or runner proceeding upwards from the top of the flange, and leading over the edge of the flask to a hollow or pit sunk in the sand of the floor.

The end of the pipe is filed quite clean at the place of junction, and a shallow nick is filed at the inner edge to assist in keying on the flange; lastly, the pipe is plugged with sand laid in the mould. After the mould is closed, about six or eight times as much hot metal as the flange requires is poured through the mould. This heats the pipe to the temperature of the fluid iron, so that on cooling the flange is attached sufficiently firm to bear the ordinary pressure of screw-bolts, steam, etc.

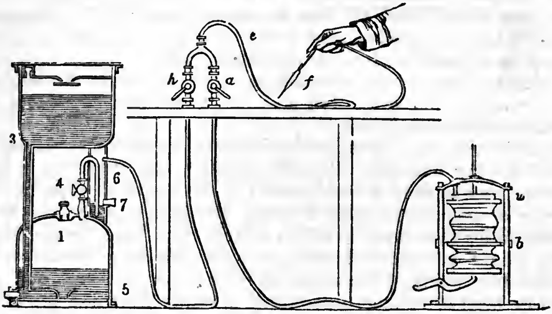
Steam and water-tight joints, in cast-iron works not requiring the power of after-separation, are often made by means of iron cement in the following proportions: 112 lbs. of cast-iron filings or borings, 1 lb. of sal-ammoniac, 1 lb. of sulphur, and 4 lbs. of whitening. Small quantities of the materials are mixed together with a little water shortly before use.

For minute cracks the cement is laid on externally as a thin seam, or for larger spaces it is driven in with calking-irons. The edges of the metal and the cement shortly commence one common process of rusting, and at the end of a week or ten days the joints will be found hard, dry, and permanent.

The method of burning is occasionally employed in most of the metals and alloys in making small additions to old castings, and also in repairing trifling holes and defects in new ones; it is only successful, however, when the pieces are filed quite clean, and abundance of fluid metal is employed, in order to impart sufficient heat to make a natural soldering—a process which is also, although differently accomplished, in plating copper with silver (page 198), as the two metals are raised to a heat just short of the melting point of the silver, and the metals then unite without solder by partial alloying.

To conclude the description of soldering processes, we have to refer to Fig. 300, which represents the *airo-hydrogen* blowpipe invented in France by the Count de Richemont. It is in a great measure converting the oxy-hydrogen blowpipe, invented by Dr. Hare, to the service of the workshop, and it is done with great simplicity and safety. The elastic tube *h* supplies hydrogen from the generator, and the pipe *a* supplies atmospheric air from a small pair of double bellows *b*, worked by the foot of the operator, and compressed by a constant weight *w*; the two pipes meet at the arch, and proceed through the third pipe *e* to the small jet *f*, from whence proceeds the flame. All the connections are by elastic tubes, which allow perfect freedom of motion, so that the portable blowpipe is carried to the work.

Fig. 300.

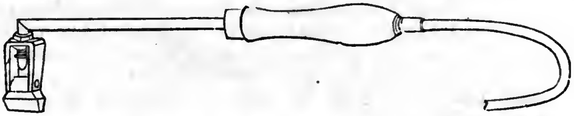


In soldering by the autogenous process, the works are first prepared and scraped clean as usual, the hydrogen is ignited, and the size of the flame is proportioned by the stop-cock *h*; the air is then admitted through *a*, until the flame assumes a fine pointed character, with which the work is united after the general method of blowpipe soldering, except that a strip of lead is used instead of solder, and generally without any flux.

This mode is described as being suitable to most of the metals, but its best application appears to be to plumbers' work, and it has been adopted for such in our government dock-yards. The weight of lead consumed in making the joints is a mere fraction of the weight of ordinary solder, which is both more expensive and more oxidizable, from the tin it contains. The gas soldering, as it is called, removes likewise the risk of accidents from the plumbers' fires, as the gas generator, which is in itself harmless, may be allowed to remain on the ground whilst the workman ascends to the roof, or elsewhere, with the pipe.

Lead is interposed as solder in uniting zinc to zinc, and it is also used in soldering the brass nozzles and cocks to the vessels of lead, and those of copper coated with lead, used as generators. Another very practical application of the gas flame, is for keeping the copper soldering tool, Fig. 301, at one temperature, which is done by leading the mixed gases through a tube in the handle, so that the flame plays on the back of the copper bit. This mode seems to be very well adapted to tin-plate and zinc works, especially as the common street gas may be used, thereby dispensing with the necessity for the gas generator, the construction and management of which alone remain to be explained.

Fig. 301.



The gas generator, Fig. 300, when it is first charged, the stopper 1, is unscrewed, and the lower chamber is nearly filled with curly shreds of sheet zinc, and the stopper is replaced. The cover is now removed, and a plug with a long wire is inserted from the top into the hole near 3; the upper chamber is next filled with dilute sulphuric acid (1 acid and 6 water), until it is just seen through the central hole to rise above the plate immediately beneath it. This measures the quantity of liquid required to charge the vessel without the risk of overflow. The plug is now withdrawn from 3, and the cocks 4, and *h*, being opened, the air escapes from the lower vessel by the pressure of the column of water which enters beneath the perforated bottom 5, upon which the zinc rests. The cocks 4 and *h* are now closed, and by the decomposition of the water hydrogen is generated, which occupies the upper part of the lower chamber, and drives the dilute acid upwards, through the aperture 3, so as to place matters in the position of the engraving. which represents the generator about two-thirds filled with gas.

The gas issues through the pipe *h*, when both cocks are opened, but it has to proceed through a safety box 6, in which the syphon tube dips two or three inches into a little plain water introduced at the lateral aperture 7; by this precaution the contents of the gasometer cannot be ignited, as, should the flame return through the pipe *h*, it would be intercepted by the water in the safety box. After three or four days' constant work the liquid becomes converted into the sulphate of zinc, and is withdrawn through the plug 8; the vessel is then refilled with fresh dilute acid as already explained, but the zinc lasts a considerable time.

The generators are made of lead, or where portability and lightness are required, of copper washed with lead, and all the exposed parts of the brass work are washed and united with lead to defend them from the acid. Occasionally the air is likewise supplied by *aerometers*, or vessels somewhat resembling the gas generator, but which are only filled with common air, and therefore do not require the zinc or acid.

The following is the broad difference between the airo-hydrogen and the oxy-hydrogen blowpipes. In the oxy-hydrogen blowpipe, the pure gases are mixed in the exact proportions of two volumes of hydrogen to one of oxygen, which quantities when combined constitute water, and in this particular case there is the greatest condensation of volume, and the greatest evolution of latent as well as of sensible heat.

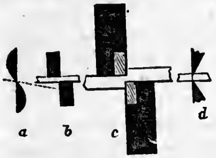
The airo-hydrogen blowpipe is supplied with common air and with pure hydrogen; this instrument is also the most effective when the oxygen and hydrogen are mixed in the proportions of 1 to 2; but the nitrogen, which constitutes four-fifths of our atmosphere, is now in the way and detracts from the intensity of the effect.

CHAPTER XX.

SHEARS.

Cutting Nippers for Wires.—Shears are instruments of a character quite different from any of those hitherto described, as the cutting edges of shearing tools are always used in pairs, and on opposite sides of the material to be sheared or severed. In many cases the shears are constructed after the manner of pincers and pliers, or as two double-ended levers united at the fulcrum by a pin, but other modes of uniting the two cutting parts of the instruments are also employed, as will be shown.

Fig. 302.



The sections of some varieties of this instrument are represented by *a b c* of the annexed Fig. 302, from which it will be seen that the edges of shears and scissors meet in lateral contact, and pass close against one another, severing the material by two cuts or indentations, or thrusts, which take place in the same plane as that in which the blades are situated and are moved.

Some of the largest shearing tools of the kinds used by engineers, such as *c*, serve to divide bars of iron, 4, 5 or 6 inches wide, and 1 to 2 inches thick, then requiring the greatest possible solidity and freedom from elasticity.

On the other hand, some of the finest scissors of the section *a*, such as are used by ladies in cutting lace, will cut with the greatest cleanness and perfection the most flexible thread or tissue of threads, or the finest membranes met with in animal or vegetable structures.

But this latter kind of shears, unlike the engineer's shears, is altogether useless unless possessed of a considerable share of elasticity, to keep their edges in accurate contact at that point in which the blades at the moment cross each other, as will be explained, otherwise such thin materials are folded down between the blades instead of being fairly cut. The transition from the elastic to the inelastic kinds of shears is not, as may be supposed, by one defined step, but by gradual stages, making it as difficult in this, as in other classifications, to adopt any precise line of demarcation.

In addition to the above, or to shears properly so considered, there are a few tools known as cutting pliers, or nippers, in which the blades meet in direct opposition, but do not pass each other as in the legitimate kind of shears. This kind is represented by the section *d*, Fig. 302.

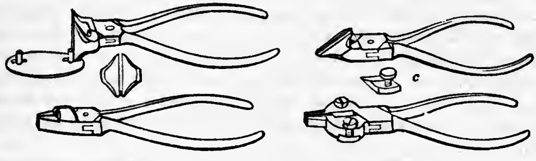
Cutting pliers, if they admit of being classed with shears, are certainly the most simple of the group, and are used for cutting asunder small wires, nails, and a few other substances. Their edges are simply opposed wedges, exactly as shown in the above diagram at *d*; and as respects the remainder of the instruments by which their wedges are composed, the most simple kind exactly resembles carpenters' ordinary pincers for drawing out nails, except that the cutting pincers are made with thinner edges; and Figs. 303 to 306 represent different kinds of cutting pliers and nippers.

When cutting nippers are compressed upon a nail or a piece of wire, they first indent it on opposite sides, and when from their penetration the surfaces of the wedges exert a lateral pressure against the material, the latter eventually yields, and is torn asunder at the moment the pressure exerted by the wedges exceeds the cohesive strength of the central metal yet uncut. Consequently the divided wire shows two beveled surfaces, terminating in a ridge slightly torn and ragged. The quantity of the material thus torn instead of being cut, will be the less, the softer the metal and the keener the pliers; but experience shows an angle of about 30 to 40 degrees to be the most economical for the edges of such tools.

Little remains to be said on the varieties of cutting pliers; most of these used by general artisans and clockmakers are smaller than carpenters' pincers, and the extremities of the jaws are beveled as in *watch-nippers*, Fig. 303, that they may cut pins lying upon a flat surface. Other cutting pliers, called *side-nippers*, are oblique, as in Fig. 304. Those used for the dressing-case, and known as *nail-nippers*, are concave on the edge, to pare the nails convex; and another kind, known as *nipper-pliers, bell-hangers'* or *bottlers' pliers*, have flat points at the end for grasping and twisting wires, and cutters on the sides for removing the waste ends, as shown in Fig. 305.

The edges of cutting nippers are apt to be notched if used upon hard wires, or if wriggled whilst the cutting edges are buried in the wire, and they scarcely admit of being reground or repaired. This inconvenience led to a modification of the instrument, Fig. 306, by the enlargement of the extremities, to admit of loose cutters fitted in shallow grooves being affixed by one screw in each as shown detached at *c*, so that the cutters may admit of removal and restoration by grinding, which end is effectually obtained, although somewhat to the prejudice of the instrument, by increasing its bulk.

Figs. 303 304



305 306.

Scissors and Shears for Soft Flexible Materials.—The nippers have edges of about 30 to 40 degrees, meeting in direct opposition, but yet leave ragged edges on the work; whereas the shears have edges commonly of 90 degrees, seldom less than 60 degrees. These edges pass each other and leave the work remarkably keen and exact.

Let the edges of scissors be ever so well sharpened, they act very imperfectly, if at all, unless the blades are in close contact at the time of passing; and this imperfection is the more sensible the thinner and more flexible the material to be cut, as it will then fold down between the blades if they do not come in contact. Whereas, when the blades exactly meet, the one serves to support the material whilst the other severs it; or rather this action is reciprocal, and each blade supports the material for the other, rendering the office of a counter-support, or of the bench, stool or cutting-board, used by the carpenter with the paring chisel.

On a cursory inspection of a pair of ordinary scissors, it may be supposed that their blades are made quite flat on their faces, or with truly plane surfaces, like the diagram Fig. 307, representing the imaginary longitudinal section of the instrument, the two blades of which are united by a screw, consisting of three parts differing in diameter, namely, the *head*, the *neck*, and the *thread*; the bottom of the countersink that receives the head of the screw is called the *shelf* or the *twitter-bit.* If, however, the insides of scissors were made flat, and as carefully as possible, they could scarcely be made to cut slender fibrous materials, or if at all, then for only a short period, and additional friction would accrue from the rubbing of their surfaces.

The form which is really adopted, more resembles the exaggerated diagram Fig. 308; the blades are each sloped some 2 or 3 degrees from the plane in which they move, so that their edges alone come into contact; instead of the blades being straight in their length they are a little curved so as to overlap; and close behind the screw-pin by which they are united, there is a little triangular elevation, insignificant in size but most important in effect, which may be considered as a miniature hillock or ridge, sloping away to the general surface near the hole for the screw. This enlargement or bulge is technically called the "*riding part,*" and, as there is one on each blade, when the scissors are opened or that the blades are at right angles, the points or extremities only of the riding parts come into contact, and the joints may then have lateral shake without any prejudice. But as the blades are closed, first the bases or points of the riding parts, and lastly the summits or tops, rub against each other, and tilt the blades beyond the central line of the instrument; the effect of which is to keep the successive portions of the two edges in contact throughout the length of the cut, as by the time the scissors are closed, the points of the blades are each sprung back to the central line of the scissors, which is dotted in the diagram.

Although scissors when in perfect condition for work may be loose, or shake on the joint when fully opened (and thereby placed beyond their range of action), they will be always found to be tight and free from shake, as soon as the blades can begin to cut the material near the joint, and so to continue tight until they meet at the points. That all scissors do exhibit this construction may be easily seen, as when they are closed and held edgeways between the eye and the light, they will be found only to touch at the points and at the riding parts, or those just behind the joint screw, the remainder being more or less open and gently curved; and their elastic action will also be experienced by the touch, as whilst good scissors are being closed, there is a smoothness of contact which seems to give evidence of some measure of elasticity.


Figs. 307


308


309.

Fig. 309 represents the section of the one blade of a pair of scissors, in which the elastic principle is differently introduced. These scissors are made without the riding part, but instead thereof, immediately behind the screw which unites the blade as usual, the one blade is perforated, for the purpose of admitting freely a small pin or stud fixed to the end of a short and powerful spring, so that the stud *s*, from acting on the opposite blade, throws the points of both towards each other, so as to give them a tendency to cross, but which being resisted by the edges of the blades touching one another, keeps them very agreeably in contact throughout their motion, and causes them to cut very well.

If further evidence is wanted of the elastic principle in scissors, it is distinctly shown in sheep shears, which besides their ostensible purpose of shearing off the fleece, are used by leather dressers and others. It is well known that sheep shears, Fig. 315, page 361, are made as one piece of steel, which is tapered at each end to constitute the cutting edges, is then for a distance fluted and straight to form the semi-cylindrical parts for the grasp, and that in the centre or opposite extremity, the steel is flattened and formed into a bow by which the blades are united and kept distended; sheep shears consequently require no joint pin, and the hands have only to compress them, as they spring open for themselves. If sheep shears are examined when fully opened, or when partially closed by tying round the blades a loop of string, it will be found that the blades have a tendency to spring into contact, as after having been pressed sideways and asunder, the cutting edges immediately return into exact contact the moment the distending pressure is removed.

The construction of scissors with the riding-place, as adverted to in Fig. 308, is that which ordinarily obtains in most scissors, from the finest of those used by ladies, to the heavy ponderous shears for tailors, which sometimes weigh above six pounds, and are rested on the cutting-board by one of their bows, that are large enough to admit the whole of the fingers.

The peculiar form of the insides of the blades is in all cases of paramount importance, and in the manufacture of fine scissors is attended by a person called a "*putter-together*," whose province it is to examine the screw-joint, and see to the form of the riding-places, and lastly to set the edges of the scissors, which for general purposes are sharpened on an oilstone at an angle of about 40 degrees, but for the fine scissors more nearly upright or at 30 degrees from the perpendicular.

So important, indeed, is the configuration of the inner face of scissors, that they should never be ground or meddled with at that part, but by a person fully experienced in their action, and scissors may with careful usage be kept in order for years without being ground, if the edges are occasionally set on the oilstone at the inclination above referred to. It will frequently happen that well-made scissors which appear to grate a little when closed, merely do so from dirt or dust, which if removed by passing the finger along the edges, will restore the scissors to their smooth and pleasant action.

It seems quite uncalled for to enter into the separate description of various instruments known as button-hole scissors, cutting-out, drapers', flower, garden, and grape scissors, horse trimming scissors; hair, lace, lamp, nail, paper, pocket, stationers', and tailors' scissors, and many others; nor of the large shears for the garden, such as pruning, trimming, and border shears, the distinctions between which varieties are sufficiently known to those who use the several kinds, but the author will merely notice such of them as present any peculiarity of structure.

Button-hole scissors are notched out towards the joint screw as in Fig. 311, so as to enable the instrument to make the incision a little distant from the edge of the material; the joint must be made stiff, so as to prevent the points catching against each other.

Figs. 310 311.

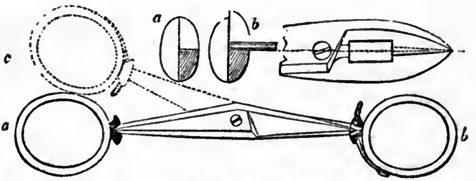


Fig. 312.

Flower and grape scissors assume the section of Fig. 310, so that they first cut the stem, and then hold it like a pair of pliers; the one blade requires to be made in two parts riveted together; when entirely closed they present an elliptical section *a*; and *b* shows how the stem of the flower is grasped; the blades are rounded at all parts that they may not injure the plants.

Lamp scissors have the one blade very broad, and with a little rim, to prevent the snuff of the lamp falling on the carpet.

Nail scissors for the dressing-case are made very strong, and with short blades. In using scissors formed in the ordinary mode, the fingers and thumb of the right hand have naturally a tendency to press the blades together, in that position in which they are intended to cut; but the left hand, on the contrary, has a tendency to separate the blades and defeat the principle on which scissors act. Therefore nail scissors are made in pairs, and formed in opposite ways, or as "rights and lefts," so that they may suit the respective hands.

Pocket scissors have blades which admit of being locked together in the form represented in Fig. 312, as the point of one blade catches into a small spring near the bow of the other; and the instrument cannot be opened until the spring or catch is released with the nail. When closed for the pocket, the bows stand on one line as at *a b*, when opened for use as at *a c*.

Surgical scissors are of many forms, but have generally short blades, and long, straight, slender handles, that the hand may not impede the vision. In some of the surgical scissors the blades are curved as scimitars, and others are curved sideways; these kinds are difficult to make, as the elasticity of contact in the blade is required nevertheless to be maintained.

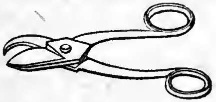
Many of the shears and scissors used in gardening, only differ from scissors and shears in general in their size, and the adaptation of their handles, some of which are of wood, and placed at an angle of 40 or 50 degrees, as in the letter Y inverted. Other garden shears used in trimming borders, have handles a yard long and inclined about 80 degrees to the blades, which may therefore lie on the ground whilst the individual stands nearly erect. Some of the border shears have rollers to facilitate their movement along the ground.

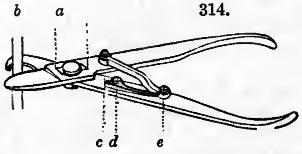
In pruning shears and scissors, two peculiarities of form are judiciously introduced. In the more simple of the two kinds, which is shown in Fig. 313, the one part of the instrument terminates in a hook, with a broad and sometimes a roughened edge, to retain the branch from slipping away; the other part of the instrument is formed as a thin cutting blade, the edge of which is convex. Theoretically it should be part of a logarithmic spiral, in which case the edge of the cutter would present a constant angle to the work throughout its action, and slide laterally through the incision made by itself, or make a sliding cut; whereas if the edge of the blade were radial, it would make a direct cut without any sliding, as in a paring chisel. The spiral blade cuts more easily, and will therefore remove a larger branch, with an action precisely analogous to that of the oblique cutters in some of the planes, although differently produced.

Some of these instruments, when a little modified in form, are mounted on poles from 6 to 10 feet long, and are actuated by a catgut; this tool, which is known as the *Averuncator*, is very efficient for pruning at a considerable distance above the head.

The other pruning shears represented in Fig. 314, are denominated *sliding shears*; the pin that unites the two parts fits in a round hole in the one blade and a long mortise in the other, and a link or bridle-rod *c e*, is attached by a screw to each lever; in consequence, when the instrument is fully opened the pin or fulcrum is at the end *a*, of the mortise, whereas, on the shears being gradually closed, the cutting blade slides downwards upon the pin until the fulcrum is near the opposite end *b*. In this modification of

Figs. 313 314.





shears the sliding action is produced to a much greater extent than with the spiral blade, but the construction is a little more expensive; and as the instrument is not provided with bows for the fingers, the spring *d e*, is added to throw it open.

Before dismissing this subject, two modifications of shears will be briefly adverted to; those used by card makers, and the revolving shears employed in manufacturing woollen cloth.

Card paper is prepared in large sheets; when dried and pressed it is cut into square pieces of the required sizes by means of long shears, the one blade of which is fixed at the end of a table, and has the joint at the farther extremity, whilst the cutting blade has a handle in front, and moves through a loop to keep the blade in its position, as in some chaff-cutting machines; there is also a stop fixed parallel with the blades, and as distant as the width of the slips into which the card is first divided, and these slips are then cut again the lengthway of the cards.. The shears are moved so rapidly, that the action sounds like that of knocking at a door, and still the cards agree most rigidly in size.

Revolving shears or "*perpetual shears*" are used for shearing off the loose fibres from the face of woollen cloths. For narrow cloths the cylinders are 30 inches long and 2 in diameter, eight thin knives are twisted around the cylinders, making 2¼ turns of a coarse screw, and are secured by screws and nuts which pass through flanges at the ends of the axis: formerly the cylinders were grooved and fitted with several thin narrow plates of steel 6 or 8 inches long. The edges of the eight blades are ground so as to constitute parts of a cylinder, by a grinder or *strickle* fed with emery, passed to and fro on a slide parallel with the axis of the cylinder, which is driven at about 1200 turns in the minute.

In use, the cylinder revolves about as quickly, and in contact with the edge of a long thin plate of steel, called the *ledger-blade*, which has a very keen rectilinear edge, measuring 40 to 50 degrees; the blade is fixed as a tangent to the cylinder, and the two are mounted on a swing carriage with two handles, so as to be brought down by the hands to a fixed stop. The edge of the ledger-blade is sharpened, by grinding it against the cylinder itself with flour emery and oil, by which the two are sure to agree throughout their length.

The cloth, before it goes through the process of cutting, is brushed so as to raise the fibres, it then passes from a roller over a round bar, and comes in contact with the *spring bed*, which is a long elastic plate of steel, fixed to the framing of the machine, and nearly as a tangent to the cylinder; this brings the fibres of the cloth within the range of the cutting edges, which reduce them very exactly to one level. The machine has several adjustments for determining, with great nicety, the relative positions of the cylinder, ledger-blade and spring bar, but which could not be conveyed without elaborate drawings. Formerly the cloth was passed over a *fixed* bed having a nearly sharp angular ridge, but which mode was far more liable to cut holes in the cloth than the spring bed.

Broadcloths require cylinders 65 inches long, and machinery of proportionally greater strength. In the cross-cutting machine, the cloth is cut from *list to list*, or transversely, in which case the cloth is stretched by hooks at the two edges, and there are two spring beds; the cylinder in this machine is 40 inches long, and the cloth is shifted that quantity between every trip until the whole piece is sheared. The perpetual shears are also successfully applied to coarse fabrics, including carpets.

A modification of the above revolving shears, made in a much less exact manner for mowing grass lawns, is fitted up somewhat as a wheelbarrow, or hand truck, so that the rotation of the wheels upon which the machine is rolled along, gives motion to the shears, which crop the grass to a level surface.

SHEARS FOR METAL WORKED BY MANUAL POWER.—When metals are very thin, such as the latten brass used for plating, and other purposes, they may be readily cut with stout scissors; and accordingly, we find the weakest of the shears for metal are merely some few removes in strength beyond the strong scissors for softer substances.

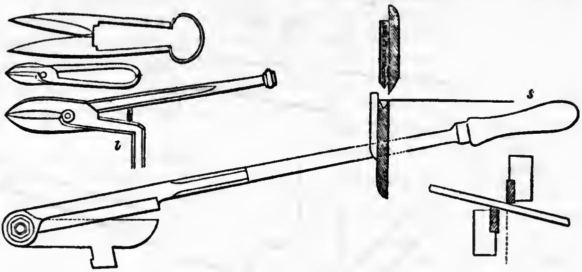
It is however to be observed that, as common scissors are sharpened to an angle varying from about 50 to 60 degrees, they may fairly be considered to *cut* the materials submitted to their action; but shears for metal have in general *rectangular* edges, as they are seldom more acute than 80 degrees, and therefore instead of cutting into the material, they rather *force* the two parts asunder, by the pressure of the two blades being exerted on opposite sides of the line of division.

It was recently stated to be of the utmost importance, that the blades of the weaker or elastic kind of shears should be absolutely in contact, or else thin flexible materials would be folded down between their blades without being cut.

And it may now be urged as of equal importance, that the blades of the shears for metal should be also exactly in contact, not that rigid plates or bars of metal could be bent or folded down between their blades, even if these were a little distant; but the resistance to the operation of cutting would be then enormously increased, because the force exerted to compress the shears would not be then exerted in the line of their greatest resistance, which is strictly the case when the edges truly meet in one plane.

If the blades were distant as in Fig. 320, from the want of direct support, the bar or plate would be tilted up and become jammed; this would tend further to separate the blades, and the shears would be strained or perhaps broken without dividing the bar, whereas all these evils are avoided if the shears close accurately in one and the same plane, as if the lower blade were shifted to the dotted line, and in which case they require the least expenditure of power and act with the best effect.

Hand shears, which are the smallest of these tools, are made of the form represented in Fig. 316, and vary from about four to nine inches in total length. They are much used by tinmen, coppersmiths, silversmiths and others who work in sheet metals, and are often called *snips,* to distinguish them from bench shears. Sometimes, however, they are fixed by the one limb in the table or tail vice, and then become essentially bench shears,—and this enables them to be used with somewhat increased power.



Figs. 315, 316, 317, 318, 319, 320.

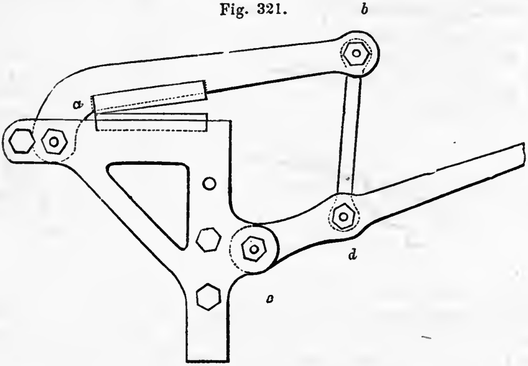
Bench shears of the ordinary form are represented in Fig. 317. The square tang *t* is inserted in a hole in the bench, or in a large block of wood, or else in the chaps of the bench vice itself. A less usual modification is seen in Fig. 318, with the joint at the far end, and the cutting part between the joint and the handle.

Bench shears vary in total length from about one foot and a half to four feet, and the blades occupy about one-fifth of the length. Sometimes to increase the power of these shears the handle is forged thicker at the end to add weight, so that when the instrument is closed with a jerk, it may by its momentum cut thicker metal than could be acted upon by a simple thrust; but when considerable power is required it is better to resort to the shears next described.

Purchase shears, which are represented in Fig. 321, are in every respect more powerful than those previously noticed; the framing is much more massive, and the cutters are rectangular bars of steel inserted in grooves, to admit of their being readily sharpened or renewed. Instead of the hand being applied on the first lever or *a b,* a second lever *c d e* is added, and united to the first by the link *b d,* and but for the limit of the paper the hand lever *c d e* would have been represented of twice its present length.

As the length of the part *a b* is three to four times the length of *c d,* the hand has to move through three to four times the space it would if applied directly to the shear lever, and consequently the purchase shears have three to four times the force of common shears, supposing the manual lever to be of equal length in each kind. There is usually at the back of the moving blade a very powerful spring or *back stay,* to keep the two edges in contact, and still further behind a *stop* to determine the lengths or widths of the pieces sheared off.

Fig. 321.



Before using the shears, in those cases where the stop is not employed to determine the width, it is usual to mark on the work the lines upon which it is intended to be sheared. The shears are then opened to the full, and the extremity of the line is placed in the angle formed by the jaws. If the work is short, it is also observed whether the opposite end of the line lies exactly on the edge of the lower blade; but if the work is long, the guidance is less easy. When the blades are closed the work will probably slip endlong, notwithstanding the resistance of the hand, until the angle at which the blades meet is so far reduced that they begin to grasp the work, when the extreme edge will be first cut through, and then the incision will be extended to the full length of the blades.

As, however, each successive portion is severed, the two parts are bent asunder to the angle formed by the blades, and both pieces become somewhat curved or curled up. Provided the cut is through the middle of the sheet, so that both are equally strong, the two parts become curved in the same degree; but when a narrow and consequently weaker piece is removed from the edge of a wide sheet, the curling-up occurs almost exclusively in the narrow strip, on account of its feebleness. In long pieces it is sometimes necessary to increase the curvature, in order that as the work is sheared off the one part may pass above, and the other below the rivet or screw by which the halves of the shears are united.

When from use or accident the joint becomes loose, so as not to retain the two parts in contact, in order to make the shears cut, the moving half must be pressed against that which is fixed to the pedestal or tail vice. Sometimes the sway of the blades of jointed shears is prevented by allowing the moving arm to pass through a loop or guide which may retain it in position.

Such a guide is mostly used in the light shears with which printers cut their space line leads, or those thin strips of metal inserted between the lines of type, to separate them and make the printing more open. The leads are cast in strips about a foot long, and are cut into pieces of the exact width of a page, by laying them in a trough having at the end a pair of shears, and beyond these a stop to determine the precise length, so that any number of the leads may be cut exactly to the length required. Before adverting to the powerful shears used by engineers, two modifications of those already described will be noticed.

Fig. 319, page 361, represents the section through the blades of a pair of shears, by which the tags or tin ferrules at the end of silk laces are cut and bent at one process, the general aspect of the tool being that of Fig. 317, page 361. The shearing blades are shaded obliquely in Fig. 319, and to the lower, which is fluted on the edge, is attached a stop that determines the width of the piece removed from the strip *s*, to make the tag. The upper shear blade, which is ground more acutely than usual, carries a ridge piece (shaded vertically), which compresses the strip as it is cut off, into the fluted edge of the lower blade, and thereby throws it into a channeled form; and by the employment of a pair of hollow pliers, or else a light hammer and a hollow crease, the bending is readily completed, and the tag attached to the cord.

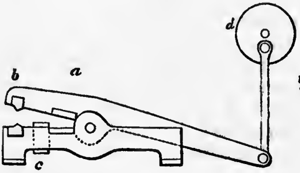
A nearly similar machine, but constructed more in accordance with the printers' space line shears, is used for cutting slips of thin latten brass, into the channeled pens used in stationers' machines for ruling the blue and red lines on paper for account books, etc. The one side of a slip of brass 1½ inch wide, is thus cut and channeled at intervals suited to every line; the sides of every channel are closed to form a narrow groove, and the intervening pieces are removed with hand shears. The compound pen is fixed on a hinged board, and a strip of thick flannel laid at the top of the pen, is saturated with ink which flows steadily down all the channels, whilst the paper is moved horizontally under the pens, by two or three rollers and tapes, somewhat as in the feeding apparatus of printing machines, and thus the whole page is ruled one way and very quickly.

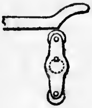
Shears of the above kinds, with rectilinear blades, are not suited to cutting out curvilinear objects, such for example as the sides of callipers *a*, Fig. 349. The outline of such callipers is first of all marked on the sheet of steel from a templet, and with a brass wire which leaves a sufficient trace; the outline is followed with a hammer and chisel upon an anvil, the chisel having a rounded or convex edge. Detached cuts running into one another are made round the curve, and the work is finally separated by pinching it in the tail-vice successively at all parts of the curve, and wriggling the other edge of the sheet with the hand until it breaks.

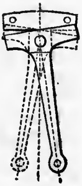
The vice is often also used for cutting off straight pieces, which are then fixed with the line of division exactly flush with the chaps, and an ordinary straight chisel is so applied, that the chamfer of the tool rests on the chaps of the vice, and the edge lies at a small angle to the work, and after each successive blow, the chisel is moved a little to the left without losing its general position.

ENGINEERS' SHEARING TOOLS; GENERALLY WORKED BY STEAM POWER.—The earliest machines of this class were scarcely more than a magnified copy of the bench shears shown on page 361, but made very much stronger; thus, Fig. 322 represents a shearing and squeezing tool used in some iron works and smithies. It has one massive piece that is fixed to the ground, and jointed to it is the lever, which carries at *a*, a pair of shearing cutters situated exactly on two radii struck from the centre of motion; this machine has also two squeezers *b*, for moulding pieces of iron when red-hot to the particular forms of the dies. The longer end of the lever is united by a connecting-rod to an eccentric stud in the disk *d*, which is made to revolve by the steam-engine.

Figs. 322 323 324 325.







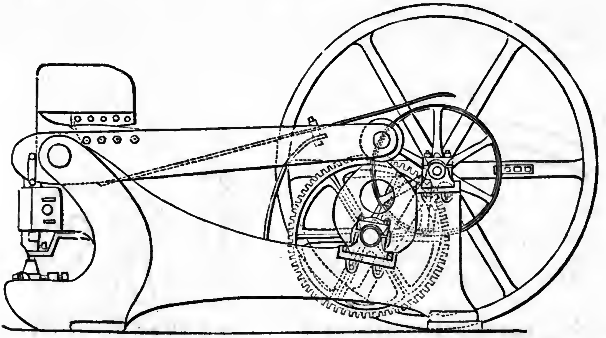
Shears are sometimes moved by means of an axis carrying two rollers, placed at the extremities of a diametrical arm, as in Fig. 323. The one roller acts on the radial part of the shear lever in the act of cutting, and the curved part then allows the lever to descend by its own weight rapidly, yet without a jerk, by the time the other roller comes into action for the succeeding stroke of the machine, which by this double eccentric makes two reciprocations for every revolution of the shaft.

It is, however, more usual to employ cams, as in Fig. 324, and in this case the part of the cam which lifts the shear lever is usually spiral, so as to raise it with equal velocity; the curve of the back is immaterial, provided it forms a continuous line so as to prevent the lever descending with a jerk.

Fig. 325 represents the double shears; the one part, shown also detached, presents two horizontal but discontinuous edges with the axis in the centre, this piece is fixed to a firm support; the other or the moving part somewhat resembles the letter **T** or a pendulum, to the lower end of which, and beneath the floor, is jointed a connecting-rod, that unites the pendulum with an eccentric or crank driven by the engine. The machine is double, or cuts on either side, and has two pairs of rectangular cutters of hardened steel, which may be shifted to bring the four edges of all of them successively into action.

Boiler makers have great use for powerful shears for cutting plate iron from ¼ to ½, and sometimes ¾ inch thick; and the next stage of their work is to punch the rivet holes by which the plates are attached. The two processes of shearing and punching are so far analogous in their requirements, that it is usual to unite the two processes in one machine; and as it sometimes happens the boiler maker's yard is at a distance from the general factory, it then becomes necessary to work the shears by hand with a winch handle, and which is effected in the manner shown in Fig. 326, by the introduction of only one wheel and pinion. The wheel is fixed on the cam shaft, the pinion on the same axis that carries the heavy fly-wheel employed to give the required momentum; this mode of working the shearing and punching engine is perfectly successful, but of course less economical than steam or water power, the agency of which the machine is also adapted to receive.

Fig. 326.

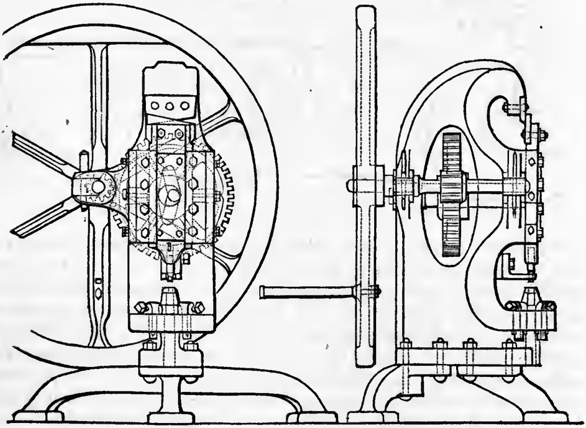


When shears that move on a joint and have radial cutters as in Fig. 322, are employed for thick bars, owing to the distance to which their jaws are opened, they meet at a considerable angle, and therefore from their obliquity they do not grasp the thick bar, but allow it to slide gradually from between them, to prevent which a rigid stop is added at the part *c*, Fig. 322, when, as the bar can no longer slide away it becomes severed. The shears with radial cutters, are also liable from their very oblique action to curve the plates; neither do they serve for making long cuts, as the joint then prevents the free passage of long work.

All these inconveniences, however, are obviated in the shearing machines with slides, in which the edges approach in a right line instead of radially, and are also nearly obviated in the very massive and powerful shearing and punching tool with jointed lever, first employed by French engineers and represented in Fig. 326, which occupies an entire length of eleven feet, and serves for cutting plates not exceeding ¾ inch thick, cutting 12 inches in length at a time, and punching holes of 1¼ inch diameter in ¾ inch iron. The shearing cutters are in this machine 15 inches long and raised above the centre of motion; as they lie on a chord instead of a radius, the longest pieces may therefore be cut without interference from the joint, and the cutters have the further advantage of meeting at a much smaller angle than if fitted radially.

The portable punching and shearing machine shown in front and side elevation in Figs. 327 and 328, will serve for a general example of such machines, as the differences in the several constructions are only those of form and arrangement, and not of principle.

Figs. 327 328.



This machine stands upon a base of a triangular form, and has in front a strong chamfer slide, which is reciprocated in a vertical line, by an eccentric that is concealed from view, it being immediately behind the slide, and upon the same axis, as the eccentric is the toothed wheel. The pinion that takes into this wheel, is on the shaft that carries the fly wheel, and one of the arms of the latter receives the handle by which the machine is usually worked; or if it is driven by power, fast and loose pulleys are then fixed on the same axis as the fly wheel.

The upper part of the slide carries a shearing cutter, which is about 7 inches wide, and meets a similar cutter that is fixed to the upper and overhanging part of the casting. The cutters, although ground with nearly rectangular edges, are beveled to the extent of about three-fourths of an inch in the direction of their length, that they may commence their work on the one edge, and therefore more gradually than if the entire width of the cutter penetrated at the same instant: this degree of obliquity does not cause the work to slide from the shears, neither does it materially curl up the work; and as the blades are quite clear of the framing, a cut may be extended throughout the longest works, provided the cut is not more than five inches from the edge of the plate, the distance of the cutters from the framing of the machine.

The above machine, which measures in total height about five feet, makes 12 or 15 strokes per minute, shears ½ inch iron plates, and punches ¾ holes in iron ½ inch thick. A larger machine makes 10 or 12 strokes per minute, shears ¾ inch plate, and punches 1¼ inch holes in iron ¾ inch thick; and a still heavier machine, working at 8 or 10 strokes in the minute, shears 1 inch plates, and punches 2 inch holes in iron 1 inch thick. Some of these are provided with railways by which the work is carried to the shears or punches, as will be described; and the bar-cutting machine, having only shearing cutters at the bottom, and the eccentric at the top of the slide, is used for cutting bars not exceeding 6⅜ inches wide by 1⅝ thick, or bars 2 or 2½ square, but we think these dimensions of the works performed might, if required, be greatly exceeded in heavier machines.

There is a shearing machine for cutting wide plates of sheet iron, which is used in the manufacture of wrought iron; it has two wide cutters of steel fixed to the edges of thick plates of cast-iron; the lower cutter is at rest and quite horizontal, the upper cutter bar is fitted in grooves at the end of the frame, so as to be carried up and down vertically, by a shaft or spindle immediately above the cutter and parallel with it; this shaft has an eccentric at each end, and one in the centre, and three connecting links, which attach the cutter frame to the eccentrics, and give it a small reciprocating motion. The upper cutter is a little oblique, so as to begin to act at the one end, and in removing the strips curls them but very little.

A vice for cutting wide pieces of boiler plate, is based on the mode of cutting thin slips of sheet metal over the chaps of the ordinary tail vice, as described on page 363–4. The jaws of the machine are about six feet long, faced with steel, and powerfully closed by two perpendicular screws and nuts, one at each end, which also secure the machine to the ground.

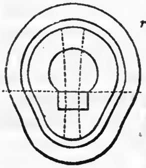
The plate of iron is therefore fixed horizontally and with the line of division level with the jaws. A strong rod chisel struck with sledge-hammers, is applied successively along the angle formed between the work and the vice, and after the iron has been indented the whole length, the blows of the sledges directed on the overhanging piece of iron complete the separation.

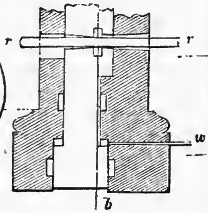
Fig. 329 represents the plan, and Fig. 330 the partial vertical section of a "hydraulic machine for cutting off copper bolts."

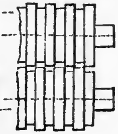
The circle in Fig. 329 represents the cylinder of a hydrostatic press, which is flattened to the width of the rectangular bar that is fixed alongside of the cylinder, the two being enveloped in the external casting which is shaded in the section Fig. 330, and resembles a stunted pillar three or four feet high. The whole of the parts are traversed by nine sets of holes suitable to bars from $\frac{3}{8}$ to $2\frac{1}{2}$ inches diameter; the holes where they meet on the lines *b b*, are furnished with annular steel cutters, and are enlarged outwards each way to admit the work more easily.

The rod *r r*, to be sheared, is introduced whilst the holes are directly opposite or continuous, and the men then pump in the injection water through the pipe *w*; it acts upon the annulus or shoulder intermediate between the two diameters of the cylinder, causes the descent of the latter with a pressure of about 100 tons, and forces the bar asunder very quietly, and, from the annular form of the cutters, without bruising it. When the bar has been cut off, the injection water is allowed to flow out from beneath the cylinder, and the latter is raised by a loaded lever beneath the floor ready for the next stroke. The machine is far more economical in its action than the old mode of cutting off the copper bolts with a frame saw used by hand, and the storekeeper in charge of the bolts can, if needful, perform the entire operation unassistedly, although usually four men work the pair of one inch injection pumps by a double-ended lever, as in a fire engine.

Figs. 329 330 331 332 333.







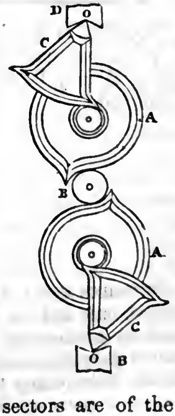
In concluding this subject it is proposed to speak of the rotary shears for metal, which have continuous action like rollers, and are pretty generally used. In the best form of the instrument, two spindles, connected together by toothed wheels of equal size, have each two thin disks of different diameters, which are opposed to each other, that is, a large and a small in the same plane, as in the diagram, Fig. 331; the larger disks overlap each other and travel in lateral contact, and therefore act just like shears, and the two disks in each plane meet, or rather nearly meet, so as just to grasp between them, after the manner of flatting the rollers, the two parts of the strip of metal which have been severed, and by carrying these forward they continually lead the yet undivided part of the metal to the edges of the larger disks, which in this manner quickly separate the entire strip of metal into two parts.

The machine requires that the spindle carrying the disks should have an adjustment for lateral distance, as in flatting rollers, to adapt their degree of separation to the thickness of the metal to be sheared. One of the spindles should also have an endlong adjustment to bring the disks into exact lateral contact, and the machine requires in addition a fence or guide fixed alongside the revolving shears to determine the width of the strips cut off. Sometimes the two smaller disks are omitted, and the larger alone used, as in Fig. 332; the circular shears are then somewhat less exact in their action, but perform nevertheless sufficiently well for most purposes.

Circular or rotary shears are very useful for shearing plates not exceeding one-eighth of an inch thick, and one of the advantages which the rotary possesses over the common shears, is the facility with which curved lines may be followed, on account of the small portion of the disks that are in contact, whereas the length of rectilinear shear blades prevents their ready application to curves. Of course the speed at which the machines may be driven depends on the nature of the work, and if the cuts are straight and the plates light, the velocity of the shears may be considerable.

The circular shears, or splitting rolls used in the works where wrought-iron is manufactured, are composed of steel disks of equal thickness, but of two diameters, arranged alternately upon two spindles, as in Fig. 333, so as at one action to split thin plates of iron of about 6 inches in width into very narrow pieces known as nail rods, and into strips from half to one inch wide, designated as bundle or split iron. Of course different pairs of rolls are required for every different width of the strips thus manufactured.

Fig. 334.



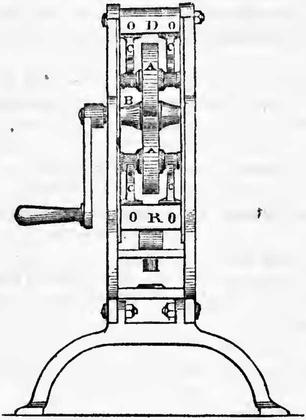
The anti-friction cam press, invented by David Dick, of Meadville, Pennsylvania, is destined to become of great use to the metal-worker. This press is much more easily constructed, and can be supplied for much less cost than that of Timothy Brahmah; it also can be made to accomplish its work with much greater expedition.

There are many arrangements for shears, punches, and presses for iron and steel, one of which may be described thus:

A A, Fig. 334, are two eccentric wheels, and B is a roller between. C C are two pair of sectors, constituting the bearings of the axes of the sectors. The axes of the sectors are of the knife-edge shape. D is the bearing, and R is the follower of the sectors.

This combination, Fig. 334, is inclosed in a frame, Fig. 335. The centre roller B is made to revolve, which carries by its traction the two eccentric wheels A A, which have their bearings on the faces of the sectors, which are transferred the length of their faces right and left, the sectors being knife-edge shaped at the centres of motion O O, which revolve with very little friction. When A A have made their revolution the follower R will have moved the sum of the two eccentrics.

Figs. 335



336.

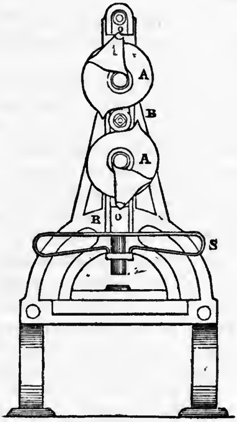


Fig. 336 is a side view with one side of the frame removed. A press constructed in this way, the follower moving down a spring S, may be used to return the moving parts when the press is relaxed.

CHAPTER XXI.

PUNCHES.

Punches used without Guides.—This title may, at the first glance, only appear to possess a very scanty relation to the tools used in mechanical manipulation, as the ostensible purpose of a punch may be considered to be only that of making a round or square hole in any thin substance. But it frequently happens that the small piece or disk so removed by the punch, is the particular object sought, and some of the very numerous objects thus made with punches assume a very great importance in the manufacturing and commercial world, as will perhaps be admitted when a few of these are referred to.

The general character of a punch is that of a steel instrument, the end of which is of precisely the form of the substance to be removed by the punch, and which instrument is forcibly driven through the material by the blow of a hammer. When the subject is entertained in a moderately extended sense, it will be seen that much variety exists in the forms of the punches themselves, and also in the modes by which the power whereby they are actuated is applied.

So far as relates to the actual edges of the punches by which the materials are severed, they may be classed under two principal divisions, namely, duplex punches, and single punches. The duplex punches have rectangular edges and are used in pairs, often just the same as in shears for metal. The single punches have sometimes rectangular but generally more acute edges, the one side being mostly perpendicular.

The single punches require a firm support of wood, lead, tin, copper, or some yielding material, into which the edge of the punch may penetrate without injury, when it has passed through the material to be punched.

The following classification has been attempted, as that best calculated to throw into something like order the miscellaneous instruments that will presently be more or less fully described.

Punches used without guides.
Punches used with simple guides.
Punches used in fly presses, and miscellaneous examples of their products.
Punching machinery used by engineers.

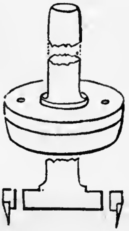
It would be hardly admitted that a carpenter's chisel, driven by a mallet through a piece of card, could be considered as a punch, still the circular punch used with a mallet on a block of lead, for cutting out circular disks of cards for gun-wadding, is indisputably a punch, and yet scarcely more than a chisel bent round into a hoop. The gun-punch is formed as in Fig. 337, and is turned conical without and cylindrical within, or rather a little larger at the top, that the waddings may freely ascend, and make their way out at the top through the aperture; when, however, annular punches exceed about 2 inches in diameter, it is found a stronger and better method to make them as steel rings, attached to iron stems or centres spread out at the ends to fill the rings, as in Fig. 338, but holes are then required to push out the disks that stick to the punch, as shown by the section beneath the figure 338.

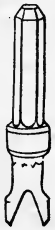
The punch used in cutting out wafers for letters is nearly similar, it being formed as a thin cylindrical tube of steel, fitted to the end of a perforated brass cone having at the top two branches for the cross handle, by which it is pressed through several of the farinaceous sheets, and as the wafers accumulate in the punch they escape at the top. Confectioners use similar cutters in making lozenges, and frequently the thin steel cutter is fixed to a straight perforated handle of wood. The lozenges are cut out singly and with a twist of the hand.

When the disk is the object required, the punch is always chamferred exteriorly, as then the edge of the disk is left square and the external or wasted part is bruised or bent; but the punch is made cylindrical without, and conical within, when the annulus or external substance is required to have a keen edge. And when pieces such as washers, or those having central holes, are required in card or leather, the punches are sometimes constructed in two parts, as shown separated in Fig. 339, the inner being made to fit the outer punch, and their edges to fall on one plane; so that one blow effects the two incisions, and the punches may then be separated for the removal of the work, should it stick fast between the two parts of the instrument.

Punches of irregular and arbitrary forms, used for cutting out paper, the leaves for artificial flowers, the figured pieces of cloth for uniforms and similar things, are made precisely after the manner of Fig. 337, and also of Fig. 338, except that they are forged in the solid, or without the loose ring. These irregular punches are, however, much more tedious to make than the circular, which admit of being fashioned in the lathe.

Figs. 337 338 339 340 341.





Figured punches of much larger dimensions have been of late used for cutting out the variously formed papers used in making envelopes for letters. The punch or cutter is sometimes made in one piece as a ring an inch to an inch and a half deep, or else in several pieces screwed around a central plate of iron, and when the punch is sharp it is really forced through three to five hundred thicknesses of paper, by the slow descent of the screw press in which it is worked. Army clothiers use similar instruments for cutting out the leather for shoes and various other parts of military clothing, and several of these punching or cutting tools are often grouped together.

Proceeding to the punches used for metal, those having the thinnest edges are known as hollow punches; they are turned of various diameters, from about ¼ to 2 inches, and of the section Fig. 340; they are always used on a block of lead, and sometimes for two or three thicknesses at a time of tinned iron, copper, or zinc, Punches 341, smaller than ¼ inch, are generally solid, quite flat at the end, and are also used on a block of lead, which, although it gives a momentary support, yields and receives into its surface the little piece of metal punched out by the tool.

Fig. 343 represents the punch used by smiths for red-hot iron; the tool is solid and quite flat at the end, and whether it is round, square, or oblong in its section, as for producing the holes represented, it is parallel for a short distance, then gradually enlarged, and afterwards hollowed for the hazel rod by which it is surrounded to constitute the handle. The smith's punch is frequently used along with a bottom or bed tool known in this case as a *bolster*, and which has a hole exactly of the same area as the section of the punch itself.

Punches when used in combination with bolsters are clearly similar in their action to the shears with rectangular edges, as will be seen on comparing Figs. 342 and 343, the only difference being that the straight blade of the shears is to be considered as bent round into a solid circle for a circular punch, or converted into a square, rectangular, or other figure, as the case may be; but every part of the punch should meet its counterpart or the bolster in *lateral contact*, the same as formerly explained in reference to shears. This supposes the tools to be accurately made and correctly held by the smith, but which is somewhat difficult, because the bolster, the work, and the punch, are all three simply built up loosely upon the anvil, and the eye can render but little judgment of their relative positions; the punch is consequently apt to be misdirected so as to catch against the bolster and damage both tools. The mode sometimes used to avoid this inconvenience is represented in Fig. 344, in which a guide is introduced to direct the punch; but agreeably to the proposed arrangement, this figure will be more fully explained hereafter, when some other tools of a lighter description have been spoken of.

Figs. 342 343 344 345

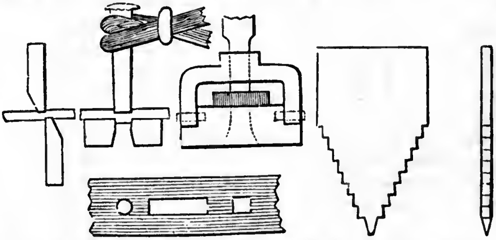
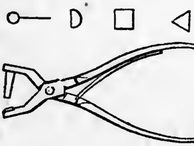


Fig. 315 shows a punch used by harp-makers and others in cutting long mortises in sheet metal. The punch is parallel in thickness, and has in the centre a square point from which proceed several steps; this punch is used with a bolster having a narrow slit as long as the width of the punch. A small hole is first drilled in the centre of the intended mortise; the first blow on the punch converts this into a square, the next cuts out two little pieces extending the hole into a short mortise, and each successive blow cuts out a little piece from each end, thereby extending the mortise if needful to the full width of the punch. From the graduated action the method entails but little risk of breaking the punch or bulging the metal, even if it should have but little width. Sometimes, to make the punch act less energetically at the commencement of its work, the steps at the point are made smaller both in height and width; the serrated edge then becomes curved instead of angular, as shown.

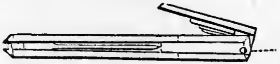
Punches used with simple Guides.—Beginning this part of the subject with the tools having the most acute edges, we have to refer to the punch pliers, Fig. 346, fitted with round hollow punches for making holes in leather straps and thin materials. Some pliers of this kind have a small oval punch, terminating in a chisel edge, for cutting those holes that have to be passed over buttons; and pliers have been made with circular, square and triangular punches for the cruel practice of marking sheep in the ear. In all these tools the punch is made to close upon a small block of ivory or copper, so as to insure the material being cut through without injuring the punch.

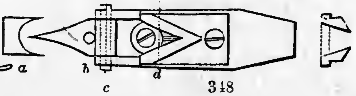
Another example of slender chisel-like punches is to be seen in the machine for cutting the teeth of horn and tortoise-shell combs. The punch or chisel is in two parts, slightly inclined and curved at the ends, to agree in form with the outline of one tooth of the comb. The cutter is attached to the end of a jointed arm, moved up and down by a crank, so as to penetrate almost through the material, and the uncut portion is so very thin that it splits through at each stroke and leaves the two combs detached.

Figs. 346



347.





348

The little instrument called a pen-making machine, is another ingenious example of punches moving on a joint. It is represented of half its true size, and ready to receive the pen, in Fig. 347, and in Fig. 348 the two cutters are shown of full size and laid back in a right line—although in reality it only opens to a right angle. The lower half has a small steel cutter *b*, pointed to the angle of the nibs of the pen, and fluted to the curve of the quill as at *a*; the upper cutter *d* is made as an inverted angle with nearly vertical edges, as seen at *e*, which exactly correspond with the lower cutter, so as between them to cut the shoulders of the pen. The upper tool also carries a thin blade or chisel, which penetrates nearly through the quill and forms the slit.

The quill having been pared down to its central line, is inserted through the hollow joint, on the line *f*, and the cutters being very near the joint, the lever on being closed gives abundant power for the penetration of the punches. The pen requires to be afterwards nibbed, and for which purpose another cutter is attached to the instrument, which has likewise an ordinary pen-blade, so as to be entirely complete in itself.

Passing from the punches with guides obtained by means of joints, and actuated by the pressure of the fingers, we will return to Fig. 344, on page 373, which with its simple guide becomes a very effective tool sometimes known as the *hammer press*, in contradistinction to the *screw*, or *fly-press* to be hereafter spoken of.

The guide in the contrivance, Fig. 344, is a strong piece of iron attached to the bottom tool, and sufficiently above it to admit the work between the two. Each part is pierced with a hole of exactly the same size, and accurately formed as if they were interrupted portions of the same hole. The punch is made exactly to fit either hole, so that from the upper it receives a correct guidance, and it therefore cuts through the material, and penetrates the lower piece, with a degree of precision and truth scarcely attainable when the tools are unattached, and are used simply upon the anvil, as before described.

As however the punch mostly sticks tight in the work, it is needful to turn the instrument over, and drive out the punch with a drift a little smaller than the punch, and on which account punching tools of this kind are often made of two parallel plates of steel firmly united by screws or steady pins, yet separated enough for the reception of the work, and frequently contrivances are added to guide the works to one fixed position, in order that any number of pieces may be punched exactly alike.

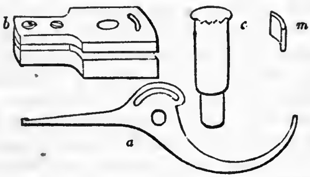
Thus in punching circular mortises, as in the half of a pair of inside and outside callipers *a*, Fig. 349, the punch *c*, is first used to produce the central hole, and this punch is then left in the bed *b*, to retain the work during the action of the second punch *m*, by which the mortise is cut. The punch *m*, is very short, to avoid the chance of its being broken, and it is also narrow, so as to embrace only a short portion of the mortise, which is then completed, with little risk to the tool, at three or four strokes, whilst the punch *c* serves as a central guide.

Occasionally also punches of this simple kind, but on a larger scale, have been placed under drop hammers, falling from a considerable height through guide rods, somewhat as in a pile-driving machine. This mode of obtaining power is not suited to the action of punches used in cutting out metals, amongst other reasons, because the punch sticks very hard in the perforation it has made, and requires some contrivance for pulling it out, which is not so easily obtained in this apparatus as in fly-presses, that are suited alike to large and small works.

The drop hammer, or as it is more commonly called *a force*, is however very much used in the manufacture of stamped works, or such as are figured between dies, of which an example is described at length in page 312. Compared with a fly-press of equal power, the force is less expensive in its first construction, but it is also less accurate in its performance.

Fig. 350 is a very simple yet effective tool, which may be viewed as a simplification of the fly-press: it consists of one very strong piece of wrought-iron, about one inch thick and four or five inches wide, thickened at the ends and bent into the form represented; the one extremity is tapped to receive a coarse screw, the end of which is formed as a cylindrical pin, or punch, that is sometimes made in the solid with a screw, but more usually as a hardened steel plug inserted in a hole in the screw. Immediately opposite to the punch is another hole in the press, the extremity of which is fitted with a hardened steel ring or bed punch. When the screw is turned round by a lever about three feet long, it will make holes as large as ¾ inch diameter in plates ⅜ inch thick, and is therefore occasionally useful to boiler makers for repairs, and also for fitting works in confined situations about the holds of ships, and other purposes. When this screw is turned backwards the punch is drawn out and relieved from the work, but the screwing motion is apt to wear out the end and side of the punch, and therefore to alter its dimensions.

Figs. 349



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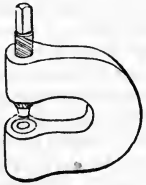


A very convenient instrument of exactly the same kind is used in punching the holes in leather straps, by which they are laced together with leather thongs, or united by screws and nuts, to constitute the endless bands or belts used in driving machinery. In this case the frame of the tool is made of gun-metal, and weighs only a few ounces, the end of the screw is formed as a cutting punch, and it is perforated throughout, that the little cylinders of leather may work out through the screw, which only requires a cross handle to adapt it to the thumb and fingers.

In this case the screwing motion is desirable, as the punch in revolving acts partly as a knife, and therefore cuts with great facility, as the leather is supported by the gun-metal which constitutes the clamp or body of the tool.

PUNCHES USED IN FLY-PRESSES, AND MISCELLANEOUS EXAMPLES OF THEIR PRODUCTS.—The punches used in fly-presses, do not differ materially from those already described, but it appears needful to commence this section with some explanation of the principal modifications of the press itself. The fly-press is a most useful machine, which, independently of the punch or dies wherewith it is used, may be considered as a means of giving a hard, unerring perpendicular blow, as if it were a powerful well-directed hammer. The precision of the blow is attained by the slide whereby the punch is guided, the force of the blow by the heavy revolving fly attached to the screw of the press. When the machine is used, the fly is put in rapid motion, and then suddenly arrested by the dies or cutters coming in contact with the substance submitted to their action. The entire momentum of the fly, directed by the agency of the screw, is therefore instantaneously expended on the work to be punched or stamped, and the reaction is frequently such as to make the screw recoil to nearly its first position.

The bare enumeration of the multitude of articles that are partially or wholly produced in fly-presses, would extend to considerable length, as this powerful and rapid auxiliary is not only employed in punching holes, and cutting out numerous articles from sheets of metal and other materials, but also in moulding, stamping, bending or raising thin metals into a variety of shapes, and likewise in impressing others with devices, as in medals and coins.

Fig. 351.

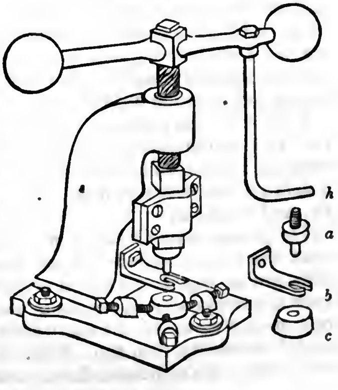


Fig. 351 represents a fly-press of the ordinary construction that is used for cutting out works, and is thence called a cutting press, in contra-distinction to the stamping or coining presses. It will be seen that the body of the press, which is very strong, is fixed upon a bed or base that is at right angles to the screw; the latter is very coarse in its pitch, and has a double or triple square thread, the rise of which is from about one to six inches in every revolution. The nut of the screw is mostly of gun-metal, and fixed in the upper part or head of the press. The top of the screw is square or hexagonal, and carries a lever of wrought iron, terminating in two solid cast-iron balls, that constitute the fly, and from the lever the additional piece *h*, descends to the level of the dies to serve as the handle, so that the left hand may be used in applying the material to be punched, whilst the right hand of the operator is employed in working the press.

The screw is generally attached to a square bar called the *follower*, which fits accurately in a corresponding aperture and is strictly in a line with the screw; and to the follower is attached the punch shown detached at *a*. The punch is sometimes fitted into a nearly cylindrical hole, and retained by a transverse pin or a side screw, but more generally the die is screwed into the follower, like the chucks of some turning lathes; the bed or bottom die *c*, which is made strictly parallel, rests on the base of the press, and is retained in position by the four screws, that pass through the four blocks called *dogs;* these screws, which point a little downwards, allow the die to be accurately adjusted, so that the punch may descend into it without catching at any part, and thereby inflicting an injury to the tools.

The piece *b*, which rests nearly in contact with the die, is called the *puller off*, it is perforated to allow free passage to the punch; when the latter rises, it carries up with it for a short distance the perforated sheet of metal that has been punched through, but which is held back by the puller off, whilst the punch continuing its ascent rises above the puller off, and leaves behind the sheet of metal so released; the sheet is again placed in position whilst another piece is punched out, and so on continually.

Before proceeding to speak of some of the works produced in stamping presses, it is proposed to describe some of the points of difference met with in fly-presses.

The body of a cutting press is in general made with one arm, as represented in Fig. 351, because the sheet of metal can be more freely applied to the die; but stamping and coining presses, which are used for pieces that have been previously cut out, require greater strength and have two arms, or are made somewhat as a strong lofty bridge with the screw in the centre.

The fly of the press is frequently made as a heavy wheel, which may be more massive and is less dangerous to bystanders than the lever and balls, and in large presses there are two, three, or four handles fixed to the rim, as many men then run round with the fly, and let go when the blow is struck.

Fly-presses are variously worked by steam-power; thus in the mint the twelve presses for cutting out the blanks or disks for coin, are arranged in a circle around a heavy fly-wheel, which revolves horizontally by means of the steam-engine. The wheel has one projecting tooth or cam, which catches successively the twelve radial levers fixed in the screws of the presses, to cut the blanks, and twelve springs immediately return the several levers to their first positions, ready for the next passage of the cam on the wheel.

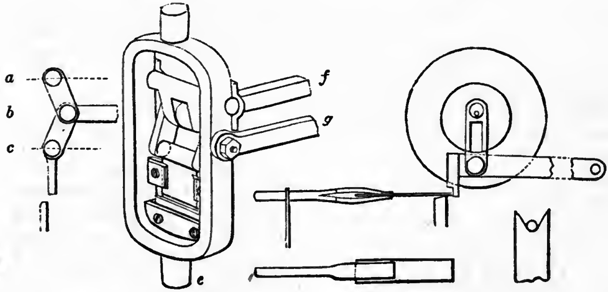
The fly and screw are also worked by power, in some cases by an eccentric or crank movement fixed at a distance; a long connecting-rod then unites the crank to an arm of the wheel, or to a straight lever, and gives it a reciprocating movement.

At other times, in place of the crank motion are ingeniously substituted a piston and cylinder worked after the manner of an oscillating steam-engine, if we imagine the boiler to be superseded by a large chamber, exhausted by the steam-engine nearly to a vacuum, thus constituting an air engine, the one side of the piston being opened for a period to the exhausted chamber, whilst the other receives the full pressure of the atmosphere.

In the manufacture of steel pens, it is important to have an exact control over the punches which cut the slits, and those which mark the inscriptions, as by descending too far they might disfigure the steel, or even cut it through. Accordingly there is introduced between the head of the press and the lever an adjustable ring, which acts as a stop, and only allows the punches to descend to one definite distance, until in fact the ring is pinched between the press and lever.

The screw of the fly-press is sometimes superseded by a contrivance known both as the toggle joint, and as the knee joint. The two parts *a*, *b*, and *b*, *c*, Fig. 352 are joined to each other at *b*, the extremity *a*, is joined to the upper part of the press, and *c*, to the top of the follower. When the parts *a*, *b*, and *b*, *c*, are inclined at a small angle, the extremities, *a*, and *c*, are brought closer together, and raise the follower, but when the two levers are straightened, *a* and *c* separate with a minute degree of motion, but almost irresistible power, especially towards the completion of the stroke. The bending and straightening of the toggle joint is effected by the revolution of a small crank, united to the point *b*, Fig. 352, by a connecting rod *b*, *f*.

Figs. 352 353.



Presses with the toggle joint are perfectly suited to cutting out works with punches and bolsters, provided the relative thickness of the work and tools are such as to bring to bear the strongest point of the mechanical action, at the moment the greatest resistance occurs in the work; but as the fly-press with a screw is in all cases powerful alike, irrespective of such proportions, provided alone that there is sufficient movement to create the required momentum, the fly-press is more generally useful.

The cut 353 refers to a lever press worked by an eccentric, and used in cutting brads and nails, which will be again alluded to when this manufacture is briefly noticed.

It is now intended to describe a few examples of works executed in fly-presses, giving the preference to those appertaining to mechanism.

The round disks of metal for coin are always cut out with the fly-press, and are then called blanks, the punch being a solid cylinder, the bed or bolster a hollow cylinder that exactly fits it. In the gold currency, more especially, great care is taken to make these punches as nearly as it is possible mathematically alike in diameter, and the sheets of gold also mathematically alike in thickness, by aid of the drawing rollers or rather drawing cylinders referred to in page 327; but notwithstanding every precaution, the pieces or blanks when thus prepared do not always weigh strictly alike. This minute difference is most ingeniously remedied by using the one error as a compensation for the other. Trial is made at each end of every strip of gold; and by cutting the thicker gold with the smaller punches, the adjustment is effected with the needful degree of accuracy, so that every piece is made critically true in weight, without the tedious necessity for weighing and scraping, otherwise needful.

Buttons are made in enormous quantities by means of the fly-press. That metal buttons should be thus cut out with tools and stamped with dies, will be immediately obvious to all, but the fly-press has been also more or less employed in making buttons of horn, shell, wood, *papier-maché,* and some other materials. Amongst others, may be noticed the silk buttons, called Florentine buttons, each of which consists of several pieces that are cut out in presses, then enveloped by the silk covering, and clasped together at the back (in the press), by a perforated iron disk, the margin of which is formed into 6 or 8 points that clutch and hold the silk, whilst the cloth by which the button is sewed on, is at the same time protruded through the centre hole in the back plate of the silk button; details that may be easily inspected by pulling one of them to pieces. Indeed great ingenuity has been displayed, and many patents have been granted, for making this necessary article of dress, a button.

Round washers that are placed under bolts and nuts in machinery, are punched out just like the blanks for coin; although in punching the larger washers, that measure 5 and 6 inches in diameter and ¼ inch thick, with the ordinary fly-presses, the iron requires to be made red hot.

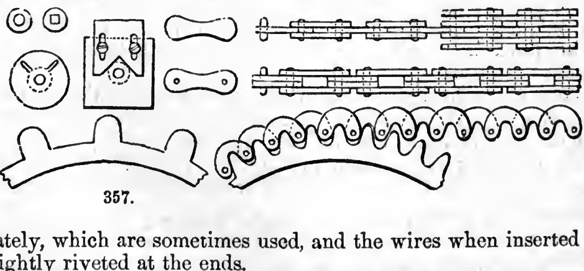
The round or square holes in the washers are made at a second process with other tools, and to insure the centrality of the holes, some kind of stop is temporarily affixed to the lower tool. The more complete stop is a thin plate of iron hollowed out at an angle of from 90 to 120 degrees and screwed on the top of the bed, as this may be set forward to suit various diameters. But the more usual plan is to drill two holes in the bed, to drive in two wires, and to bend their ends flat down towards the central hole, as also shown in Fig. 354; the end of the wires are filed away until, after a few trials, it is found the blank, when held in contact with the stops by the left hand, is truly pierced; the whole quantity may be then proceeded with as rapidly as the hands can be used, with confidence in the centrality of all the holes thus produced.

Chains with flat links that are used in machinery are made in the fly-press. The links are cut out of the form shown at *a*, Fig. 355, the holes are afterwards punched just as in washers and one at a time, every blank being so held that its circular extremity touches the stops on the bed or die, and thereby the two holes become equidistant in all the links, which are afterwards strung together by inserting wire rivets through the holes.

The pins or rivets for the links are cut off from the length of wire in the fly-press, by a pair of cutters like wide chisels with square edges, assisted by a stop to keep the pins of one length; or by one straight cutter and an angular cutter hollowed to about 60 degrees; or by two cutters each hollowed to 90 degrees. In the three cases, the wire is respectively cut from two, three, or four equidistant parts of its circumference: semicircular cutters are also used. The straight cutters first named, are moreover very usefully employed in the fly-press for many of the smaller works, that would otherwise be done with shears.

Sometimes the succession of the links for the chain, is one and two links alternately, as at *b*, Fig. 355; at other times 3 and 2, or 4 and 3 links, as at *c*, and so forth up to about 9 and 8 links alternately, which are sometimes used, and the wires when inserted are slightly riveted at the ends.

Figs. 354



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357.

The pin is generally the weakest part of the chain and gives way first, but in the chains with 8 or 9 links, the pin must be cut through at 16 places simultaneously, before the chain will yield.

Chains are sometimes intended to catch on pins or projections, around a wheel of the kind shown in Fig. 357, to fulfil the office of leather bands, without the possibility of the slipping, which is apt to occur with bands when subjected to unusual strains.

Such chains are made after the manner shown in Fig. 356: to constitute the square openings that fit over the pins of the wheel, the central links are made shorter, by which means the apertures are brought closer together than if the longer links were used throughout. Fig. 358 shows a different kind of chain, that has been used for catching in the teeth of an ordinary spur-wheel with epicycloidal teeth: this chain was invented by John Oldham, Engineer to the Bank of Ireland.

Chains for watches, time-pieces, and small machinery, are too minute to be made as above described, therefore the slip of steel is first punched through with the rivet holes required for a number of links, by means of a punch in which two steel wires are inserted; the distance between the intended links is obtained (somewhat as in file cutting) by resting the burrs of the two previous holes against the sharp edge of the bed or bolster. The links are afterwards cut out by a punch and bolster of the kind already noticed, but very minute, and the punch has two pins inserted at the distance of the rivet holes, the slip of steel being every time fitted by two of the holes to these pins; all the links are thereby cut centrally around the rivet holes.

The tools are carried in a thick block having a perpendicular square hole, fitted with a stout square bar; the latter is driven with a hammer, which is supported on pivots, raised by a spring, and worked by a pedal; but when the links measure from ¼ to ½ an inch in length, such tools are worked by a screw.

The punches are fitted to the side of the square bar, in a projecting loop or mortise, and secured by a wedge. They are drilled with holes for the pins, and across each punch there is a deep notch to expose the reverse ends of the pins, in order that when broken they may be driven out and replaced. The pins are taper pointed, that they may raise burrs, instead of cutting the metal clean out, and being taper, no puller-off is required, and the bed tools are fitted in chamfer grooves in the base of this old yet very efficient instrument.

A large chain for a pocket chronometer now before the author, measures nearly 14 inches in length, and contains in every inch of its length 22 rivets and also 33 links, (in three rows); the total number of pieces in the chain is therefore 770, and its weight is 9½ grains. A chain for a small pocket-watch measures 6 inches in length, and has 42 rivets and 63 links in every inch, in all 630 pieces, and yet the entire chain only weighs one grain and three-quarters.

The square links of chains for jewelry are often cut out with punches, the exterior and interior being each rectangular; after which each alternate link is slit with a fine saw for the introduction of the two contiguous links, and then soldered together so that the gaps become filled up. Other chains are drawn as square tubes, and cut off in short lengths with a saw; these, after having been strung together, are often drawn through a draw-plate with round holes, to constitute chains which present an almost continuous cylindrical surface like round wire; a very neat manufacture, invented in France.

The teeth of saws are for the most part cut in the fly-press. Teeth, whether large or small, require but one punch, the sides of which meet at 60 degrees. Two studs are used to direct the edge of the blade for the saw to the punch, at the required angle depending on the *pitch* or inclination of the teeth, and an adjustable stop determines the *space* or interval from tooth to tooth, by catching against the side of the last tooth previously made. Gullet teeth, and the various other kinds shown, require punches of their several compounded figures, and of different dimensions for each size of tooth.

The teeth of circular saws are similarly punched out by mounting the perforated circular disk on a pin or axis, but in cutting the last six or eight teeth, it is needful to be watchful, so as to divide the remaining space into moderately equal parts.

In cutting the teeth of circular saws not exceeding 12 inches diameter, Holtzapffel and Co. have been in the habit of mounting the steel plates on a spindle in a lathe with a dividing plate, and using a punch and bed fitted to a square socket fixed horizontally in the ordinary rest or support for the turning tool, the punch being driven through the plate by one revolution of a snail or cam, by means of a winch handle, and thrown back by a spring. In this arrangement the dividing plate insures the exact dimensions and equality of the teeth, which are rapidly and accurately cut.

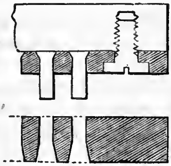
The copper caps for percussion guns are punched out in the form of a cross with short equal arms, or sometimes in a similar shape with only three arms, and the blanks, after having been annealed, are thrown out into form by means of dies, which fold up the arms and unite them to constitute the tubular part, whilst the central part of the metal forms the top of the cap that receives the composition and sustains the blow of the hammer.

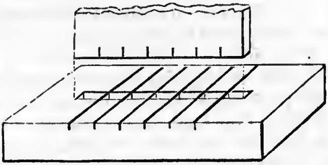
Steel pens are another most prolific example of the result of the fly-press; they pass through the hands many times, and require to be submitted to the action of numerous dies, to five of which alone we shall advert. The blanks are cut by dies of the usual kind, so as in general to produce a flat piece of the exterior form of Fig. 359, page 384; the square mortise at the bottom of the slit is then punched through. The next process is usually to strike on the blanks the maker's name.

The slit is now cut by a thin chisel-like cutter, which makes an angular gap nearly through the steel, from that side of the metal intended to form the inner or concave part of the pen, and the act of curling up the pen into the channeled form, brings the angular side of the groove into contact, rendering the slit almost invisible. The slit, which is as yet only part way through the pen, is in general completed in the process of hardening, as the sudden transition into the cooling liquid generally causes the little portion yet solid to crack through, or else the slit remains unfinished until the moment the pen is pressed on the nail to open and examine its nibs.

Larivière's perforated plates for strainers, lanterns, meat safes, colanders, and numerous other articles, exhibit great delicacy and accuracy in the mode in which they are punched out. The tools are illustrated by the enlarged sections, Fig. 360. The punch consists of a plate of steel called the punch plate, which is in some cases pierced with only one single line of equidistant holes, that are countersunk on their upper extremities. Every hole is filled with a small cylindrical punch made of steel wire, the end of which is bumped up, or upset to form a head, that fills the chamfer in the punch plate, so that the punch cannot be drawn out by the work in the ascent of the press. The bed punch or matrix has a number of equidistant holes corresponding most exactly with the punches. In this case the holes in the work are punched out one line at a time, and between each descent of the punches the sheet of metal is shifted laterally by a screw slide until it is in proper position to receive the adjoining line of holes.

Figs. 359 360 361.





At other times, the tool, instead of having only one line of punches, is wide, and entirely covered with several lines, so as to punch some hundreds or even thousands of holes at one time. For circular plates the punches are sometimes arranged in one radial line, but more usually the whole of the punches required for the fourth, sixth or eighth part of the circular disks are placed in the form of a sector, and the central hole, having been first punched, is made to serve as the guide for the four, six or eight positions at which these beautiful tools are applied.

Many of the thin plates thus punched require to be strained like the head of a drum to keep the metal flat, in which case the metal is grasped between little clamps or vices around its four edges, and then stretched by appropriate screws and slides with which the apparatus is furnished, and the same mechanism prevents the metal from rising, and therefore fulfils the office of the puller-off commonly used with punches.

The construction of the tools above described calls for the greatest degree of precision. The drill employed to pierce the punch and matrix is of exceedingly small size in the finest perforated works, as it is said as many as six or seven hundred holes have been inserted in the length of six inches, which, considering the intervening spaces to be half as wide as the diameter of the holes, would make the latter of the minute size of only six-thousandths of an inch diameter. Such finely perforated metal appears to offer nearly the transparency of muslin, and is a manifest proof of the great skill displayed in the construction of the instruments, and in conducting the entire process.

M. Marc Larivière's patent was granted 28th Nov., 1825, and is described in the *Repertory of Patent Inventions*, vol. iii., 3d series, page 182.

All the foregoing examples of punched works suppose the punch to have been *fixed* to the follower of the press, and the matrix to the base of the same, in which case the bed punch requires to be very exactly adjusted by the set screws or dogs of the press. But it remains, in concluding this section, to advert to a different arrangement, in which the cutting tools are quite *detached*, and are far less liable to accident or fracture, even when the punches are of very large area and complicated figure, than when constructed in the ordinary manner with a shank, by which they are united to the follower of the press.

Punches, to be used in this manner, for works with various detached apertures requiring any especial arrangement, and for various straggling and complicated objects, are constructed as shown in Figs. 362 to 364. There are two steel plates somewhat larger than the work, and from $\frac{3}{16}$ to $\frac{3}{8}$ thick, the plates are hinged together like the leaves of a book, but are placed sufficiently distant to admit between them the work to be stamped out, and which is pinched between them by a thumb screw *a*. The two plates whilst folded together are perforated with all the apertures required in the work, which perforation may be either detached, continuous or arranged in any ornamental design that may be required. To all the apertures are fitted punches, which in length or vertical height are about one-eighth of an inch longer than the thickness of the upper plate, so as to stand up one-eighth when resting on the material to be punched, as seen in the partial section 364, in which the work is shaded obliquely and the punch vertically.

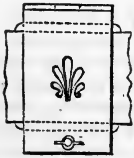
As it would be difficult to fit the punches in one single piece to the ornamental or straggling parts of some devices, and as moreover such large and complicated punches would be almost sure to become distorted in the hardening, or broken when in use, the difficulty is boldly met by making the punch of as many small pieces as circumstances may render desirable, but which pieces must, collectively fill up all the interstices of the plate.

In using these punching tools, it is only necessary first to fix between the plates the metal to be pierced, then to insert all the punches into their respective apertures, and lastly to give the whole one blow between the flat disks of a powerful fly-press; this drives all the punches through the work, and leaves them flush with the upper surface. The whole is then removed from the press, and placed over an aperture in the work bench, and with a small drift and hammer the punches are driven out of the plates into a drawer beneath, and on the plates being separated, the work will be found to be exactly perforated to the same design as that of the tool itself; or with any part of the design instead of the whole, if part only of the punches were inserted in their respective places. The punches are selected from amidst the corresponding pieces of brass, which latter are laid on one side and the routine is recommenced.

It is by this ingenious application of punches that the beautiful buhl works of the late Robert B. Henesey, of Holborn, London, were stamped. If a honeysuckle should be the device, the piece of brass is first placed between the plate and punched out, and provided the punches are of the same length, the honeysuckle is removed in *one* piece although the punch may be in *several;* the wood is afterwards inserted, and is punched to exactly the same form, so that the brass honeysuckle will be found to fit in the most perfect manner, as it is an exact counterpart of the removed wood.

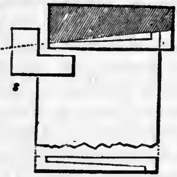
The process is very economical and exact, but is only suited to large designs, because of the injury it would otherwise inflict on the wood, and on account of the expense of the tools, the mode is only proper for those patterns of which very large numbers are wanted; whereas the buhl saw is not liable to these limitations, but is of universal, although less rapid application.

Figs. 362 363 365 366.



a

364



Cut brads and *nails,* or those which, instead of being forged, are cut out of sheet iron by machinery, constitute the last example it is proposed to advance in this section.

Brads of the most simple kind, as in Fig. 365, have no heads, but are simply wedge form, and are cut out of strips of sheet iron, equal in width to the length of the brads: these strips are slit with circular shears, *transversely* from the ends of the sheets of iron, so that the fibre of the iron may run lengthways through the nails.

When such brads are cut in the fly-press, the bed has a rectangular mortise shown by the strong black line in Fig. 365, the punch is made rather long and rectangular so as exactly to fill the bed, but the last portion of the punch, say for half an inch of its length, is nicked in, or filed back exactly to the size and angle of the brad, as shown in the inverted plan, in which the shaded portion shows the reduced part or tail of the punch. The punch is never raised entirely out of the bed, in order that the strip of metal may be put so far over the hole in the bed as the tail of the punch will allow it, and also in contact with a stop or pin fixed to the bed, and in the descent of the punch its outer or rectangular edge moves the brad.

The strip of metal is turned over between every descent of the press, so as to cut the head of the one brad from the point of that previously made, and the double guides afforded by the tail and stop enable this to be very quickly and truly done. The upper surface of the bed is not quite horizontal but a little inclined, so that the cutting may commence at the point of the brad, and thereby curl it less than if the tools met in absolute parallelism.

In cutting brads that have heads, the general arrangements are somewhat different, as explained in the diagram Fig. 366, in which as before, the rectangular aperture in the bottom tool is bounded by the strong black line, the tail of the punch is shaded, the stop *s*, is situated as far beyond the aperture in the bed as the vertical height of the head, and it is so made that the small part which extends to the right, overhangs the slip of iron that is being cut, after the manner of a puller-off; but the overhanging part only comes into action when the slip is tilted up, either by accident, or from being so short as to give an insufficient purchase for the hand. It is also to be observed that the width of the point of the brad is just equal to the projection of its head.

On the end of the strip of iron being first applied, a wedge-form piece is cut off, exactly equal to the difference between the tail of the punch and the bed, and a little projection is left near *s*, and which projection, after the iron is turned over, rests against the tail of the punch, as shown in the figure, so that the succeeding cut removes the one brad and forms the head of the following; the tail of the punch being inclined to the precise angle drawn from the point to the head of the brad, as denoted in the diagram.

When, as it is more usual, brads are cut out by steam-power, the cutters are not worked in a fly-press, but the moving cutter is commonly fixed at the end of a long arm which is moved rapidly up and down by a crank; the strip of metal is held in a spring clamp, terminating in a long iron rod which rests in a **Y** or fork, so that the boy who attends the machine, can turn the metal over very rapidly between every alternation of the machine; these particulars are shown in Fig. 353.

The machine, Fig. 353, may be used for brads either with or without heads; it is, however, always necessary to turn the iron over between every cut; but in the toggle press, Fig. 352, and which acts much more quickly, it is not requisite to reverse the metal, as the entire press is moved on its pivots *e e*, by the rod *g*, so as to incline the press alternately to the right and left, to the angle of such nails as are simply wedge-form, or have no heads, as in Fig. 365, page 386.

In some machines resembling Fig. 353, the nail as soon as cut off is grasped in a pair of forceps or dies, whilst a hammer, also moved by the machine, strikes a blow that upsets the metal, and constitutes the flat head in the kinds known as cut nails, and tacks.

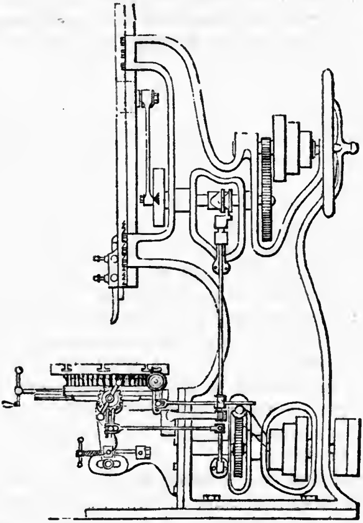
PUNCHING MACHINERY USED BY ENGINEERS.—After the remarks offered on pages 364 to 367, on shearing tools, little remains to be said in this place on the punching machinery used by engineers, as it was there stated that the cutters for shearing and the punches, were most usually combined in the same machine; the punch being placed either at the outer extremity of the jointed lever, or at the bottom of the slide in those machines having rectilinear action. The punch is fixed to the slide or moving piece, the die is secured to the framing by means of four holding and adjusting screws just as in fly-presses, and the puller off or stop is likewise added, all which details are represented in the woodcuts on pages 365 and 366.

The principal application of the engineer's punching engine, is for making the rivet-holes around the edges of the plates of which steam-boilers, tanks, and iron ships are composed. Another important use, and in which the punches trench upon the office of the shears, is in cutting out curvilinear parts and apertures or panels in boiler work, to which straight bladed shears cannot be applied. In this case the round punch is used in making a series of holes running into one another, along the particular line to be sheared through, or in other words the punch is used as a gouge, by which the hole that has been first formed, is extended by cutting away crescent-form pieces, thus leading the incision in any required direction.

This employment of the punch to shearing curved lines, is also much used in cutting out the side plates of the framings of locomotive engines, which consist of two pieces of stout boiler plate (the technical name for iron in sheets from $\frac{1}{4}$ to $\frac{3}{4}$ inch thick), riveted alongside a central piece of wood, that is sometimes also covered above and below with iron, all the parts being united by rivets. The punching engine serves admirably for cutting out all the curved lines in these side plates, also the spaces where the bearings for the wheels are situated, and various apertures.

Fig. 367 is a slotting and paring machine manufactured at the Lowell Machine Shop, Mass. The base plate and upright frame are of cast-iron. The tool bar moves by an adjustable crank of ten-inch stroke. It will range over a wheel of four feet diameter. Work may be executed by a circular or straight line movement. The tool is made self-acting, and inclines, when necessary, from a horizontal position to cut key grooves in tapering holes. The table apparatus is adjustable up and down in front of the frame by means of a rack, pinion worm, and worm-wheel.

Fig. 367.



In England the name of the inventor is suppressed of a very great improvement in the punching engine, as applied to making boilers and tanks, in which the rivet-holes are usually required to be made in straight lines, and at exactly equal distances, so that holes in two pieces punched separately may exactly correspond.

The plate was fixed down upon a long rectilinear slide or carriage, and during every ascent of the punch, was advanced by the machine itself, the interval from hole to hole, the moment after the punch was disengaged from the work. Subsequently 2, 3, or 4 punches were fixed at equal distances in the vertical slide, but the punches were made of unequal lengths, so that they came successively into action, thereby dividing the strain, and the horizontal slide was consequently shifted every time, a distance equal to 2, 3, or 4 intervals. This machine, which displayed much ingenuity of invention, served as the foundation of the more simple punching engines that are now met with. We believe the invention to be by M. Cavé of Paris.

The following experiments were performed with a cast-iron lever, 11 feet long, multiplying the strain ten times, with a screw adjustment at the head, and a counterpoise. The sheets of iron and copper which were experimented upon, were placed between two perforated steel plates, and the punch, the nipple of which was perfectly flat on the face, being inserted into a hole in the upper plate, was driven through by the pressure of the lever.

The average results of the several experiments (which are given in a detailed tabular form), show that the power required to force a punch half an inch diameter through copper and iron plates, is as follows:

Iron plate	0.08	thick, required a	pressure of	6,025	pounds.
"	0.17	"	"	11,950	"
"	0.24	"	"	17,100	"
Copper plate	0.08	"	"	3,983	"
"	0.17	"	"	7,883	"

Hence it is evident that the force necessary to punch holes of different diameters through metal of various thicknesses, is directly as the diameter of the holes and the thickness of the metal. A simple rule for determining the force required for punching may be thus deduced. Taking one inch diameter and one inch in thickness as the units of calculation, it is shown that 150·00 is the constant number for wrought-iron plates, and 96·000 for copper plates. Multiply the constant number by the diameter in inches, and by the thickness in inches; the product is the pressure in pounds, that will be required to punch a hole of a given diameter through a plate of a given thickness.

It was observed that the duration of pressure lessened considerably the ultimate force necessary to punch through metal, and that the use of oil on the punch reduced the pressure about 8 per cent. A drawing of the experimental lever and apparatus accompanied the communication.

The second experiments were by means of a hydrostatic press having four cylinders in combination, punching through various pieces of iron; the thickest of them measured 3½ inches thick, and from which was punched out a disk of 8 inches diameter, with a pressure of 2000 tons.

The removed piece was rather thinner than the remainder and a little taper, which arose from the circumstance of the bolster having been purposely made with a flat bottom, and a little larger in diameter than the punch, so that the disk when removed was a little spread or flattened out.

It is curious that experiments so distant from one another in their scale of proportion, should yet agree so nearly:

The computed force is . . 150,000 × 8 × 3½ = 4,200,000 lbs.
The actual force was . . . 2000 × 20 × 112 = 4,480,000 lbs.

Figure 368 is an upright drill, manufactured at the Lowell machine shop, Lowell, Mass., and invented by W. B. Bennet, who has invented many other useful metal-worker's tools.

The base and frame are of cast-iron; the table that holds the work is elevated or depressed by a screw; the drill feeds down by hand; the drilling-shaft has four changes of speed, and geared with iron cone pulleys. This instrument will drill a hole ten inches from the nearest edge of the object operated upon, and six inches deep.

Fig. 368.

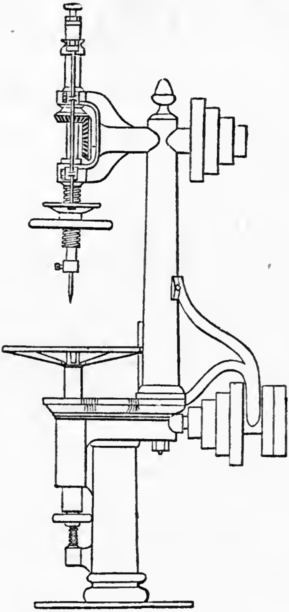
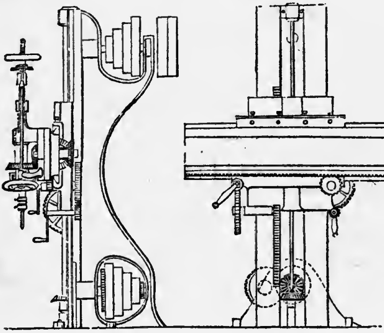


Fig. 369 is the Universal Drilling Machine, manufactured at the Lowell Machine Shop, Lowell, Mass., of which establishment Wm. A. Burke is superintendent.

This machine is designed for drilling pieces of castings, which, from their size, cannot be operated upon by drilling machines of the ordinary kinds. It consists of a very strong upright frame or column, which carries upon its front side a heavy beam or arm, that can be moved out from the column to the distance of 8 feet. This beam has also a movement up or down of 6 feet, upon the front of the column. It also carries upon its extreme outer end the drill headstock. The spindle in this headstock is driven by means of bevel gears and shafts from the first driving shaft. A hole can be drilled in a piece 8 feet distant from the nearest side or edge, and a piece can be brought under the drill 6 feet in height.

Fig. 369.



The headstock and spindle are made adjustable, so that the whole can be drilled at any angle required, and ten inches deep. The driving shaft with cast-iron pulleys is attached to the frame. The machine is back geared, giving 8 different speeds to the drill.

CHAPTER XXII.

DRILLS.

Drills for Metal, used by Hand.—The frequent necessity, in metal works, for the operation of drilling holes, which are required of all sizes and various degrees of accuracy, has led to so very great a variety of modes of performing the process, that it is difficult to arrange with much order the more important of these methods and apparatus.

The ordinary piercing drills for metal do not present quite so much variety as the wood drills. The drills for metal are mostly pointed; they consequently make conical holes, which cause the point of the drill to pursue the original line, and eventually to produce the cylindrical hole. The comparative feebleness of the drill-bow limits the size of the drills employed with it to about one-quarter of an inch in diameter; but as some of the tools used with the bow agree in kind with those of much larger dimensions, it will be convenient to consider as one group the forms of the edges of those drills which cut when moved in *either* direction.

Figs. 370, 371, and 372, represent, of their largest sizes, the usual forms of drills proper for the reciprocating motion of the drill bow, because, their cutting edges being situated on the line of the axis, and chamfered on each side, they cut, or rather *scrape*, with equal facility in both directions of motion.

Fig. 370 is the ordinary double-cutting drill, the two facets forming each edge meet at an angle of about 50 to 70 degrees, and the two edges forming the point meet at about 80 to 100; but the watch-makers, who constantly employ this kind of drill, sometimes make the end as obtuse as an angle of about 120 degrees; the point does not then protrude through their thin works long before the completion of the hole. Fig. 371, with two circular chamfers, bores cast-iron more rapidly than any other reciprocating drill, but it requires an entry to be first made with a pointed drill. By some this kind is also preferred for wrought-iron and steel. The flat-ended drill, Fig. 372, is used for flattening the bottoms of holes. Fig. 373 is a duplex expanding drill, used by the cutlers for inlaying the little plates of metal in knife handles; the ends are drawn full size.

Figs. 370 371 372 373 374 375.

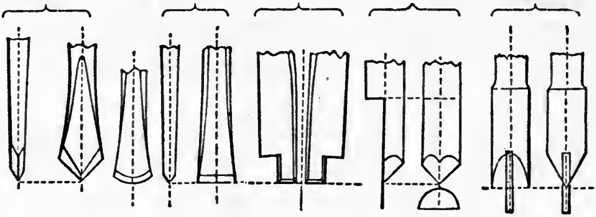


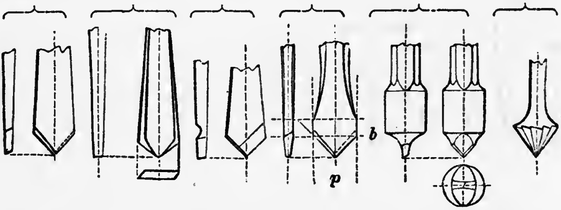
Fig. 374 is also a double-cutting drill; the cylindrical wire is filed to the diametrical line, and the end is formed with two facets. This tool has the advantage of retaining the same diameter when it is sharpened. It is sometimes called the Swiss drill, and was employed by M. Le Rivière, for making the numerous small holes in the delicate punching machinery for manufacturing perforated sheets of metal and pasteboard. These drills are sometimes made either semi-circular or flat at the extremity.

The square countersink, Fig. 375, is also used with the drill-bow; it is made cylindrical, and pierced for the reception of a small central pin—after which it is sharpened to a chisel-edge, as shown. This countersink is in some measure a diminutive of the pin drills, Figs. 382 to 385; and occasionally circular collars are fitted on the pin for its temporary enlargement, or around the larger part to serve as a stop and limit the depth to which the countersink is allowed to penetrate, for inlaying the heads of screws. The pin is removed when the instrument is sharpened.

By way of comparison with the double-cutting drills, the ordinary forms of those which only cut in *one* direction are shown in Figs. 376, 377, and 378. Fig. 376 is the common single cutting drill for the drill-bow, brace, and lathe. The point, as usual, is nearly a rectangle, but is formed by only two facets, which meet the sides at about 80° to 85°; and therefore lie very nearly in contact with the extremity of the hole operated upon, thus strictly agreeing with the form of the turning tools for brass. Fig. 377 is a similar drill, particularly suitable for horn, tortoise-shell, and substances liable to agglutinate and clog the drill. The chamfers are rather more acute, and are continued around the edge behind its largest diameter, so that, if needful, the drill may also cut its way *out* of the hole.

Fig. 378, although never used with the drill-bow, nor of so small a size as in the wood-cut, is added to show how completely the drill proper for iron, follows the character of the turning tools for that metal; the flute or hollow filed behind the edge, gives the hook-formed acute edge required in this tool, which is in other respects like Fig. 376; the form proper for the cutting edge is shown more distinctly in the diagram *a*, Fig. 382.

Figs. 376 377 378 379 380 381.



Care should always be taken to have a proportional degree of strength in the shafts of the drills, otherwise they tremble and chatter when at work or they occasionally twist off in the neck; the point should be also ground exactly central, so that both edges may cut. As a guide for the proportional thickness of the point, it may measure at *b*, Fig. 379, the base of the cone, about one-fifth the diameter of the hole, and at *p*, the point, about one-eighth, for easier penetration; but the fluted drills are made nearly of the same thickness at the point and base.

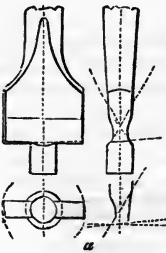
In all the drills previously described, except Fig. 374, the size of the point is lessened each time of sharpening; but to avoid this loss of size, a small part is often made parallel, as shown in Fig. 379. In Fig. 380 this mode is extended by making the drill with a cylindrical lump, so as to fill the hole; this is called the *re-centering drill.* It is used for commencing a small hole in a flat-bottomed cylindrical cavity; or else, in rotation with the common piercing drill, and the half-round bit. in drilling small and very deep holes in the lathe. Fig. 380 may be also considered to resemble the *stop-drill*, upon which a solid lump or shoulder is formed, or a collar is temporarily attached by a side screw, for limiting the depth to which the tool can penetrate the work.

Fig. 381, the *cone countersink*, may be viewed as a multiplication of the common single cutting drill. Sometimes, however, the tool is filed with four equi-distant radial furrows, directly upon the axis, and with several intermediate parallel furrows sweeping at an angle around the cone. This makes a more even distribution of the teeth, than when all are radial as in the figure, and it is always used in the spherical cutters, or countersinks, known as *cherries*, which are used in making bullet-moulds.

On comparison, it may be said the single chamfered drill, Fig. 376, cuts more quickly than the double chamfered, Fig. 370, but that the former is also more disposed of the two to swerve or *run* from its intended position. In using the double cutting drills, it is also necessary to drill the holes at once to their full sizes, as otherwise the thin edges of these tools stick abruptly into the metal, and are liable to produce jagged or groovy surfaces, which destroy the circularity of the holes; the necessity for drilling the entire hole at once, joined to the feebleness of the drill-bow, limits the size of these drills.

In using the single chamfered drills, it is customary, and on several accounts desirable, to make large holes by a series of two or more drills; first the run of the drill is in a measure proportioned to its diameter, therefore the small tool departs less from its intended path, and a central hole once obtained, it is followed with little after-risk by the single cutting drill, which is less penetrative. This mode likewise throws out of action the less favorable part of the drill near the point, and which in large drills is necessarily thick and obtuse; the subdivision of the work enables a comparatively small power to be used for drilling large holes, and also presents the choice of velocity best suited to each progressive diameter operated upon. But where sufficient power can be ob-

Figs. 382



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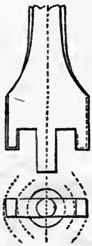

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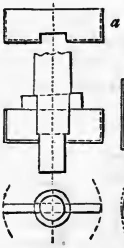
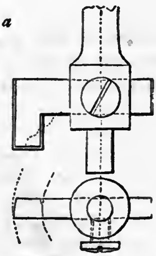


385.



tained, it is generally more judicious to enlarge the holes previously made with the pointed drills, by some of the group of pin drills, Figs. 382 to 385, in which the guide principle is very perfectly employed: they present a close analogy to the plug centre-bit, and the expanding centre-bit, used in carpentry.

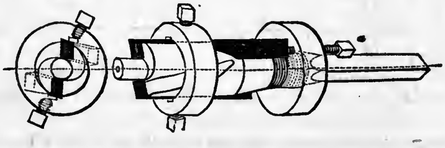
The ordinary *pin-drill*, Fig. 382, is employed for making countersinks for the heads of screw-bolts inlaid flush with the surface, and also for enlarging holes commenced with pointed drills, by a cut parallel with the surface; the pin-drill is also particularly suited to thin materials, as the point of the ordinary drill would soon pierce through, and leave the guidance less certain. When this tool is used for iron it is fluted as usual, and *a* represents the form of the one edge separately.

Fig. 383 is a pin drill principally used for cutting out large holes in cast-iron and other plates. In this case the narrow cutter removes a ring of metal, which is of course a less laborious process than cutting the whole into shavings. When this drill is applied from both sides, it may be used for plates half an inch and upwards in thickness; as should not the tool penetrate the whole of the way through, the piece may be broken out, and the rough edges cleaned with a file or a broach.

Fig. 384 is a tool commonly used for drilling the *tube-plates* for receiving the tubes of locomotive boilers; the material is about $\frac{3}{4}$ inch thick, and the holes $1\frac{3}{4}$ diameter. The loose cutter *a*, is fitted in a transverse mortise, and secured by a wedge; it admits of being several times ground, before the notch which guides the blade for centrality is obliterated. Fig. 385 is somewhat similar to the last two, but is principally intended for sinking grooves; and when the tool is figured as shown by the dotted line, it may be used for cutting bosses and mouldings on parts of work not otherwise accessible.

Many ingenious contrivances have been made to insure the dimensions and angles of tools being exactly retained. In this class may be placed O'Tool's pin drill, Figs. 386 and 387; in action it resembles the fluted pin drill, Fig. 382, but the iron stock is

Figs. 386 387.



much heavier, and is attached to the drilling machine by the square tang; the stock has two grooves at an angle of about 10 degrees with the axis, and rather deeper behind than in front. Two steel cutters, or nearly parallel blades represented black, are laid in the grooves; they are fixed by the ring and two set screws, and are advanced as they become worn away, by two adjusting screws, *a a*, (one only seen), placed at the angle of 10° through the second ring; which, for the convenience of construction, is screwed upon the drill shaft just beyond the square tang whereby it is attached to the drilling machine. The cutters are ground at the extreme ends, but they also require an occasional touch on the oilstone, to restore the keenness of the outer angles, which become somewhat rounded by the friction. The diminution from the trifling exterior sharpening, is allowed for by the slightly taper form of the blades.

The process of drilling generally gives rise to more friction than that of turning, and the same methods of lubrication are used, but rather more commonly and plentifully; thus oil is used for the generality of metals, or from economy, soap and water; milk is the most proper for copper, gold, and silver; and cast-iron and brass are usually drilled without lubrication. For all the above-named metals and for alloys of similar degrees of hardness the common pointed steel drills are generally used; but for lead and very soft alloys, the carpenters' spoon bits, and nose bits, are usually employed, with water.

Having considered the most general forms of the cutting parts of drills, we will proceed to explain the modes in which they are put in action by hand-power, beginning with those for the smallest diameters, and proceeding gradually to the largest.

METHODS OF WORKING DRILLS BY HAND-POWER.—The smallest holes are those required in watch-work, and the general form of the drill is shown on a large scale in Fig. 388; it is made of a piece of steel wire, which is tapered off at the one end, flattened with the hammer, and then filled up in the form shown at large in Fig. 370; lastly, it is hardened in the candle. The reverse end of the instrument is made into a conical point, and is also hardened; near this end is attached a little brass sheave for the line of the drill-bow, which in watchmaking is sometimes a fine horse-hair, stretched by a piece of whalebone of about the size of a goose's quill stripped of its feather

Fig. 388.

The watchmaker holds most of his works in the fingers, both for fear of crushing them with the table vice, and also that he may the more sensibly feel his operations; drilling is likewise performed by him in the same manner. Having passed the bow-string around the pulley in a single loop (or with a *round turn*), the centre of the drill is inserted in one of the small centre holes in the sides of the table vice, the point of the drill is placed in the mark or cavity made in the work by the centre punch; the object is then pressed forward with the right hand, whilst the bow is moved with the left; the Swiss workmen apply the hands in the reverse order, as they do in using the turn-bench.

Clockmakers, and artisans in works of similar scale, fix the object in the tail-vice, and use drills, such as Fig. 388, but often larger and longer; they are pressed forward by the chest, which is defended from injury by the breast-plate, namely, a piece of wood or metal about the size of the hand, in the middle of which is a plate of steel, with centre holes for the drill. The breast-plate is sometimes strapped round the waist, but is more usually supported with the left hand, the fingers of which are ready to catch the drill should it accidentally slip out of the centre.

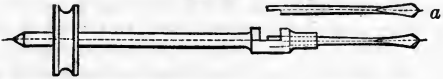
As the drill gets larger, the bow is proportionally increased in stiffness, and eventually becomes the half of a solid cone, about 1 inch in diameter at the larger end, and 30 inches long; the catgut string is sometimes nearly an eighth of an inch in diameter, or is replaced by a leather thong. The string is attached to the smaller end of the bow by a loop and notch, much the same as in the archery bow, and is passed through a hole at the larger end, and made fast with a knot; the surplus length is wound round the cane, and the cord finally passes through a notch at the end, which prevents it from uncoiling.

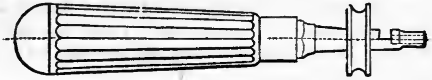
Steel bows are also occasionally used; these are made something like a fencing foil, but with a hook at the end for the knot or loop of the cord, and with a ferrule or a ratchet, around which the spare cord is wound. Some variations also are made in the sheaves of the large drills; sometimes they are cylindrical, with a fillet at each end; this is desirable, as the cord necessarily lies on the sheave at an angle, in fact in the path of a screw; it pursues that path, and with the reciprocation of the drill-bow, the cord traverses, or screws backwards and forwards upon the sheave, but is prevented from sliding off by the fillet. Occasionally, indeed, the cylindrical sheave is cut with a screw coarse enough to receive the cord, which may then make three or four coils for increased purchase, and have its natural screw-like run without any fretting whatever; but this is only desirable when the holes are large, and the drill is almost constantly used, as it is tedious to wind on the cord for each individual hole. The structure of the bows, breast-plates, and pulleys, although often varied, is sufficiently familiar to be understood without figures.

When the shaft of the drill is moderately long, the workman can readily observe if the drill is square with the work as regards the horizontal plane; and to remove the necessity for the observation of an assistant as to the vertical plane, a trifling weight is sometimes suspended from the drill shaft by a metal ring or hook; the joggling motion shifts the weight to the lower extremity; the tool is only horizontal when the weight remains central.

In many cases, the necessity for repeating the shaft and pulley of the drill is avoided by the employment of holders of various kinds, or *drill-stocks,* which serve to carry any required number of drill points. The most simple of the drill-stocks is shown in Fig. 389; it has the centre and pulley of the ordinary drill, but the opposite end is pierced with a nearly cylindrical hole, just at the inner extremity of which a diametrical notch is filed. The drill is shown separately at *a*; its shank is made cylindrical, or exactly to fit the hole, and a short portion is nicked down also to the diametrical line so as to slide into the gap in the drill-stock, by which the drill is prevented from revolving: the end serves also as an abutment, whereby it may be thrust out with a lever. Sometimes a diametrical transverse mortise, narrower than the hole, is made through the drill-stock, and the drill is nicked in on both sides; and the designer, Mr. R. Balfe, of Kilkenny, proposes that the cylindrical hole of 389 should be continued to the bottom of the notch, that the end of the drill should be filed off obliquely, and that it should be prevented from rotating by a pin inserted through the cylindrical hole parallel with the notch; the taper end of the drill would then wedge fast beneath the pin.

Figs. 389





390.

Drills are also frequently used in the *drilling-lathe;* this is a miniature lathe-head, the frame of which is fixed in the table vice; the mandrel is pierced for the drills, and has a pulley for the bow, therein resembling Fig. 390, except that it is used as a fixture.

The figure 390, just referred to, represents one variety of another common form of the drill-stock, in which the revolving spindle is fitted in a handle, so that it may be held in any position without the necessity for the breast-plate; the handle is hollowed out to serve for containing the drills, and is fluted to assist the grasp.

Figs. 391 392 393.

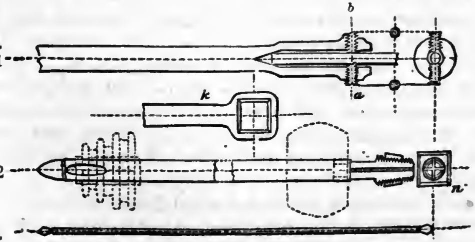


Fig. 391 represents the socket of an "*universal drill-stock,*" invented by James O'Ryan: it is pierced with a hole as large as the largest of the wires of which the drills are formed, and the hole terminates in an acute hollow cone. The end of the drill-stock is tapped with two holes, placed on a diameter; the one screw, *a*, is of a very fine thread, and has at the end two shallow diametrical notches; the other, *b*, is of a coarser thread, and quite flat at the extremity. The wire-drill is placed against the bottom of the hole, and allowed to lean against the adjusting-screw *a*, and if the drill be not central, this screw is moved one or several quarter-turns, until it is adjusted for centrality; after which the tool is strongly fixed by the plain set-screw *b*.

Fig. 392 is a drill-stock contrived by Mr. Murphy. It consists of a tube, the one end of which has a fixed centre and pulley, much the same as usual. The opposite end of the tube has a piece of steel fixed into it which is first drilled with a central hole, and then turned as a conical screw, to which is fitted a corresponding screw nut, *n*; the socket is then sawn down with two diametrical notches, to make four internal angles; and lastly, the socket is hardened. When the four sections are compressed by the nut, their edges stick into the drill and retain it fast, and, provided the instrument is itself concentric, and the four parts are of equal strength, the centrality of the drill is at once insured. The outside of the nut, and the square hole in the key *k*, are each taper, for more ready application; and the drills are of the most simple kind, namely, lengths of wire pointed at each end, as in Fig. 393.

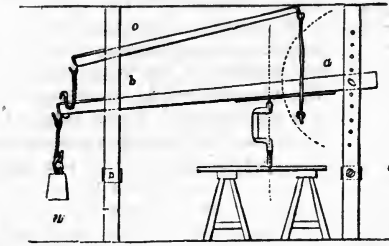
The sketch, Fig. 392, is also intended to explain another useful application of this drill-stock as an *upright* or *pump-drill*, well known among the ancient Irish as the breast-drill. Occasionally the pump-drill and the common drill-stock are mounted in frames, by which their paths are more exactly defined; but these contrivances are far from being generally required, and enough will be said in reference to the use of revolving braces, to lead to such applications, if considered requisite, for reciprocating drills.

Holes that are too large to be drilled *solely* by the breast-drill and drill-bow, are frequently commenced with those useful instruments, and are then enlarged by means of the hand-brace, which is very similar to that used in carpentry, except that it is more commonly made of iron instead of wood, is somewhat larger, and generally made without the spring-catch.

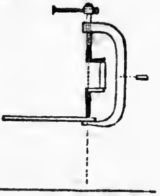
Holes may be extended to about half an inch diameter with the hand-brace; but it is much more expeditious to employ still larger and stronger braces, and to press them into the work in various ways by weights, levers, and screws, instead of by the muscular effort alone.

Fig. 394 represents the old smith's press-drill, which although cumbrous and much less used than formerly, is nevertheless simple and effective. It consists of two pairs of wooden standards, be tween which works the beam *a b*, the pin near *a* is placed at any height, but the weight *w* is not usually changed, as the greater or

Figs. 394



395.



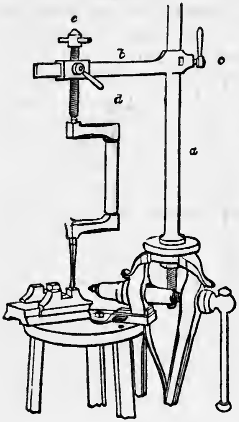
less pressure for large and small drills is obtained by placing the brace more or less near to the fulcrum *a*; and this part of the beam is shod with an iron plate full of small centre holes for the brace. The weight is raised by the second lever *c d*, the two being united by a chain, and a light chain or rope is also suspended from *d*, to be within reach of the one or two men engaged in moving the brace. It is necessary to relieve the weight when the drill is nearly through the hole, otherwise it might suddenly break through, and the drill becoming fixed, might be twisted off in the neck.

The inconveniences in this machine are, that the upper point of the brace moves in an arc instead of a right line; the limited path when strong pressures are used, which makes it necessary to shift the fulcrum *a*; and also the necessity for re-adjusting the work under the drill for each different hole, which in awkwardly-shaped pieces is often troublesome.

A portable contrivance, of similar date, is an iron bow frame or clamp, shown in Fig. 395. The pressure is applied by a screw, but in almost all cases, whilst the one individual drills the hole, the assistance of another is required to hold the frame; 395 only applies to comparatively thin parallel works, and does not present the necessary choice of position. Another tool of this kind, used for boring the side holes in cast-iron pipes for water and gas, is doubtless familiarly known; the cramp or frame divides into two branches about two feet apart, and these terminate like hooks, which loosely embrace the pipe, so that the tool retains its position without constraint, and it may be used with great facility by one individual.

Fig. 396 will serve to show the general character of various constructions of more modern apparatus, to be used for supplying the pressure in drilling holes with hand braces. It consists of a cylindrical bar *a*, upon which the horizontal rectangular rod *b* is fitted with a socket, so that it may be fixed at any height, or in any angular position, by the set-screw *c*. Upon *b* slides a socket, which

Fig. 396.



is fixed at all distances from *a* by its set-screw *d*; and lastly, this socket has a long vertical screw *e*, by which the brace is thrust into the work.

The object to be drilled having been placed level, either upon the ground, on trestles, on the work bench, or in the vice, according to circumstances, the screws *c* and *d* are loosened, and the brace is put in position for work. The perpendicularity of the brace is then examined with a plumb-line, applied in two positions (the eye being first directed as it were along the north and south line, and then along the east and west), after which the whole is made fast by the screws *c* and *d*. The one hole having been drilled, the socket and screws present great facility in re-adjusting the instrument for subsequent holes without the necessity for shifting the work, which would generally be attended with more trouble than altering the drill-frame by its screws.

Sometimes the rod *a* is rectangular, and extends from the floor to the ceiling; it then traverses in fixed sockets, the lower of which has a set screw for retaining any required position. In the tool represented, the rod *a* terminates in a cast-iron base, by which it may be grasped in the tail-vice, or when required it may be fixed upon the bench; in this case the nut *a* is unscrewed, the cast-iron plate, when reversed and placed on the bench, serves as a pedestal, the stem is passed through a hole in the bench, and the nut and washer, when screwed on the stem beneath, secure all very strongly together. Even in establishments where the most complete drilling machines driven by power are at hand, modifications of the press drill are among the indispensable tools: many are contrived with screws and clamps, by which they are attached directly to such works as are sufficiently large and massive to serve as a foundation.

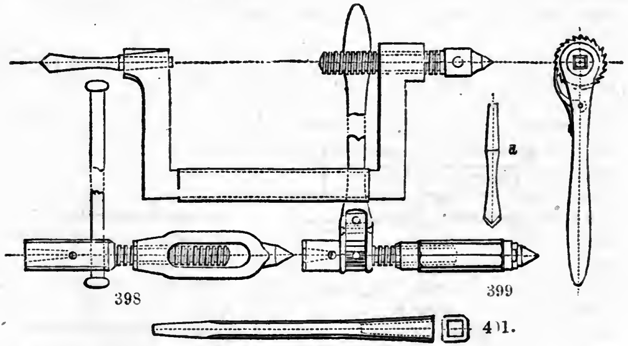
Various useful drilling tools for engineering works are fitted with left hand screws, the unwinding of which elongate the tools; so that for these instruments which supply their own pressure, it is only necessary to find a solid support for the centre. They apply very readily in drilling holes within boxes and panels, and the abutment is often similarly provided by projecting parts of the castings; or otherwise the fixed support is derived from the wall or ceiling, by aid of props arranged in the most convenient manner that presents itself.

Fig. 397 is the common brace, which only differs from that in

Fig. 396 in the left hand screw; a right hand screw would be unwound in the act of drilling a hole when the brace is moved round in the usual direction, which agrees with the path of a left hand screw. The cutting motion produces no change in the length of the instrument, and the screw being held at rest for a moment during the revolution, sets in the cut; but towards the last, the feed is discontinued, as the elasticity of the brace and work suffice for the reduced pressure required when the drill is nearly through, and sometimes the screw is unwound still more to reduce it.

The *lever-drill*, Fig. 398, differs from the latter figure in many respects; it is much stronger, and applicable to larger holes; the drill socket is sufficiently long to be cut into the left hand screw, and the piece serving as the screwed nut, is a loop terminating in the centre point. The increased length of the lever gives much greater purchase than in the crank-formed brace, and in addition the lever-brace may be applied close against a surface where the crank-brace cannot be turned round; in this case the lever is only moved a half circle at a time, and is then slid through for a new purchase, or sometimes a spanner or wrench is applied directly upon the square drill socket.

Figs. 397 400

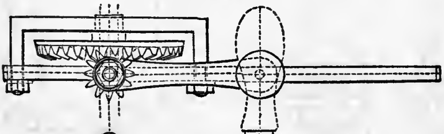


The same end is more conveniently fulfilled by the *ratchet-drill*, Fig. 399, apparently derived from the last: it is made by cutting ratchet teeth in the drill shaft, or putting on the rachet as a separate piece, and fixing a pall or detent to the handle; the latter may then be moved backward to gather up the teeth, and forward to thrust round the tool, with less delay than the lever in Fig. 398, and with the same power, the two being of equal length. This tool is also peculiarly applicable to reaching into angles and places in which neither the crank-form brace, nor the lever-drill will apply. Fig. 400, the *ratchet-lever*, in part resembles the ratchet-drill, but the pressure-screw of the latter instrument must be sought in some of the other contrivances referred to, as the ratchet-lever has simply a square aperture to fit on the tang of the drill *d*, which latter must be pressed forward by some independent means.

Fig. 401, which is a simple but necessary addition to the braces and drill tools, is a socket having at one end a square hole to receive the drills, and at the opposite, a square tang to fit the brace; by this contrivance the length of the drill can be temporarily extended for reaching deeply seated holes. The sockets are made of various lengths, and sometimes two or three are used together, to extend the length of the brace to suit the position of the prop; but it must be remembered that, with the additional length, the torsion becomes much increased, and the resistance to end-long pressure much diminished, therefore the sockets should have a bulk proportionate to their length.

The French brace is also constructed in iron, with a pair of equal bevel pinions, and a left hand centre screw, like the tools Figs. 397, 398, and 399; it is then called the *corner-drill.* Sometimes also, as in Figs. 402 and 403, the bevel wheels are made with a hollow square or axis, as in the ratchet-lever, Fig. 400; the driver then hangs loosely on the square shank of the drill tool, or cutter bar, and when the pinion on the handle is only one-third or fourth of the size of the bevel wheel with the square hole, it is an effective driver for various uses; the long tail or lever serves to prevent the rotation of the driver, by resting against some part of the work or of the work-bench.

Fig. 402



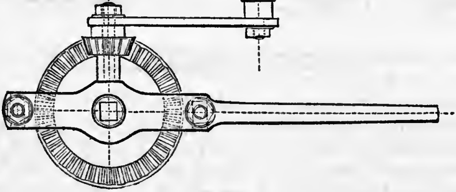


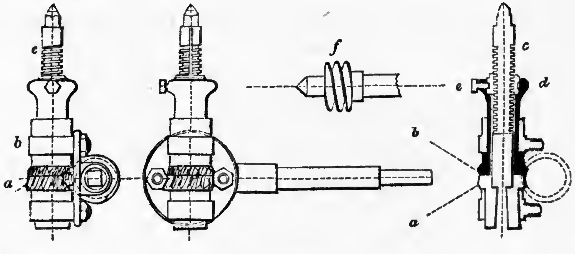
Fig. 403.

All the before-mentioned tools are commonly found in a variety of shapes in the hands of the engineer, but it will be observed they are all driven by hand power, and are carried to the work. I shall conclude this section with the description of a more recent drill tool of the same kind, invented by Mr. O'Kelly of Dublin.

This instrument is represented of one-eighth size, in the side view, Fig. 404, in the front view, 405, and in the section, 406; it is about twice as powerful as Fig. 403, and has the advantage of feeding the cut by a differential motion. The tangent screw moves at the same time the two worm wheels *a* and *b*; the former has 15 teeth, and serves to revolve the drill; the latter has 16 teeth, and by the difference between the two, or the *odd tooth*, advances the drill slowly and continually, which may be thus explained.

The lower wheel *a*, of 15 teeth, is fixed on the drill shaft, and this is tapped to receive the centre screw *c*, of four threads per inch. The upper wheel of 16 teeth is at the end of a socket *d*, (which is represented black in the section Fig. 406), and is connected with the centre screw *c*, by a collar and internal key, which last fits a longitudinal groove cut up the side of the screw *c*; now, therefore, the internal and external screws travel constantly round, and nearly at the same rate, the *difference* of one tooth in the wheels serving continually and slowly to project the screw *c*, for feeding the cut. To shorten or lengthen the instrument rapidly, the side screw *e* is loosened; this sets the collar and key free from the 16 wheel, and the centre screw may for the time be moved independently by a spanner.

Figs. 404 405 406.



The *differential screw-drill*, having a double thread in the large worm, shown detached at *f*, requires 7½ turns of the handle to move the drill once round, and the feed is one 64th of an inch for each turn of the drill; that being the sum of 16 by 4.

Drilling and Boring Machines.—The motion of the lathe mandrel is particularly proper for giving action to the various single-cutting drills referred to; they are then fixed in square or round hole drill-chucks which screw upon the lathe mandrel. The motion of the lathe is more uniform than that of the hand tools, and the popit-head, with its flat boring flange and pressure screw, forms a most convenient arrangement, as the works are then carried to the drill exactly at right angles to the face. But in drilling very small holes in the lathe, there is some risk of unconsciously employing a greater pressure with the screw than the slender drills will bear. Sometimes the cylinder is pressed forward by a horizontal lever fixed on a fulcrum; at other times the cylinder is pressed forward by a spring, by a rack and pinion motion, or by a simple lever, and the best arrangement of this latter kind is that next to be described.

In the manufacture of harps there is a vast quantity of small drilling, and the pressure of the cylinder popit-head is given by means of a long, straight, double ended lever, which moves horizontally (at about one-third from the back extremity), upon a fixed post or fulcrum erected upon the back-board of the lathe. The front of the lever is connected with the sliding cylinder by a link or connecting rod, and the back of the lever is pulled towards the right extremity of the lathe, by a cord which passes over a pulley at the edge of the back-board, and then supports a weight of about twenty pounds.

Both the weight and connecting rod may be attached at various distances from the fixed fulcrum between them. When they are fixed at equal distances from the axis of the lever, the weight, if twenty pounds, presses forward the drill with twenty pounds, less a little friction; if the weight be two inches from the fulcrum and the connecting rod eight inches, the effect of the weight is reduced to five pounds; if, on the other hand, the weight be at eight and the connecting rod at two inches, the pressure is fourfold, or eighty pounds.

The connecting rod is full of holes, so that the lever may be adjusted exactly to reach the body of the workman, who standing with his face to the mandrel, moves the lever with his back, and has therefore both hands at liberty for managing the work. Sometimes a stop is fixed on the cylinder, for drilling holes to one fixed depth; gages are attached to the flange, for drilling numbers of similar pieces at any fixed distance from the edge: in fact, this very useful apparatus admits of many little additions to facilitate the use of drills and revolving cutters.

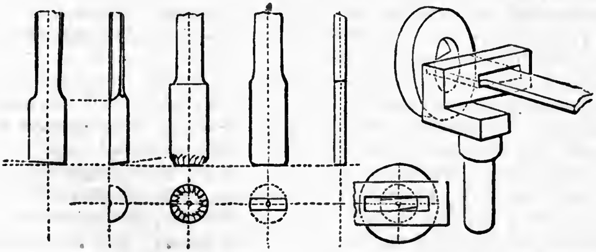
Great numbers of circular objects, such as wheels and pulleys, are chucked to revolve truly upon the lathe mandrel, whilst a stationary drill is thrust forward against them, by which means the concentricity between the hole and the edge is insured.

The drills employed for boring works chucked on the lathe, have mostly long shafts, some parts of which are rectangular or parallel, so that they may be prevented from revolving by a hook wrench, a spanner or a hand-vice, applied as a radius, or by other means. The ends of the drill shafts are pierced with small centre holes, in order that they may be thrust forward by the screw of the popit-head, either by hand or by self-acting motion: namely, a connection between either the mandrel or the prime mover of the lathe, and the screw of the popit-head, by cords and pulleys, by wheels and pinions, or other contrivances.

The drills, Figs. 376 and 378, p. 394, are used for boring ordinary holes: but for those requiring greater accuracy, or a more exact repetition of the same diameter, the lathe drills, Figs. 407 to 409 are commonly selected. Fig. 407, which is drawn in three views and to the same scale as the former examples, is called the *half-round bit*, or the *cylinder bit.* The extremity is ground a little inclined to the right angle, both horizontally and vertically, to about the extent of three to five degrees. It is necessary to turn out a shallow recess exactly to the diameter of the end of the bit as a commencement; the circular part of the bit fills the hole, and is thereby retained central, whilst the left angle removes the shaving. This tool should never be sharpened on its diametrical face, or it would soon cease to deserve its appellation of *half-round* bit: some indeed give it about one-thirtieth more of the circumference. It is generally made very slightly smaller behind, to lessen the friction; and the angle, not intended to cut, is a little blunted half-way round the curve, that it may not scratch the hole from the pressure of the cutting edge. It is lubricated with oil for the metals generally, but is used dry for hard woods and ivory, and sometimes for brass.

The rose-bit, Fig. 408, is also very much used for light finishing cuts, in brass, iron, and steel; the extremity is cylindrical, or in the smallest degree less behind, and the end is cut into teeth like a countersink; the rose-bit, when it has plenty of oil, and but very little to remove, will be found to act beautifully, but this tool is less fit for cast-iron than the bit next to be described. The rose-bit may be used without oil for the hard woods and ivory, in which it makes a very clean hole; but as the end of the tool is chamfered, it does not leave a flat-bottomed recess the same as the half-round bit, and is therefore only used for thoroughfare holes.

Figs. 407 **408** **409** **410**



411.

The drill, Fig. 409, is much employed, but especially for cast-iron work; the end of the blade is made very nearly parallel, the two front corners are ground slightly rounding, and are chamfered, the chamfer is continued at a reduced angle along the two sides, to the extent of about two diameters in length: this portion is not strictly parallel, but is very slightly largest in the middle or barrel-shaped: this drill is used dry for cast-iron.

Fig. 409, in common with all drills that cut on the side, may, by improper direction, cut sideways, making the hole above the intended diameter; but when the hole has been roughly bored with a common fluted drill, the end of the latter is used as a turning tool, to make an accurate chamfer, the bit 409 is then placed through the stay, as shown in Fig. 410, and is lightly supported between the chamfer upon the work and the centre of the popit-head; the moment any pressure comes on the drill, its opposite edges stick into the inner sides of the loop (as more clearly explained in Fig. 411), which thus restrains its position; much the same as the point and edges of the turning tools for iron dig into the rest, and secure the position of those tools.

It is requisite the drill and loop should be exactly central; Fig. 410 shows the common form of the stay when fitted to the lathe rest, but it is sometimes made as a swing gate, to turn aside, whilst the piece which has been drilled is removed, and the next piece to be operated upon is fixed in the lathe. Sometimes also the drill 409 has blocks of hardwood attached above and below it, to complete the circle; this is usual for wrought-iron and steel, and oil is then employed.

These three varieties are exclusively lathe-drills, and are intended for the exact repetition of a number of holes of the particular sizes of the bits, and which, on that account, should remove only a thin shaving to save the tools from wear.

The cylinder bits, however, may be used for enlarging holes below half an inch, to the extent of about one-third their diameter at one cut; and for holes from half an inch to one inch, about one-fourth their diameter or less, and as the bits increase in size, the proportion of the cut to the diameter should decrease.

The cylinder bit is not intended to be used for drilling holes in the solid material, and as the piercing drills are apt to swerve in drilling small and very deep holes, the following rotation in the tools is sometimes resorted to. A drill, Fig. 376, p. 394, say three-sixteenths diameter, is first sent into the depth of an inch or upwards, and the hole is enlarged by a cylinder bit of one-quarter inch diameter. The centre at the end of the hole is then restored to exact truth, by Fig. 380, a re-centering drill, the plug of which exactly fits the hole made by the cylinder bit; the extremity of the re-centering drill then acts as a fixed turning tool, and should the first drill have run out of its position, Fig. 380 corrects the centre at the end of the hole. Another short portion is then drilled with Fig. 376, enlarged with the half-round bit, and the conical extremity is again corrected with the re-centering drill; the three tools are thus used in rotation until the hole is completed, and which may be then cleaned out with one continued cut, made with a half-round bit a little larger than that previously used.

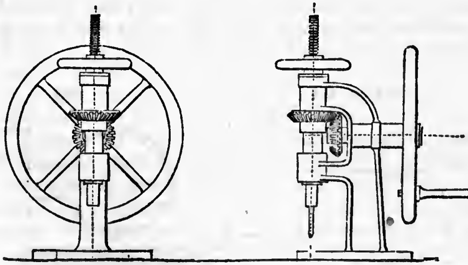
Some of the large half-round bits are so made that the one stock will serve for several cutters of different diameters. In the bits used for boring out ordnance, the parallel shaft of the boring bar slides accurately in a groove, exactly parallel with the bore of the gun; the cutting blade is a small piece of steel affixed to the end of the half-round block, which is either entirely of iron, or partly of wood; and the cut is advanced by a rack and pinion movement, actuated either by the descent of a constant weight, or by a self-acting motion derived from the prime mover. For making the spherical, parabolical or other termination to the bore, cutters of corresponding forms are fixed to the bar.

The outside of the gun is usually turned, whilst the boring is going on, by hand tools. A plug of copper is screwed into the brass guns to be perforated for the touch-hole, copper being less injured by repeated discharges, than the alloy of nine parts copper and one part tin, used for the general substance of the gun; the curved bit smooths off the end of the plug.

There are very many works which from their weight or size, cannot be drilled in the lathe in its ordinary position, as it is scarcely possible to support them steadily against the drill; but these works are readily pierced in the drilling machine, which may be viewed as a lathe with a vertical mandrel, and with the flange of the popit-head, enlarged into a table for the work, which then lies in the horizontal position simply by gravity, or is occasionally fixed on the table by screws and clamps. The structure of these important machines admits of almost endless diversity, and in nearly every manufactory some peculiarity of construction may be observed.

Figs. 412 and 413, exhibit a "Portable Hand-drill," which is introduced as a simple and efficient example, that may serve to

Figs. 412 413.



convey the general characters of the drilling machines. The spindle is driven by a pair of bevel pinions, the one is attached to the axis of the vertical fly-wheel, the other to the drill shaft, which is depressed by a screw moved by a small hand-wheel.

Sometimes, as in the lathe, the drilling spindle revolves without endlong motion, and the table is raised by a treadle or by a hand lever; but more generally the drill-shaft is cylindrical and revolves in, and also slides through fixed cylindrical bearings. The drill spindle is then depressed in a variety of ways; sometimes by a simple lever, at other times by a treadle, which either lowers the shaft only one single sweep, or by a ratchet that brings it down by several small successive steps, through a greater distance; and mostly a counterpoise weight restores the parts to their first position when the hand or foot is removed. Friction clutches, trains of differential wheels, and other modes are also used in depressing the drill spindle, or in elevating the table by self-acting motion. Frequently also the platform admits of an adjustment independent of that of the spindle, for the sake of admitting larger pieces; the horizontal position of the platform is then retained by a slide, to which a rack and pinion movement, or an elevating screw is added.

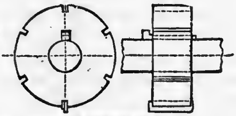
Drilling machines of these kinds are generally used with the ordinary piercing drills, and occasionally with pin drills; the latter instrument appears to be the type of another class of boring tools, namely, *cutter bars*, which are used for works requiring holes of greater dimensions, or of superior accuracy, than can be attained by the ordinary pointed drills.

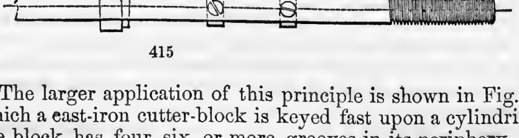
The small application of this principle, or of cutter bars, is shown on the same scale as the former drills, in Fig. 414; the cutter is placed in a diametrical mortise in a cylindrical boring bar, and is fixed by a wedge; the cutter extends equally on both sides, as the two projections or ears embrace the sides of the bar, which is slightly flattened near the mortises.

Cutter bars of the same kind are occasionally employed with cutters of a variety of forms, for making grooves, recesses, mouldings, and even screws, upon parts of heavy works, and those which cannot be conveniently fixed in the ordinary lathe. Fig. 415 represents one of these, but its application to screws will be found in the chapter on the tools for screw cutting.

Figs. 414

416





415

The larger application of this principle is shown in Fig. 415, in which a cast-iron cutter-block is keyed fast upon a cylindrical bar; the block has four, six, or more grooves in its periphery. Sometimes, the work is done with only one cutter, and should the bar vibrate, the remainder of the grooves are filled with pieces of hard wood, so as to complete the bearing at so many points of the circle; occasionally cutters are placed in all the grooves, and carefully adjusted to act in succession, that is, the first stands a little nearer to the axis than the second, and so on throughout, in order that each may do its share of work; but the last of the series takes only a light finishing cut, that its keen edge may be the longer preserved. In all these cutters, the one face is radial, the other differs only four or five degrees from the right angle, and the corners of the tools are slightly rounded.

These cutter bars, like the rest of the drilling and boring machinery, are employed in a great variety of ways, but which resolve themselves into three principal modes:

First, the cutter bar revolves without endlong motion, in fixed centres or bearings, in fact, as a spindle in the lathe; the work is traversed, or made to pass the revolving cutter in a right line, for which end the work is often fixed to a traversing slide rest. This mode requires the bar to measure between the supports, twice the length of the work to be bored, and the cutter to be in the middle of the bar; it is therefore unfit for long objects.

Secondly, the cutter bar revolves, and also slides with endlong motion, the work being at rest; the bearings of the bar are then frequently attached in some temporary manner to the work to be bored, and are often of wood. Cylinders of forty inches diameter for steam-engines, have been thus bored, by attaching a cast-iron cross to each end of the cylinder; the crosses are bored exactly to fit the boring bar, one of them carries the driving gear, and the bar is thrust endlong by means of a screw, moved by a ratchet or star wheel.

In another common arrangement, the boring bar is mounted in headstocks, much the same as a traversing mandrel, the work is fixed to the bearers carrying the headstocks, and the cutter bar is advanced by a screw. The screw is then moved either by the hand of the workman; by a star-wheel, or a ratchet wheel, one tooth only in each revolution; or else by a system of differential wheels, in which the external screw has a wheel say of 50 teeth, the internal screw a wheel of 51 teeth, and a pair of equal wheels or pinions drives these two screws continually, so that the advance of the one-fiftieth of the turn of the screw, or their difference, is equally divided over each revolution of the cutter bar, much the same as in the differential motion of the screw drill, Fig. 404.

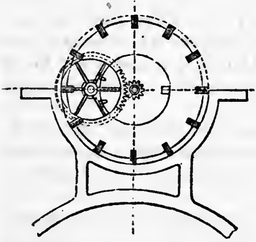
This second method only requires the interval between the fixed bearings of the cutter bar to be as much longer than the work as the length of the cutter-block; but the bar itself must have more than twice the length of the work, and requires to slide through the supports.

Cutter bars of this kind are likewise used in the lathe; in the act of boring, the end of the bar then slides like a piston into the mandrel. Such bars are commonly applied to the vertical boring machines of the larger kinds, which are usually fitted with a differential apparatus, for determining the progress of the cut; the bar then slides through a collar fixed in the bed of the machine.

In some of the large boring machines either one or two horizontal slides are added, and by their aid series of holes may be bored in any required arrangement. For instance, the several holes in the beams, or *side levers*, and cranks of steam-engines, are bored exactly perpendicular, in a line, and at any precise distances, by shifting the work beneath the revolving spindle upon the guide or railway; in pieces of other kinds, the work is moved laterally during the revolution of the cutters, for the formation of elongated countersinks and grooves.

Thirdly. In the largest applications of this principle, the boring bar revolves upon fixed bearings without traversing; and it is only needful that the boring bar should exceed the length of the work, by the thickness of the cutter block, of which it has commonly several of different diameters. The cutter block, now sometimes ten feet diameter, traverses as a slide down a huge boring bar, whose diameter is about thirty inches. There is a groove and key to couple them together, and the traverse of the cutter block down the bar is caused by a side screw, upon the end of which is a large wheel, that engages in a small pinion, *fixed* to the stationary centre or pedestal of the machine. With every revolution of the cutter bar, the great wheel is *carried around the fixed pinion*, and supposing these be as ten to one, the great wheel is moved one-tenth of a turn, and therefore moves the screw one-tenth of a turn also, and slowly traverses the cutter block.

Fig. 417.



The contrivance may be viewed as a huge, self-acting, and revolving sliding-rest, and the diagram 417 shows that the cutter bars are equally applicable to portions of circles, such as the D valves of steam-engines, as well as to the enormous interior of the cylinder itself.

All the preceding boring tools cut almost exclusively upon the end alone. They are passed entirely through the objects, and leave each part of their own particular diameter, and therefore cylindrical; but I now proceed to describe other boring tools, that cut only on their sides, go but partly through the work, and leave its section a counterpart of the instrument. These tools are generally conical, and serve for the enlargement of holes to sizes intermediate between the gradations of the drills, and also for the formation of conical holes, as for valves, stopcocks, and other works. The common pointed drill, or its multiplication in the rose countersink, is the type of the series; but in general the broaches have sides which are much more nearly parallel.

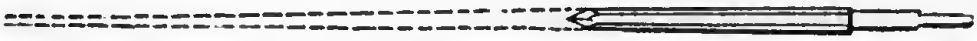
Broaches for making Taper Holes.—The tools for making taper holes are much less varied than the drills and boring tools for cylindrical holes.

Figs. 418 419 420 421 422 423






424



425.

The broaches for metal are made solid, and of various sections; as half-round, like Fig. 418; the edges are then rectangular, but more commonly the broaches are polygonal, as in Fig. 419, except that they have 3, 4, 5, 6, and 8 sides, and their edges measure respectively 60, 90, 108, 120, and 135 degrees. The four, five, and six-sided broaches are the most general, and the watchmakers employ a round broach in which no angle exists, and the tool is therefore only a burnisher, which compresses the metal and rounds the hole.

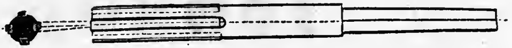
Ordinary broaches are very acute, and Fig. 425 may be considered to represent the general angle at which their sides meet, namely, less than one or two degrees; the end is usually chamfered off with as many facets as there are sides, to make a penetrating point, and the opposite extremity ends in a square *tang*, or shank, by which the instrument is worked.

Square broaches, after having been filed up, are sometimes twisted whilst red-hot; Fig. 424 shows one of these; the rectangular section is but little disturbed, although the faces become slightly concave. The advantage of the tool appears to exist in its screw form: when it is turned in the direction of the spiral, it cuts with avidity and requires but little pressure, as it is almost disposed to dig too forcibly into the metal: when turned the reverse way, as in unscrewing, it requires as much or more pressure than similar broaches not twisted. This instrument, if bent in the direction of its length, either in the act of twisting or hardening, does not admit of correction by grinding, like those broaches having plane faces. It is not much used, and is almost restricted to wrought-iron and steel.

Large countersinks that do not terminate in a point, are sometimes made as solid cones; a groove is then formed up one side, and deepest towards the base of the cone, for the insertion of a cutter; see Fig. 420. As the blade is narrowed by sharpening, it is set a little forward in the direction of its length, to cause its edge to continue slightly in advance of the general surface, like the iron of a plane for cutting metal.

Figure 426 represents the broach, invented by James Kinselaugh, of Wicklow, Ireland, in which four detached blades are introduced, for the sake of retaining the cone or angle of the broach with greater facility. The bar or stack has four shallow longitudinal grooves, which are nearly radial on the cutting face, and slightly undercut on the other. The grooves are also rather deeper behind, and the blades are a little wedge-form both in section and in length, to constitute the cone, and the cutting edges. In restoring the edges of the blades, they are removed from the stock, and their angles are then more easily tested: when replaced, they are set nearer to the point, to compensate for their loss of thickness.

Fig. 426.



Broaches are also used for perfecting cylindrical holes, as well as for making those which are taper. The broaches are then made almost parallel, or a very little the highest in the middle; they are filed, with two or three planes at angles of 90 degrees, as in Figs. 421 or 422. The circular part not being able to cut, serves as a more certain base or foundation, than when the tool is a complete polygon; and the stems are commonly made small enough to pass entirely through the holes, which then agree very exactly as to size. Such tools are therefore rather entitled to the name of finishing drills, than broaches.

The size of the parallel broaches is often slightly increased by placing a piece or two of paper at the convex part. Leather and thin metal are also used for the same purpose. Gun-barrels are broached with square broaches, the cutting parts of which are about eight to ten inches long; they are packed on the four sides with slips or spills of wood to complete the circle, as in Fig. 423, in which the tool is supposed to be at work. The size of the bit is progressively enlarged by introducing slips of thin paper, piece by piece, between two of the spills of wood and the broach; the paper throws the one angle more towards the centre of the hole, and causes a corresponding advance in the opposite or the cutting angle. Sometimes, however, only one spill of wood is employed.

A broach used by the philosophical instrument-makers in finishing the barrels of air-pumps, consisted of a thin plate of steel inserted diametrically between two blocks of wood, the whole constituting a cylinder with a scraping edge slightly in advance of the wood. Slips of paper were also added.

According to the size of the broaches, they are fixed in handles like brad-awls; they are used in the brace, or the tap wrench, namely, a double-ended lever with square central holes. Sometimes also broaches are used in the lathe just like drills, and for large works broaching machines are employed. These are little more than driving gear terminating in a simple kind of universal joint to lead the power of the steam-engine to the tool, which is generally left under the guidance of its own edges, according to the common principle of the instrument.

In drills and broaches the penetrating angles are commonly more obtuse than in turning tools; thus in drills of limited dimensions the hook-form of the turning tool for iron is inapplicable, and in the larger examples the permanence of the tool is of more consequence than the increased friction. But on account of the additional friction excited by the nearly rectangular edges, it is commonly necessary to employ a smaller velocity in boring than in turning corresponding diameters, in order to avoid softening the tool by the heat generated; and in the ductile fibrous metals, as wrought-iron, steel, copper and others, lubrication with oil, water, etc., becomes more necessary than in turning.

The drills and broaches form together a complete series. First, the cylinder bit, the pin drills, and others with blunt sides, produce cylindrical holes by means of cutters at *right angles* to the axis; then the cutter becomes *inclined* at about 45 degrees, as in the common piercing drill and cone countersink; the angle becomes much less in the common taper broaches; and finally disappears in the parallel broaches, by which we again produce the cylindrical hole, but with cutters *parallel* with the axis of the hole.

Still considering the drills and broaches as one group, the drills have comparatively thin edges, always less than 90 degrees, yet they require to be urged forward by a screw or otherwise, the resistance being sustained in the line of their axes. The broaches have much more obtuse edges, never less than 90, and sometimes extending to 135 degrees; and yet the greater force required to cause the penetration of their obtuse edges into the material is supplied without any screw, because the pressure in all these varied tools is at right angles to the cutting edge.

Thus supposing the sides of the broach extended until they meet in a point, as in Fig. 425, we shall find the length will very many times exceed the diameter, and by that number will the force employed to thrust forward the tool be multiplied, the same as in the wedge, whether employed in splitting timber or otherwise; and the broach being confined in a hole, it cannot make its escape, but acts with lateral pressure, directed radially from each cutting edge; and the broach under proper management leaves the holes very smooth and of true figure.

CHAPTER XXIII.

SCREW-CUTTING TOOLS.

An elementary idea of the form of the screw, or helix, is obtained by considering it as a continuous circular wedge; and it is readily modeled by wrapping a wedge-formed piece of paper around a cylinder. The edge of the paper then represents the line of the screw, and which preserves one constant angle to the axis of the contained cylinder, namely, that of the wedge.

The ordinary wedge, or the diagonal, may be produced by the composition of two *uniform* rectilinear motions, which, if equal, produce the angle of 45°, or if unequal, various angles more or less acute; and in an analogous manner, the circular wedge or the screw may be produced of every angle or coarseness by the composition of an uniform circular motion, with an uniform rectilinear motion. And as either the rectilinear or the circular motion may be given to the work or to the tool indifferently, there are four distinct modes of producing screws, and which are all variously modified in practice.

The screw admits of great diversity. It may possess any diameter; it may also have any angle—that is, the interval between the threads may be either coarse or fine, according to the angle of the wedge or the ratio of the two motions; and the wedge may be wound upon the cylinder to the right hand or to the left, so as to produce either right or left hand screws.

The idea of double, triple, or quadruple screws, will be conveyed by considering two, three, or four black lines drawn on the uncovered edge of the wedge-formed paper, or likewise by two, three, or four strings or wires placed in contact, and coiled as a flat band around the cylinder, the angle remains unaltered, it is only a multiplication of the furrows or threads; and lastly, the screw may have any section, that is, the section of the worm or thread may be angular, square, round, or of any arbitrary form. Thus far as to the variety in screws.

The importance of this mechanical element, the screw, in all works in the constructive arts, is almost immeasurable. For instance, great numbers of screws are employed merely for connecting together the different parts of which various objects are composed; no other attachment is so compact, powerful, or generally available; these *binding* or *attachment* screws require, by comparison, the least degree of excellence. Other screws are used as *regulating* screws, for the guidance of the slides and the moving parts of machinery, for the screws of presses and the like; these kinds should possess a much greater degree of excellence than the last. But the most exact screws that can be produced, are quite essential to the good performance of the engines employed in the graduation of right lines and circles, and of astronomical and mathematical instruments; in these delicate *micrometrical* screws, our wants ever appear to outstrip the most refined methods of execution.

The attempt to collect and describe *all* the ingenious contrivances which have been devised for the construction of screws, would be in itself a work of no ordinary labor or extent: I must, therefore, principally restrict myself to those varied processes now commonly used in the workshops, for producing with comparative facility, screws abundantly exact for the great majority of purposes. It has been found rather difficult to arrange these extremely different processes in tolerable order, but that which seems to be the *natural order* has been adopted, thus:—

There appears to be no doubt, but that in the earliest production of the apparatus for cutting screws, the external screw was the first piece made; this plain circular metal screw was serrated and thus converted into the *tap*, or cutting tool, by which internal screws of corresponding size and form were next produced; and one of these *hollow screws* or *dies* became in its turn the means of regenerating, with increased truth and much greater facility, any number of copies of the original external screw. In these several stages there is a progressive advance towards perfection, as will be hereafter adverted to.

These hand processes are mostly used for screws, which are at least as long, if not longer than their diameters. The rotatory and rectilinear guides, and the one or several series of cutting points, are then usually combined within the tool. This first group will be considered in the succeeding order:—

On originating screws.
On cutting internal screws, with screw taps.
On cutting external screws, with screw dies.

Subsequent improvements have led to the employment of the lathe in producing from the above, and in a variety of ways, still more accurate screws. These methods are sometimes used for screws which possess only a portion of a turn, at other times for screws twenty or thirty feet long and upwards. The rotatory guide is always given by the mandrel, the rectilinear guide is variously obtained, and the detached screw tool or cutter, may have one single point, or one series of points which touch the circle at only one place at a time. This second group will be arranged thus:—

On cutting screws, in the common lathe by hand.
On cutting screws, in lathes with traversing mandrels.
On cutting screws, in lathes with traversing tools.

It may be further observed that the modes described under these heads are in general applied to very different purposes, and are only to a limited extent capable of substitution one for the other; it is to be also remarked that it has been considered convenient, in a great measure to abandon, or rather to modify, the usual distinction between the tools respectively used for wood and for metal. The eighth and concluding section of this subject describes some refinements in the production of screws which are not commonly practiced, and it is in some measure a sequel to the second section.

ON ORIGINATING SCREWS.—It appears more than probable, that in the earliest attempts at making a screw, a sloping piece of paper was cemented around the iron cylinder; this oblique line was cut through with a stout knife or a thin edged file, and was then gradually enlarged by hand until it gave a rude form of screw. Doubtless as soon as the application of the lathe was generally known, the work was mounted between centres, so that the progress of filing up the groove could be more easily accomplished, or a pointed turning tool could be employed to assist. Such, in fact, is one of the modes recommended by Plumier, for cutting the screw upon a lathe mandrel for receiving the chucks, even in preference to the use of the die-stocks, which, he urged, were liable to bend the mandrel in the act of cutting the screw.

Nearly similar modes have been repeatedly used for the production of original screws; one account differing in several respects from the above, is described as having been very successfully resorted to above fifty years back, at the Soho works, Birmingham, by a workman of the name of Joe Baggs, before the introduction of the screw-cutting lathe. This is an English account of an English supposed invention.

The screw was seven feet long, six inches diameter, and of a square triple thread; after the screw was accurately turned as a cylinder, the paper was cut parallel exactly to meet around the same, and was removed and marked in ink with parallel oblique lines, representing the margins of the threads; and having been replaced on the cylinder, the lines were pricked through with a centre punch. The paper was again removed, the dots were connected by fine lines cut in with a file, the spaces were then cut out with a chisel and hammer and smoothed with a file, to a sufficient extent to serve as a lead or guide.

The partly formed screw was next temporarily suspended in the centre of a cast-iron tube or box strongly fixed against a horizontal beam, and melted lead mixed with tin, was poured into the box to convert it into a guide nut; it then only remained to complete the thread by means of cutters fixed against the box or nut, but with the power of adjustment, in fact in a kind of slide-rest, the screw being handed round by levers.

Another very simple way of originating screws, and which is sufficiently accurate for some purposes, is to coil a small wire around a larger straight wire as a nucleus; this last is frequently the same wire the one end of which is to be cut into the screw. The covering wire, whose diameter is equal to the space required between the threads of the screw, is wound on close and tight, and made fast at each end. The coiled screw, being enclosed between two pieces of hard wood, indents a hollow or counterpart thread, sufficient to guide the helical traverse, and a fixed cutter completes this simple apparatus.

Common screws, for some household purposes, have been made of tinned iron wire; two covering wires are rolled on together, the one being removed leaves a space such as the ordinary hollow of the thread, and when these screws are dipped in a little melted tin, the two wires become soldered together.

Other modes have been resorted to for making original screws, by indenting a smooth cylinder with a sharp-edged cutter placed across the same at the required angle, and trusting to the surface or rolling contact to produce the rotation and traverse of the cylinder, with the development of the screw. In the most simple application of this method a deep groove is made along a piece of board in which a straight wire is buried a little beneath the surface. A second groove is made nearly at right angles across the first, exactly to fit the cutter, which is just like a table knife, and is placed at the angle required in the screw. The cutter when slid over the wire indents it, carries it round, and traverses it endways in the path of a screw. A helical line is thus obtained, which, by cautious management, may be perfected into a screw sufficiently good for many purposes.

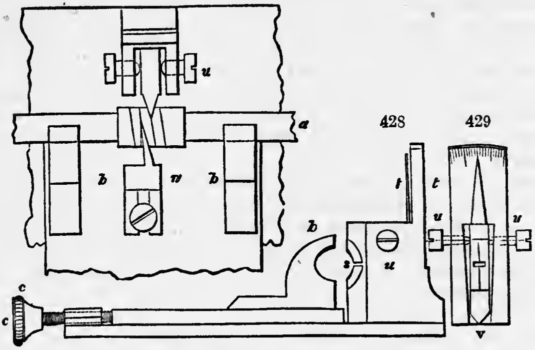
Mr. Walsh, of Dublin, employed a cutter upon cylinders of wood, tin, brass, iron, and other materials, mounted to revolve between centres in a triangular bar lathe; the knife was hollowed to fit the cylinder, and fixed at the required angle on a block adapted to slide upon the bar; the oblique incision carried the knife along the revolving cylinder. Some hundreds of screws were thus made, and their agreement with one another was in many instances quite remarkable. On the whole he gave the preference to this mode of originating screws.

The apparatus for originating screws for astronomical and other purposes is represented in plan in Fig. 427, in side elevation in Fig. 428, and 429 is the front elevation of the cutter frame alone. This method is also due to Mr. Walsh. The piece intended for the screw, namely, *a a*, Fig. 427, is turned cylindrical, and with two equal and cylindrical necks; it is supported in a metal frame with two semi-circular bearings, *b b*, which are fixed on a slide moved by an adjusting screw *c*.

The instrument generates original screws perfectly true, of any number of threads, and right or left handed. In this case, the stock and cutter are made as in Figs. 427, 428, and 429; the back of the stock is made into the segment of a circle, *s*; and the top of the cutter is continued into an index, *t*. The cutter is a single thread, and moves on its edge, *v*, as a centre. This must fit true, and the stock fit close to the cutter, to keep it perfectly steady; *u*, *u*, two screws, to adjust and fasten the cutter to any required angle. The cutter should be rather elliptical, for it is best to fit well to the cylinder at the greatest angle it will be ever used.

When one turn has been given to the cylinder, Fig. 427, a tooth, *w*, is put into the cut, and screwed fast. This tooth secures the lead, and causes every following thread to be a repetition of the first; and though it might do without, yet this is a satisfactory security.

427 428 429



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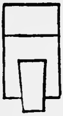

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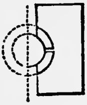

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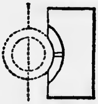


433.

In cutting ordinary screws, the dies shown separately in Figs. 430 to 433, the consideration of which is for the present deferred, takes the place of the oblique cutter in the former figures.

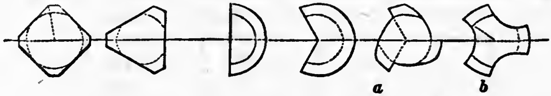
The screw is also originated by traversing the tool in a right line alongside a plain revolving cylinder. Sometimes the tool has many points, and is guided by the hand alone; at other times the tool has but one single point, and is guided mechanically so as to proceed, say one inch or one foot in a right line, whilst the cylinder makes a definite number of revolutions. The tool is then traversed either by a wedge placed transversely to the axis, by a chain or metallic band placed longitudinally, or by another screw connected in various ways with the screw to be produced, by wheel-work and other contrivances.

On Cutting Internal Screws, with Screw Taps.—The screw is converted into the tap by the removal of parts of its circumference, in order to give to the exposed edges a cutting action; whilst the circular parts which remain, serve for the guidance of the instrument within the helical groove, or hollow thread, it is required to form.

In the most simple and primitive method, four planes were filed upon the screw, as in Fig. 434, but this exposes very obtuse edges which can hardly be said to cut, as they form the thread partly by indenting, and partly by raising or burring up the metal; and as such they scarcely produce any effect in cast-iron or other crystalline materials. Conceiving, as in Fig. 434, only a very small portion of the circle to remain, the working edges of squared taps, form angles of (90 + 45 or) 135 degrees with the circumference, and the angle is the greater, the more of the circle that remains. It is better to file only three planes, as in Fig. 435, but the angle is then as great as 120 degrees even under the most favorable circumstances.

In taps of the smallest size it is imperative to submit to these conditions, and to employ the above sections. Sometimes small intermediate facets or planes are tipped off a little obliquely with the file, to relieve the surface friction; this gives the instrument partly the character of a six or eight sided broach, and improves the cutting action.

Figs. 434 435 436 437 438 439.



There appears to be no doubt that, for general purposes, the most favorable angle for the edges of the screw taps and dies is the radial line, or an angle of 90 degrees. This condition manifestly exists in the half-round tap, Fig. 436. I propose that this should be made half-round, as it will be found that a tap formed in this way will cut a full clear thread (even if it may be of a sharp pitch), without making up any part of it by the burr, as is almost universally the case when blunt-edged or grooved taps are used.

It has sometimes been objected to me by persons who had not seen half-round taps in use, that from their containing less substance than the common forms do, they must be very liable to be broken by the strain required to turn them in the work. It is proved, however, by experience, that the strain in their case is so much smaller than usual, that there is even less chance of breaking them than the stouter ones. Workmen are aware that a half-round opening bit makes a better hole and cuts faster than a five sided one, and yet that it requires less force to use it.

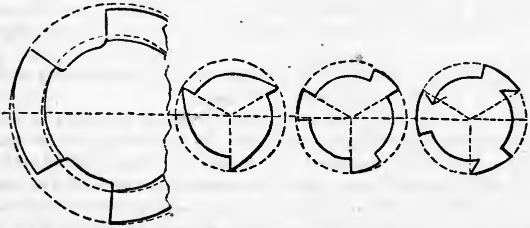
Fig. 437, in which two-thirds of the circle are allowed to remain, has been also employed for taps; this, although somewhat less penetrative than the last, is also less liable to displacement with the tap wrench. It is much more usual to employ three radial cutting edges instead of one only; and as in the best forms of taps, they are only required to cut in the one direction, or when they are screwed into the nut, the other edges are then chamfered to make room for the shavings; thereby giving the tap a section somewhat like that of a ratchet wheel, with either three, four, or five teeth, as in Figs. 438 and 446.

It is more common, however, either to file up the side of the tap, or to cut by machinery, three concave or elliptical flutes, as in 439; this form sufficiently approximates to the desideratum of the radial cutting edges, it allows plenty of room for the shavings, and is easily wiped out. What is of equal or greater importance, it presents a symmetrical figure, little liable to accident in the hardening, either of distortion from unequal section, as in Figs. 436 and 437, or of cracking from internal angles as in 437 and 438.

Still, considering alone the transverse section of the tap, it will be conceived that before any of the substance can be removed from the hole that is being tapped, the circular part of the instrument must become embedded into the metal a quantity equal to the thickness of the shaving; and in this respect Figs. 434 and 435, in which the circular parts are each only the tenth or twelfth of the circumference, appear to have the advantage over the modern taps 438 and 439, in which each arc is twice as long. Such, however, is not the case, as the first two act more in the manner of the broach, if we conceive that instrument to have serrated edges; but Figs. 438 and 439 act nearly as turning tools, as in general the outer or the circular surface is slightly relieved with a file, so as to leave the cutting edges *a*, somewhat in advance of the general periphery; which is equivalent to chamfering the lower plane of the turning tool some three degrees to produce that relief which has been appropriately named the *angle of separation.*

But in the tap Fig. 440, invented by F. O'Neal, this is still more effectually accomplished. The instrument, instead of being turned of the ordinary circular section in the lathe (or as the outer dotted line), is turned with three slight undulations, by means of an alternating radial motion given to the tool. From this it results that, when the summits of these hills are converted into the cutting edges, that not only are the extreme edges or points of the teeth

Figs. 440 441 442 443.



made prominent, but the entire serrated surface becomes inclined at about the three degrees to the external circle, or the line of work, so as exactly to assimilate to the turning tool; and therefore there is little doubt but that, under equal circumstances, O'Neal's tap would work with less friction than any other.

The principle of chamfering, or relieving the taps, must not, however, be carried to excess, or it will lead to mischief. For example, the tap, if sloped behind the teeth as is Fig. 441, would be much exposed to fracture; and the instrument being entirely under its own guidance, the three series of keen points would be apt to stick irregularly into the metal, and would not produce the smooth, circular, or helical hole, obtained when the tool, Fig. 442, is used. The relief should be slight, and the surfaces of the teeth then assimilate to the condition of the graver for copper plates, and thereby direct the tap in a very superior manner.

The teeth sloped in front, as in Fig. 443, would certainly cut more keenly than those of 442, but they would be much more exposed to accident, as the least backward motion or violence would be liable to snip off the keen points of the teeth; and therefore, on the score of general economy and usefulness, the radial and slightly relieved teeth of Fig. 442, or rather of 439, are proper for working taps.

It appears further to be quite impolitic, *entirely* to expunge the surface-bearing, or *squeeze*, from the taps and dies, when these are applied to the ductile metals; as not only does it, when slight, greatly assist in the more perfect guidance of the instrument, but it also serves somewhat to condense or compress the metal.

Unless the taps cut very freely, it is the general aim to avoid the necessity for tapping cast-iron, which is a granular and crystalline substance, apt to crumble away in the tapping, or in the after use. The general remedy is the employment of bolts and nuts made of wrought-iron, or fixing screwed wrought-iron pins in the work, by means of transverse keys and other contrivances, and sometimes by the insertion of plugs of gun-metal, to be afterwards tapped with the screw-threads. In general also, the *small* screws for cast-iron are coarse and shallow in the thread compared with those for wrought-iron, steel, and brass.

The *transverse* sections hitherto referred to, are always used for those taps employed in screwing the inner surfaces of the nuts, and holes required in general mechanism. The *longitudinal* section of the working tap is taper and somewhat like a broach, the one end being small enough in external diameter to enter the blank hole to be screwed, and the other end being as large as the screw for which the nut is intended.

In many cases a series of two, three, or four taps must be used instead of only one single conical tap, and the modifications in their construction are explained by the following diagrams; namely, Fig. 444, the tap formerly used for nuts and thoroughfare holes, and Fig. 445, the modern tap for the same purposes: the dotted lines in each represent the bottoms of the threads.

In the former kind, the thread was frequently finished of a taper figure, with the screw tool in the lathe; after which either the four or three plane surfaces were filed upon it, as shown by the section at *s*; the neck from *f* to *g* was as small as the bottom of the thread, and the tang from *g* to *h* was either square or rectangular for the tap wrench. The tang, if square, was also taper, the tap wrench then wedged fast upon the tap; the sides of the tang, if parallel, were rectangular, and measured as about one to two, and there were shoulders on two sides to sustain the wrench.

Fig. 444.

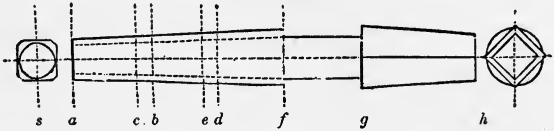
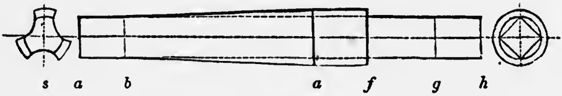


Fig. 445.



In the modern thoroughfare taps for nuts, drawn to the same scale in Fig. 445, the thread is left cylindrical, from the screw tool or the dies; then from *a* to *b*, or about one diameter in length, is turned down cylindrical until the thread is nearly obliterated; from *d* to *f*, also nearly one diameter in length at the other end, is left of the full size of the bolt, and the intermediate part, *b* to *d*, equal to three or four diameters, is turned to a cone, after which the tap is fluted as seen at *s*. The neck *f g*, as before, is as small as the bottom of the thread, and the square *g h*, measures diagonally the same as the turned neck.

In using the modern instrument, Fig. 445, the hole to be tapped is bored out exactly to fit the cylindrical plug *a b*, which therefore guides the tap very perfectly in the commencement; the tool is simply passed once through the nut without any retrograde motion whatever, and the cylindrical part *d f*, takes up the guidance when the larger end of the cone enters the hole; at the completion, the tap drops through, the head being smaller than the bottom of the thread. The old four square taps could not be thus used, for as they rather squeezed than cut, they had much more friction; it was necessary to move them backwards and forwards, and to make the square for the wrench larger, to avoid the risk of twisting off the head of the tap. In taps of modern construction of less than half an inch diameter, it is also needful to make the squares larger than the proportion employed in Fig. 445.

In tapping shallow holes, as only a small portion of the end of the tap can be used, the screwed part seldom exceeds two diameters in length, and as they will not take hold when made too conical, a succession of three or four taps is generally required. The screwed part of the first may be considered to extend from *a* to *b* of Fig. 444, of the second, from *c* to *d*, of the third from *e* to *f*; so that the prior tap may, in each case, prepare for the reception of the following one. The taps are generally made in sets of three; the first, which is also called the *entering* or *taper* tap, is in most cases regularly taper throughout its length; the second, or the *middle* tap, is sometimes taper, but more generally cylindrical, with just two or three threads at the end tapered off; the third tap, which is also called the *plug* or *finishing* tap, is always cylindrical, except at the two or three first threads, which are slightly reduced.

Taps are used in various ways, according to the degree of strength required to move them. The smallest taps should have considerable length, and should be fixed exactly in the axis of straight handles; the length serves as an index by which the true position of the instrument can be verified in the course of work; with the same view as to observation, and as an expeditious mode, taps of a somewhat larger size are driven round by a hand brace, whilst the work is fixed in the vice. Still larger taps require tap wrenches, or levers with central holes to fit the square ends of the taps; for screw taps from one to two inches diameter, the wrenches have assumed the lengths of from four to eight feet, although the recent improvements in the taps have reduced the lengths of the wrenches to one-half.

Notwithstanding that the hole to be tapped may have been drilled straight, the tap may by improper direction proceed obliquely; the progress of the operation should be therefore watched, and unless the eye serve readily for detecting any falseness of position, a square should be laid upon the work, and its edge compared with the axis of the tap in two positions.

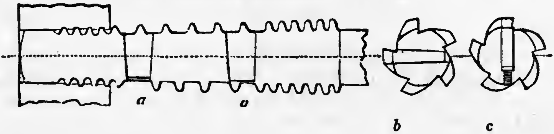
In tapping deeply seated holes, the taps are temporarily lengthened by sockets, frequently the same as those used in drilling, which are represented in Fig. 401, page 403; the tap wrench can then surmount those parts of the work which would otherwise prevent its application.

Sometimes for tapping two distant holes exactly in one line, the ordinary taper tap, Fig. 445, is made with the small cylindrical part *a b* exceedingly long, so as to reach from the one hole to the other and serve as a guide or director. This is only an extension of the short plug *a b*, Fig. 445, which it is desirable to leave on most taps used for thoroughfare holes.

Some works are tapped whilst they are chucked on the lathe mandrel; in this case the shank of the tap, if in false position, will swing round in a circle whilst the mandrel revolves, instead of continuing quietly in the axis of the lathe. Sometimes the centre point of the popit-head is placed in the centre hole in the head of the tap; in those which are fixed in handles it is better the handle of the tap should be drilled up to receive the cylinder of the popit-head, as in the lathe taps for making chucks; this retains the guidance more easily.

Taps of large size, as well as the generality of cutting instruments, have been constructed with detached cutters. For those exceeding about 1½ inch diameter, two steel plugs *a a*, may be inserted within taper holes in the body of the tap, as represented in Fig. 446, and in the two sections *b* and *c*; the whole is then screwed and hardened.

Fig. 446.



The advance of the cutters slightly beyond the general line of the thread, is caused by placing a piece of paper within the mortises *a b*, and to relieve the surface friction, each alternate tooth in the middle part of the length of the tap is filed away. Sometimes the cutters are parallel and inserted only partway through, and are then projected by set screws placed also on the diameter, as in the section *c*.

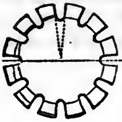
The cutter bar, Fig. 415, p. 410, may also be viewed as a tap with detached cutters. The cylindrical bar is supported in temporary fixed bearings, one of which embraces the thread (sometimes by having melted load poured around the same), the bar moves therefore in the path of a screw. In cutting the external thread, the cutter represented is shifted inwards with the progress of the work; or a straight cutter shifted outwards, serves for making an internal screw; pointed instead of serrated cutters may be also used; they are frequently adjusted by a set screw instead of the hammer, and are worked by a wrench.

This screw cutter bar, independently of its use for large awkward works, is also employed for cutting, in their respective situations, screws required to be exactly in a line with holes or fixed bearings, as the nuts of slides, presses, and similar works.

Some taps or cutters are made cylindrical, and are used for cutting narrow pieces and edges, such as screw-cutting dies, screw tools, and worm wheels; therefore it is necessary to leave much more of the circle standing, and to make the notches narrower than the width of the smallest pieces to be cut. But the grooves should still possess radial sides, and when these are connected by a curved line, as in Fig. 447, there is less risk of accident in the hardening. The number of the notches increases with the diameter, but the annexed figure would be better proportioned if it had one or two less notches, as inadvertently the teeth have been drawn too weak.

When the tool, Figs. 447 and 448, is used for cutting the dies of die stocks it is called an *original tap*, of which further particulars will be given in the succeeding section; the tool is then fixed in the vice, and the die-stock is handed round, as in cutting an ordinary screw. When Fig. 448 is used for cutting up screw tools, or the chasing-tools for the use of the turning lathe, the cutter is then called a *hob*, or a *screw-tool* cutter, and its diameter is usually greater; it is now mounted to revolve in the lathe, and the screw tool to be cut is laid on the rest as in the process of turning, and is pressed forcibly against the cutter. Another method is proposed: the inside screw tool is laid in a lateral groove in a cylindrical piece of iron, and the tool and cylinder are cut up with the die-stocks as a common screw; by which mode the inside screw tool obviously becomes the exact counterpart of the hollow thread of that particular diameter.

Figs. 447



448.

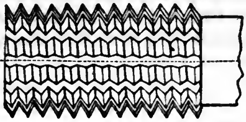


Fig. 448 is also used as a *worm-wheel* cutter, that is, for cutting or for finishing the hollow screw-form teeth, of those wheels which are moved by a tangent screw; as in the dividing-engine for circular lines, and many other cases in ordinary mechanism. The worm-wheel cutter is frequently set to revolve in the lathe, and the wheel is mounted on a temporary axis so as to admit of its being carried round horizontally by the cutter; sometimes the wheel and cutter are connected by gear.

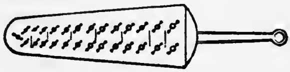
The contact of the ordinary tangent screw with the worm-wheel, resembles that of the tangent to the circle, whence the name; but Hindley, of York, made the screw of his dividing engine to touch 15 threads of the wheel perfectly, by giving the screw a curved section derived from the edge of the wheel, and smallest in the middle.

In cutting the metal screw, or the bolt, the tools are required to be the converse of the tap, as they must have internal instead of external threads, but the radial notches are essential alike in each. For small works, the internal threads are made of fixed sizes and in thin plates of steel; such are called *screw plates;* for larger works, the internal threads are cut upon the edges of two or three detached pieces of steel, called dies; these are fitted into grooves within *die-stocks,* and various other contrivances which admit of the approach of the screwed dies, so that they may be applied to the decreasing diameter of the screw, from its commencement to the completion.

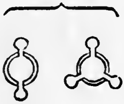
The thickness of the screw plate is in general from about two-thirds to the full diameter of the screw, and mostly several holes are made in the same plate; from two to six holes are intended for one thread, and are accordingly distinguished into separate groups by little marks, as in Fig. 449. The serrating of the edges is sometimes done by making two or three small holes and connecting them by the lateral cuts of a thin saw, as in Fig. 450. The notches alone are sometimes made, and when the holes are arranged as in Fig. 451, should the screw be broken short off by accident, it may be cut in two with a thin saw, and thus removed from the plate.

In making small screws, the wire is fixed in the hand-vice, tapered off with a file, and generally filed to an obtuse point; then, after being moistened with oil, it is screwed into the one or several holes in the screw plate, which is held in the left hand. At other times, the work fixed in the lathe is turned or filed into form, and the plate is held in the right hand; but the force then applied is less easily appreciated. The harp-makers and some others, attach a screw plate with a single hole to the sliding cylinder of the popit-head.

Figs. 449



450

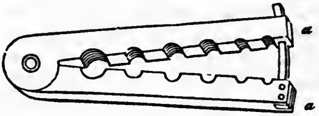


451.

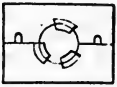
The screw plate is sometimes used for common screws as large as from half to three-quarters of an inch diameter; such screws are fixed in the tail vice, and the screw plate is made from about 15 to 30 inches long, and with two handles; the holes are then made of different diameters, by means of a taper tap, so as to form the thread by two, three, or more successive cuts, and the screw should be entered from the large side of the taper hole. It is, however, very advisable to use the diestocks, in preference to the screw plates, for all screws exceeding about one-sixteenth of an inch diameter, although the unvarying diameter of the screw plate has the advantage of regulating the equal size of a number of screws, and as such, is occasionally used to follow the diestocks, by way of a gage for size.

The diestock, in common with other general tools, has received a great many modifications that it would be useless to trace in greater detail, than so far as respects the varieties in common use, or those which introduce any peculiarity of action in the cutting edges. A notion of the early contrivances for cutting metal screws will be gathered from the figures 452 to 455, which are copied half-size from "Leupold's Theatrum Machinarum Generale, 1724." For instance, Fig. 452 is the screw plate in two, and jointed together like a common rule; the inner edges are cut with threads, the larger of which is judiciously placed near the joint, that it may be more forcibly compressed; there is a guide *a*, *a*, to prevent the lateral displacement of the edges, which would be fatal to the action. Similar instruments are still used, but more generally for screws made in the turning lathe.

Figs. 452



453



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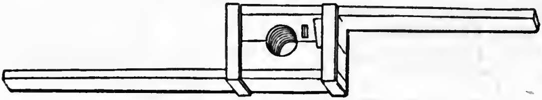
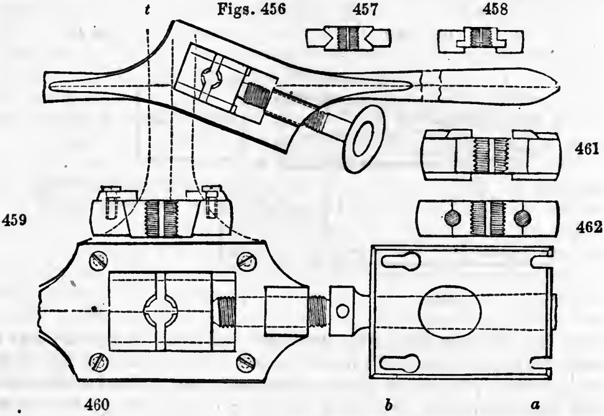


455.

In one of these tools, the frame or stock is made exactly like a pair of flat pliers, but with loose dies cut for either one or two sizes of threads. Plier diestocks are also made in the form of common nut-crackers, or in fact, much like Fig. 452, if we consider it to have handles proceeding from *a a*, to extend the tool to about two or three times its length; the guide *a a* is retained, and removable dies are added, instead of the threads being cut in the sides of the instrument.

In general, however, the two dies are closed together in a straight line, instead of the arc of a circle: one primitive method, Fig. 455, extracted from the work referred to, has been thus remodeled; the dies are inserted in rectangular taper holes, in the ends of two long levers, which latter are connected by two cylindrical pins, carefully fitted into holes made through the levers, and the ends of the pins are screwed and provided with nuts, which serve more effectually to compress the dies than the square rings represented in Fig. 455.

The diestock in its most general form has a central rectangular aperture, within which the dies are fitted, so as to admit of compression by one central screw; the kinds most in use being distinguished as the *double chamfered diestocks*, Figs. 456 and 457; and the *single chamfered diestock*, Figs. 459 and 460, the handles of which are partly shown by dotted lines. In the former, the aperture is about as long as three of the dies; about one-third of the length of the chamfer is filed away at the end, for the removal of the dies laterally, and one at a time. In the single chamfered diestock 460, which is preferable for large threads, the aperture but little exceeds the length of two dies, and these are removed by first taking off the side plate *b a*, which is either attached by its chamfered edges as a slide, or else by four screws; these, when loosened, allow the plate to be slid endways, and it will be then disengaged, as the screws will leave the grooves at *a*, and the screw heads will pass through the holes at *b*.



Sometimes dies of the section of Fig. 458 are applied after the manner of 457, and occasionally the rectangular aperture of Fig. 460 is made parallel on its inner edges, and without the side plate *b a;* the dies are then retained by steel plates either riveted or screwed to the diestock, as represented in Fig. 461, or else by two steel pins buried half-way in the sides of the stock, and the remaining half in the die, as shown in Fig. 462. These variations are of little moment, as are also those concerning the general form of the stock: for instance, whether or not the handles proceed in the directions shown (the one handle being occasionally a continuation of the pressure screw), or whether the handles are placed as in the dotted position *t*. In small diestocks, a short stud or handle is occasionally attached at right angles to the extremity, that the diestock may be moved like a winch handle; and sometimes graduations are made upon the pressure screw, to denote the extent to which the dies are closed. These and other differences are matters comparatively unimportant, as the accurate fitting of the dies, and their exact forms, should receive the principal attention.

In general only two dies are used, the inner surface of each of which includes from the third to nearly the half of a circle, and a notch is made at the central part of each die, so that the pair of dies present four arcs, and eight series of cutting points or edges; four of which operate when the dies are moved in the one direction, and the other four when the motion is reversed; that is when the curves of the die and screw are alike.

The formation of these parts has given rise to much investigation and experiment, as the two principal points aimed at require directly opposite circumstances. For instance, the *narrower* the edges of the dies, or the less of the circle they contain, the more easily they penetrate, the more quickly they cut, and the less they compress the screw by surface friction or squeezing, which last tends to elongate the screw beyond its assigned length. But, on the other hand, the *broader* the edges of the dies, or the more of the circle they contain, the more exactly do they retain the true helical form and the general truth of the screw.

The action of screw-cutting dies is rendered still more difficult, because in general one pair of dies, the curvatures and angles of which admit of *no change*, are employed in the production of a screw, the dimensions of which during its gradual transit from the smooth cylinder to the finished screw *continually change.*

For instance, the thread of a screw necessarily passes two magnitudes, namely, the top and bottom of the groove, and also two angles at these respective diameters, as represented by the dotted lines in the diagrams, Figs. 463, 465, and 467 (which are drawn with straight instead of curved lines). The angles are nearly in the inverse proportion of the diameters; or if the bottom were *half* the diameter of the top of the thread, the angle at the bottom would be nearly *twice* that at the top.

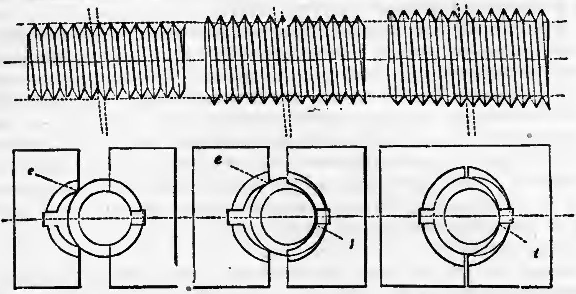
The figures show the *original* taps, *master* taps, or *cutters*, from which the dies, Figs. 464, 466, and 468, are respectively made; and in each of the three diagrams the dies *a* are supposed to be in the act of commencing, and the dies *b* in finishing, a screw of the same diameter throughout as that in Fig. 463.

Of course the circumstances become the more perplexing the greater the depth of the thread, whereas in shallow threads the interference may be safely overlooked. As the dies cannot have both diameters of the screw, it becomes needful to adopt that curvature which is least open to objection. If, as in Fig. 464, the curved edges of the dies *a* and *b* have the same radii as the finished screw, in the commencement, or at *a*, the die will only touch at the corners, and the curved edges being almost or quite out of contact, there will be scarcely any guidance from which to get the *lead* or first direction of the helix, and the dies will be likely to cut false screws, or else parallel grooves or rings. In addition to this, the curved edges present, at the commencement, a greater angle than that proper for the top of the screw; but at the completion of the screw, or at *b*, the die and screw will be exact counterparts, and will be therefore perfectly suitable to each other.

If, as in Fig. 468, the inner curvature of the dies *a* and *b* be the same as in the blank cylinder, *a* will exactly agree both in diameter and angle at the commencement of the screw, but at the conclusion, or as at *b*, each will be too great, and the die and screw will be far from counterparts, and therefore ill adapted to each other.

Figs. 463 465 467

SMALL MASTER TAP. *Same diameter as Screw.* MEDIUM MASTER TAP. *One depth larger than Screw.* LARGE MASTER TAP. *Two depths larger than Screw.*



464 466 468.

The most proper way of solving the difficulty in dies made in two parts, is by having two pairs of dies, such as 468 and 464, and which is occasionally done in very deep threads, see Figs. 432 and 433. But it is more usual to pursue a medium course, and to make the original tap or cutter, Fig. 465, used in cutting the dies, not of the same diameter as the bolt, as in Figs. 463 and 464, not to exceed the diameter of the bolt by twice the depth of the thread, as in Figs. 467 and 468, but with only one depth beyond the exact size, or half-way between the extremes as in Figs. 465 and 466, in which latter it is seen the contact, although not quite perfect either at *a* or *b*, is sufficiently near at each for general practice.

The obvious effect of different diameters between the die and screw must be a falsity of contact between the surfaces and angles of the dies; thus in 464 the whole of the cutting falls upon *e*, the external angles, until the completion of the screw in *b*, when the action is rather compressed than cutting. In Fig. 468 the first act is that of compressing, and all the work is soon thrown on *i*, the internal angles of the die, which become gradually more penetrative, but eventually too much so, being in all respects the reverse of the former. In the medium and most common example, Fig. 466, the cut falls at first upon the external angles *e*, it gradually dies away, and it is during the brief transition of the cut from the external to the internal angles *i*, that is, when the screw is exactly half-formed, that the compression principally occurs.

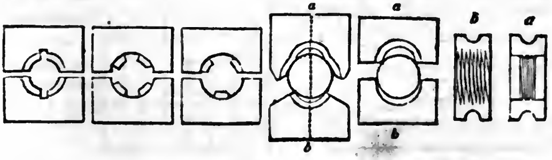
The compression or squeezing is apt to enlarge the diameter of the screw (literally by swaging up the metal), and also to elongate it beyond its assigned length, and that unequally at different parts. Sometimes the compression of the dies makes the screw so much coarser than its intended pitch that the screw refuses to pass through a deep hole cut with the appropriate tap. Not only may the total increase in length be occasionally detected by a common rule, but the differences between twenty or thirty threads, measured at various parts with fine-pointed compasses, are often plainly visible.

Other and vastly superior modes for the formation of long screws, or those requiring any very exact number of threads in each inch or foot of their length, will be shortly explained. Yet notwithstanding the interferences which deprive the diestocks of the refined perfection of these other methods, they are a most invaluable and proper instrument for their intended use; and the disagreement of curvature and angle is more or less remedied in practice, by reducing the circular part of the dies in various ways; and also in some instances, by the partial separation of the guiding from the cutting action.

The most usual form of dies is shown in Fig. 469, but if every measure be taken at the mean, as in Fig. 470, the tool possesses a fair, average, serviceable quality; that is, the dies should be cut over an original tap of medium dimensions, namely one depth larger than the screw, such as Fig. 465; the curved surface should be halved, making the spaces and curves as nearly equal as may be; and the edges should be radial. Fig. 471, nearly transcribed from Leupold's figure, 453, has been also used, but it appears as if too much of the curve were then removed.

Sometimes the one die is only used for guiding, and the other only for cutting: thus *a*, Fig. 472, is cut over two different diameters of master taps, which gives it an elliptical form. A large master tap, Fig. 467, is first used for cutting the pair of dies; this leaves the large parts of the curve in *a*; the dies are subsequently cut over a small master tap, 463.

Figs. 469 470 471 472 473.

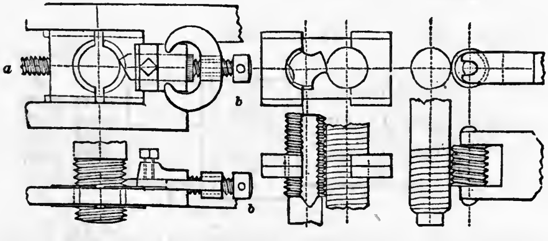


In beginning the screw, the die *a*, serves as a bed with guiding edges; these indent without cutting, and also agree at the first start, with the full diameter of the bolt; with the gradual reduction of the bolt, it sinks down to the bottom of *a*, which continually presents an angular ridge, nearly agreeing in diameter, and therefore in angle with the nascent screw. The inconveniences of the dies, Fig. 472, are, that they require a large and a small master tap for the formation of every different sized pair of dies, and which latter are rather troublesome to repair. The dies also present more friction than most others, apparently from the screw becoming wedged within the angular sides of the die *a*.

In Fig. 473, the dies are first cut over a small master tap, Fig. 464, the threads are then partially filed or turned out of *b*, to fit the blank cylinder; which therefore rests at the commencement upon blunt triangular, curved surfaces, instead of upon keen edges; and as the screw is cut up, its thread gradually descends into the portions of the thread in *b*, which are not obliterated. About one-third of the thread is turned out from each side of the cutting die *a*, leaving only two or three threads in the centre, as shown in the last view; and the surface of this die is left flat, that it may be ground up afresh when blunted, and which is also done with other dies having plane surfaces.

Mr. William Ryan and Mr. Patrick Mullen have each proposed to assist the action of dies for large screws, by means of cutters; their plans will be sufficiently explained by the diagrams, Figs. 474 and 475. This mode to large screws of *square* threads was applied for gun carriages; the dies were cut very shallow, say one-third of the full depth, and they were serrated on their inner faces to act like saws or files. The dies were used to cut up the commencement of the thread, but when it filled the shallow dies, their future office was not to cut, but only to guide the ascent and descent of the stocks, by the smooth surfaces of the dies rubbing upon the top of the square thread. The remaining portion of the screw was afterwards ploughed out by a cutter like a turning tool, the cutter being inserted in a hole in the one die, and advanced by a set screw, somewhat after the manner represented in the figures 474 and 475.

Figs. 474 476 478



475 477 479.

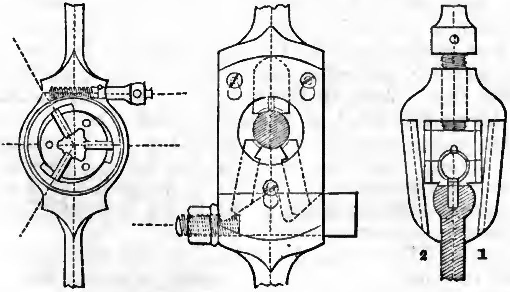
Mullen employed a similar method for *angular* thread screws, and the cutter was placed within a small frame fixed to the one die. The screw bolt was commenced with the pair of dies which were closed by the set screw *a*, 474, the cutter being then out of action. When the cutter was set to work by its adjusting screw *b*, it was advanced a little beyond the face of the die, and not afterwards moved; but the advance of *a* closed the dies upon the decreasing diameter of the screw, the cutter always continuing prominent and doing the principal share of the work.

Figure 476 is the plan, and 477 the side elevation, of an old although imperfect expedient, for producing a left-handed screw from a right-handed tap. It will be remembered the right and left-hand screws only differ in the *direction* of the angle, the thread of the one coils to the right, of the other to the left hand; and on comparing a corresponding tap and die, the inclinations of the external curve of the one, and the internal curve of the other necessarily differ in like manner as to direction. The mode employed, therefore, is to carry a right-hand tap *around* the screw to be cut; the temporary screw-cutter possesses the same interval or thread as before, but the cutting angles of the tap, having the reverse direction of those of the die, the screw becomes left-handed.

The one die in 476 and 477 is merely a blank piece of brass or iron without any grooves, the other is a brass die in which the tap is fixed; as may be expected, the thread produced is not very perfect, but in the absence of better means, this mode is available as the germ for the production of a set of left-hand taps and dies. Figs. 478 and 479 represent a different mode of originating a left-handed screw, proposed by Mr. Walsh; the tool is to be a small piece of a right-handed screw, which is hardened and mounted in a frame like an ordinary *milling* or *nurling* tool, and intended to act by pressure alone; the diameter of the tool and cylinder should be alike.

The screw stock represented in Fig. 480: three narrow dies were fitted in three equidistant radial grooves in the stock, the ends of the dies came in contact with an exterior ring, having on its inner edge three spiral curves (equivalent to three inclined planes), and on its outer surface a series of teeth into which worked

Figs. 480 481 482.



a tangent screw, so that on turning the ring by the screw, the three dies were simultaneously and equally advanced towards the centre.

These screw stocks were found to cut very rapidly, as every circumstance was favorable to that action. For instance, on the principle of the triangular bearing, all the three dies were constantly at work; the original tap being slightly taper, every thread in the length of the die was performing its part of the work, the same as in a taper tap, every thread of which removes its shaving or share of the material; and the dies were narrow, with radial edges, which admitted of being easily sharpened.

The diestock has been abandoned in favor of the screw stock, which is represented in Fig. 481. The one die embraces about one-third of the circle, the two others much less; the latter are fitted into grooves which are not radial, but lead into a point situated near the circumference of the screw-bolt; the edges of the dies are slightly hooked or ground respectively within the radius, and they are simultaneously advanced by the double wedge and nut; the dies are cut over a large original, such as Fig. 467, that is, two depths larger than the screw. The large die serves to line out or commence the screw, and the two others act alternately; the one whilst the stock descends down the bolt, the other during its ascent.

We will notice but one more screw stock. It is seen that the one die embraces about one-third the screw, the other is very narrow; the peculiarity of this construction is that a circular recess is first turned out of the screw stock, and a parallel groove is made into the same, the one handle of the stock (which is shaded), nearly fills this recess, and receives the small die. If the handle fitted mathematically true, it is clear it would be immovable, but the straight part of the handle is narrower than the width of the groove; when the stock is turned round, say in the direction from 2 to 1, the first process is to rotate the handle in the circle, and to bring it in hard contact with the side 1, this slightly rotates the die also, and the one corner becomes somewhat more prominent than the other. When the motion of the stock is reversed, the handle leaves the side 1, of the groove, and strikes against the other side 2, and then the opposite angle of the die becomes the more prominent; and that without any thought or adjustment on the part of the workman, as the play of the handle in the groove 1, 2, is exactly proportioned to cause the required angular change in the die.

The cutting edges of the die act exactly like turning tools, and therefore they may very safely be beveled or hooked as such; as when they are not cutting, they are removed a little way out of contact, and therefore out of danger of being snipped off, or of being blunted by hard friction. The opposite die affords during the time an efficient guidance for the screw, and the broad die is advanced in the usual manner, by the pressure screw made in continuation of the second handle of the diestock; the dies are kept in their places by a side plate, which is fitted in a chamfered groove in the ordinary manner.

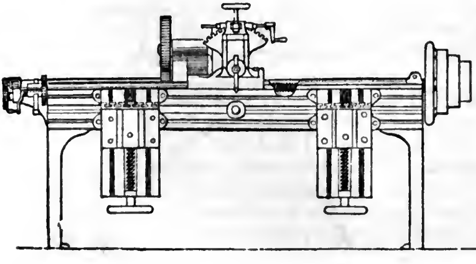
There is less variety of method in cutting external screws with the diestocks, than internal screws with taps, but it is desirable in both cases, to remove the rough surface the work acquires in the foundry or forge, in order to economize the tools; and the best works are either bored or turned cylindrically to the true diameters corresponding with the screwing tools.

The bolt to be screwed is mostly fixed in the tail vice vertically, but sometimes horizontally, the dies are made to apply fairly, and a little oil is applied prior to starting. As a more expeditious method suitable to small screws, the work is caused to revolve in the lathe, whilst the diestock is held in the hand; and larger screws are sometimes *marked* or *lined out* whilst fixed in the vice, the principal part of the material is then removed with a chasing tool or hand-screw tool, and the screw is concluded in the diestocks. In cutting up large screw bolts, two individuals are required to work the screw stocks, and they walk round the standing vice or screwing clamp, which is fixed to a pedestal in the middle of the workshop.

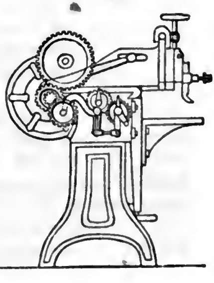
For screwing large numbers of bolts, the engineer employs the *bolt-screwing machine,* which is a combination of the ordinary taps and dies, with a mandrel, driven by steam-power. In the machine the mandrel revolves, traverses, and carries the bolt, whilst the dies are *fixed* opposite to the mandrel; or else the mandrel carries the tap, and the nut to be screwed is grasped opposite to it. In another machine, the mandrel does not traverse, it carries the bolt, and the dies are mounted on a slide; or else the mandrel carries the nut, and the tap is fixed on the slide. The tap or die gives the traverse in every case, and the engine and strap supply the muscle; of course the means for changing the direction of motion and closing the dies, as in the hand process, are also essential.

The screwing table is a useful modification of the bolt machine, intended to be used for small bolts, and to be worked by hand. The mandrel is replaced by a long spindle running loosely in two

Figs. 483

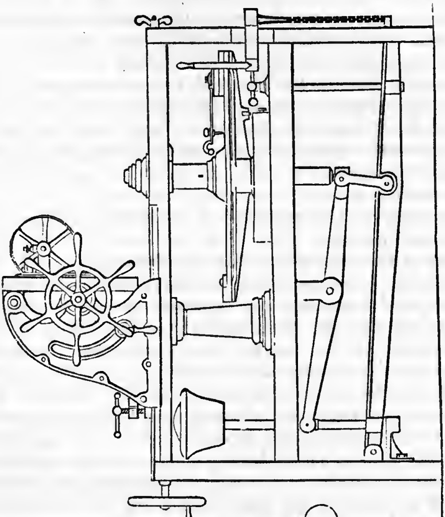


484.



bearings; the one end of the spindle terminates in a small wheel with a winch-handle, the other in a pair of jars closed by a screw. The jaws embrace the head of the bolt, which is presented opposite to dies that are fixed in a vertical frame or stock, and closed by a loaded lever to one fixed distance. In tapping the nut, it is fixed in the place before occupied by the dies, and the spindle then used is bored up to receive the shank of the tap, which is fixed by a side screw. This machine insures the rectangular position of the several parts, and the power is applied by the direct rotation of a hand wheels.

It will be gathered from the foregoing remarks, that the die-



486.

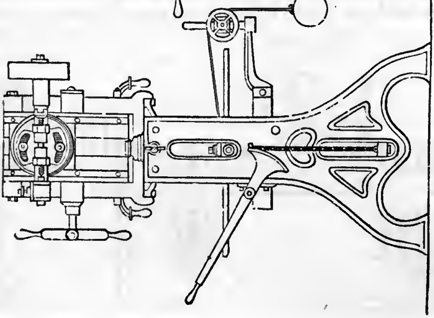


Fig4. 485

stock is an instrument of most extensive use, and it would indeed almost appear as if every available construction had been tried, with a general tendency to foster the cutter, and to expunge the surface friction or rubbing action; by the excess of which latter the labor of work is greatly increased, and risk is incurred of stretching the thread.

Figures 483 and 484 show a shaping machine, built at the Lowell Machine Shop, Lowell, Mass. Many of the machines built at the Lowell Machine Shop, were much improved by W. B. Bennet. This shaping and planing instrument will plane either flat or curved surfaces.

The tool bar is moved by a variable crank adjustable to any length of motion not exceeding eight inches. It has a self-acting horizontal and circular feed motion, with a hand-feed motion for internal curves.

Figs. 485, 486 show a gear-cutting machine manufactured at the Lowell Machine Shop, Lowell, Massachusetts. The dividing plate is forty-eight inches in diameter. This machine will cut every number of teeth up to 133, and every even number to 268, also 272, 276, and 360 teeth.

The cutter stock is so arranged as to move either horizontally or vertically, or at any angle, so as to cut bevel, spur, and spiral wheels and gearing.

Screws Cut by Hand in the Common Lathe.—Great numbers of screws are required in works of wood, ivory and metal, that cannot be cut with the taps and dies, or the other apparatus hitherto considered. This arises from the nature of the materials, the weakness of the forms of the objects, and the accidental proportions of the screws, many of which are comparatively of very large diameter and inconsiderable length. These, and other circumstances, conspire to prevent the use of the diestocks for objects such as the screws of telescopes and other slender tubes, those on the edges of disks, rings, boxes, and very many similar works.

Screws of this latter class are frequently cut in the lathe with the ordinary screw tool, and by dexterity of hand alone; there is little to be said in explanation of the apparatus and tools, which then consist solely of the lathe with an ordinary mandrel incapable of traversing endways, and the screw tools or the chasing tools, with the addition of the arm rest.

The screw tool held at rest would make a series of rings, because at the end of the first revolution of the object, the points A B C of the tool would fall exactly into the scratches A B C commenced respectively by them. But if, in its first revolution, the tool is shifted exactly the space between two of its teeth, at the end of the revolution, the point B of the tool drops into the groove made by the point A, and so with all the others, and a true screw is formed, or a continuous helical line, which appears in steady lateral motion during the revolution of the screw in the lathe.

It is likely the tool will fail *exactly* to drop into the groove, but if the difference be inconsiderable, a tolerably good screw is nevertheless formed; as the tool being moved forward as equally as the hand will allow, corrects most of the error. But if the difference be great, the tool finds its way into the groove with an abrupt break in the curve; and during the revolution of the screw, as it progresses it also appears to roll about sideways, instead of being quiescent, and is said by workmen to be "drunk:" this error is frequently beyond correction.

It sometimes happens that the tool is moved too rapidly, and that the point C drops into the groove commenced by A; in this case the coarseness of the groove is the same as that of the tool, but the inclination is double that intended, and the screw has a double thread, or two distinct helices instead of one; the tool may pass over three or four intervals and make a treble or quadruple thread, but these are the results of design and skill, rather than of accident.

On the other hand, from being moved too slowly, the point B of the tool may fail to proceed so far as the groove made by A, but fall midway between A and B; in this case the screw has half the rise or inclination intended, and the grooves are as fine again as the tool; other accidental results may also occur which it is unnecessary to notice.

On Cutting Screws in Lathes with Traversing Mandrels.—One of the oldest, most simple, and general apparatus for cutting short screws in the lathe, by means of a mechanical guidance, is the *screw*-mandrel or *traversing*-mandrel, which appears to have been known almost as soon as the iron mandrel itself was introduced.

Fig. 487.

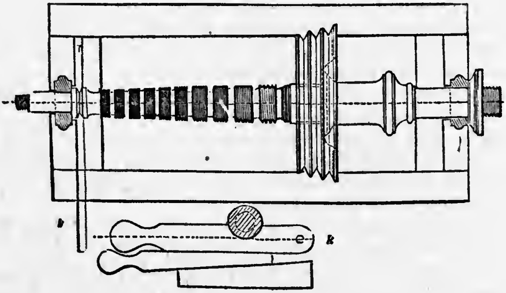


Figure 487 is copied from an old French mandrel mounted in a wooden frame, and with tin collars cast in two parts; the upper halves of the collars are removed to show the cylindrical necks of the mandrel, upon the shaft of which are cut several short screws. In ordinary turning, the retaining key *k*, which is shown detached in the view *k′*, prevents the mandrel from traversing, as its angular and circular ridge enters the groove in the mandrel; but although not represented, each thread on the mandrel is provided with a similar key, except that their circular arcs are screw-form instead of angular. In screw cutting, *k* is depressed to leave the mandrel at liberty; the mandrel is advanced slightly forward, and one of the screw-keys is elevated by its wedge until it becomes engaged with its corresponding guide-screw, and now as the mandrel revolves, it also advances or retires in the exact path of the screw selected.

The modern screw-mandrel lathe has a cast-iron frame, and hardened steel collars which are not divided; the guide screws are fitted as rings to the extreme end of the hardened steel mandrel, and they work in a plate of brass, which has six scollops, or semicircular screws upon its edge. When this mandrel is used for plain turning, its traverse is prevented by a cap which extends over the portion of the mandrel protruding through the collars.

In cutting screws with either the old or modern screw-mandrel, the work is chucked, and the tool is applied, exactly in the manner of turning a plain object; but the mandrel requires an alternating motion backwards and forwards, somewhat short of the length of the guide screw; this is effected by giving a swinging motion or partial revolution to the foot wheel. The tool should retain its place with great steadiness, and it is therefore often fixed in the sliding rest, by which also it is then advanced to the axis of the work with the progress of the external screw; or by which it is also removed from the centre in cutting an internal screw.

To cut a screw exceeding the length of traverse of the mandrel, the screw tool is first applied at the end of the work, and when as much has been cut as the traverse will admit, the tool is shifted the space of a few threads to the left, and a further portion is cut; and this change of the tool is repeated until the screw attains the full length required. When the tool is applied by hand, it readily assumes its true position in the threads; when it is fixed in the slide rest, its adjustment requires much care.

In screwing an object which is too long to be attached to the mandrel by the chuck alone, its opposite extremity is sometimes supported by the front centre or popit-head; but the centre point must then be pressed up by a spring, that it may *yield* to the advance of the mandrel: this method will only serve for very slight works, as the pressure of the screw-tool is apt to thrust the work out of the centre. It is a much stronger and more usual plan to make the extremity or some more convenient part of the work cylindrical, and to support that part within a stationary cylindrical bearing, or *collar plate*, which retains the position of the work notwithstanding its helical motion, and supplies the needful resistance against the tool.

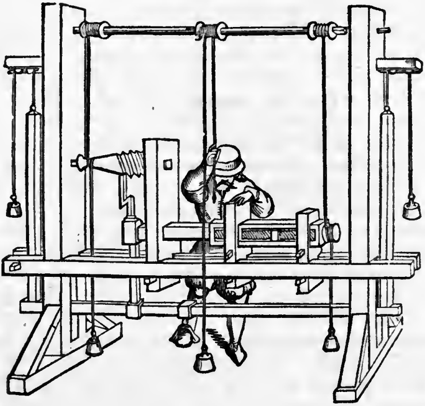
The amateur who experiences difficulty in cutting screws flying, or with the common mandrel and hand-tool unassistedly, will find the screw-mandrel an apparatus by far the most generally convenient for those works, in wood, ivory, and metal turning, to which the screw box and the taps and dies are inapplicable; for the screw-mandrel requires but a very small change of apparatus, and whatever may be the diameter of the work, it insures perfect copies of the guide screws, the half dozen varieties of which will be found to present abundant choice as to coarseness, in respect to the ordinary purposes of turning.

ON CUTTING SCREWS IN LATHES WITH TRAVERSING TOOLS.—A great number of the engines for cutting screws, and also of the other shaping and cutting engines now commonly used, are clearly to be traced to a remote date, so far as their principles are concerned.

For instance, the germs of many of these cutting machines, in which the principles are well developed, will be found in the primitive rose engine machinery with coarse wooden frames, and arms, shaper plate, cords, pulleys, and weights, described in the earliest works on the lathe, whilst many are as distinctly but more carefully modeled in metal, in the tools used in clock and watch making, many of which have also been published.

The principles of these machines being generally few and simple, admit of but little change; but the structures, which are most diversified, nay, almost endless, have followed the degrees of excellence of the constructive arts at the periods at which they have been severally made, combined with the inventive talent of their projectors.

Fig. 488.



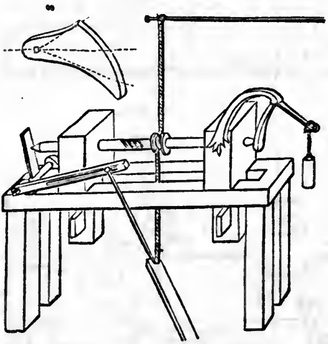
In most of the screw-cutting machines a previously-formed screw is employed to give the traverse; such are *copying* machines, and will form the subject of the present section; and a few other engines serve to *originate* screws, by the direct employment of an inclined plane, or the composition of a rectilinear and a circular motion.

The earliest screw-lathe known to the author bears the date of 1569, and this curious machine, which is represented in Fig. 488, is thus described by its inventor, *Besson: "Espèce de Tour en nulle part encore veüe et qui n'est sans subtilité, pour engraver petit à petit la Vis à l'entour de tout Figure ronde et solide, voire mesmes ovale."*

The tool is traversed alongside the work by means of a guide-screw, which is moved simultaneously with the work to be operated upon, by an arrangement of pulleys and cords too obvious to require explanation. It is however worthy of remark, that bad and imperfect as the constructive arrangement is, this early machine is capable of cutting screws of any pitch, by the use of pulleys of different diameters; and right and left-hand screws at pleasure, by crossing or uncrossing the cord; and also that in this first machine the inventor was aware that a screw-cutting-lathe might be used upon elliptical, conical, and other solids.

The next illustration, Fig. 489, represents a machine described as "A Lathe in which without the common art all sorts of screws and other curved lines can be made;" this was invented by *M. Grandjean* prior to 1729. The constructive details of this machine, which are also sufficiently apparent, are in some respects superior to those in Besson's; but the two are alike open to the imperfection due to the transmissions of motion by cords; and Grandjean's is additionally imperfect, as the scheme represented will fail to produce an equable traverse of the mandrel compared with its revolution, owing to the continual change in the angular relations between the arms of the bent lever, and the mandrel and cord respectively. Sometimes the spiral board or templet *s*, is attached

Fig. 489.

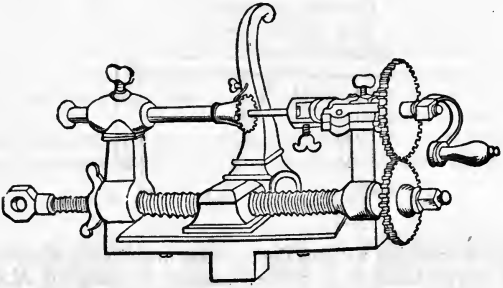


to the bent lever to act upon the end of the mandrel; this also is insufficient to produce a true screw in the manner proposed.

Several of the engines for cutting screws appear to be derived from those used for cutting *fusees*, or the short screws of hyperbolical section, upon which the chains of clocks and watches are wound, in order to counteract the unequal strength of the different coils of the spiral springs. The fusee engines, which are very numerous, have in general a guide-screw from which the traverse of the tool is derived, and the illustration, Fig. 490, selected from an old work published in 1741, is not only one of the earliest, but also of the most exact of this kind; and it exhibits likewise the primitive application of change wheels, for producing screws of varied coarseness from one original.

This instrument is nearly thus described by *Thiout:* "A lathe which carries at its extremity two toothed wheels; the upper is attached to the arbor, the clamp at the end of which holds the axis of the fusee to be cut, the opposite extremity is retained by the centre; the fusee and arbor constitute one piece, and are turned by the winch handle. The lower wheel is put in movement by the upper, and turns the screw which is fixed in its centre; the nut can traverse the entire length of the screw, and to the nut is strongly hinged the lever that holds the graver or cutter, and which is pressed up by the hand of the workman. Several pairs of wheels are required, and the smaller the size of that upon the mandrel the less is the interval between the threads of the fusee."

Fig. 490.

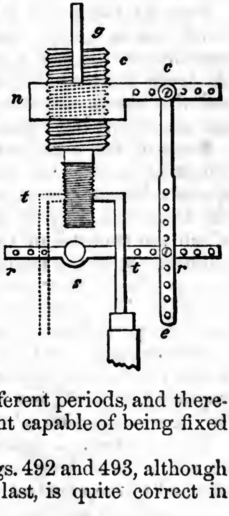


In the general construction of the fusee engine, the guide-screw and the fusee are connected together on one axis, and are moved by the same winch handle; the degree of fineness of the thread on the fusee is then determined by the intervention of a lever generally of the first order; a great variety of constructions have been made on this principle. Three are described in Thiout's Treatise: namely, in plates 25, 26, and 27, the first by *Regnaud de Chaalon.* The mode of action will be more clearly seen in the next figure, wherein precisely the same movements are applied to the lathe for the purpose of cutting ordinary screws.

The apparatus now referred to is that invented by Mr. Healey of Dublin, an amateur; it is universal, or capable within certain limits of cutting all kinds of screws, either right or left-handed, and is represented in plan in Fig. 491, in which C is the chuck which carries the work to be screwed, and *t* is the tool which lies upon *r r′* the lathe-rest, that is placed at right angles to the bearer, and is always free to move in its socket *s*, as on a centre, because the binding screw is either loosened or removed.

On the outside of the chuck C is cut a coarse guide screw, which we will suppose to be right-handed. The nut *n n*, which fits the screw of the chuck, is extended into a long arm, and the latter communicates with the lathe-rest by the connecting rod *c c*. As the lathe revolves backwards and forwards the arm *n* (which is retained horizontally by a guide pin *g*) traverses to and fro as regards the chuck and work, and causes the lathe-rest *r r′*, to oscillate in its socket *s*. The distance *s t* being half *s r′*, a right-handed screw of half the coarseness of the guide will be cut; or the tool being nearer to, and on the other side of, the centre *s*, as in the dotted position *t′*, a finer and left-hand screw will be cut.

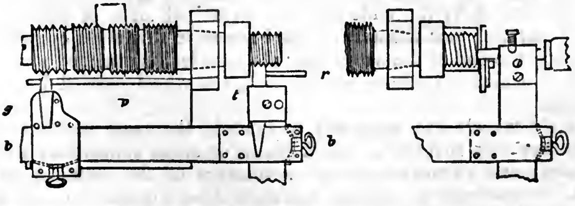
Fig. 491.



The rod *c c* may be attached indifferently to any part of *n n*, but the smallest change of the relation of *s t* to *s r′* would mar the correspondence of screws cut at different periods, and therefore *t* and *r* should be united by a swivel-joint capable of being fixed at any part of the lathe-rest *r r′*.

The apparatus represented in plan in Figs. 492 and 493, although it does not present the universality of the last, is quite correct in its action; it is evidently a combination of the fixed mandrel, and the old screw mandrel, Fig. 487. Four different threads are cut on the tube which surrounds the mandrel, and the connection between

Figs. 492 493.



the guide screw and the work is by the long bar *b b*, which carries at the one end a piece *g* filed to correspond with the thread, and at the other a socket in which is fixed a screw tool *t*, corresponding with the guide at the time employed.

The lathe revolves with continuous motion; and the long bar or rod being held by the two hands in the position shown, the guide *g* and the tool *t* are traversed simultaneously to the left by the screw guide; and when the tool meets the shoulder of the work both hands are suddenly withdrawn and the bar is shifted to the right for a repetition of the cut, and so on until the completion of the screw. The guide *g* is supported upon the horizontal plate *p*, which is parallel with the mandrel, and the tool *t* lies upon the lathe rest *r*.

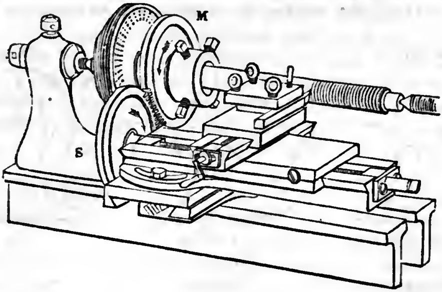
Beneath the tool is a screw which rubs against the lathe rest *r*, and serves as a stop; this makes the screw cylindrical or conical, according as the rest is placed parallel or oblique. For the internal screw the tool is placed *parallel* with the bar, as in Fig. 493; and the check screw is applied on the side towards the centre against a short bar parallel with the axis of the lathe.

None of the machines which have been hitherto described are proper for cutting the accurate screws, of considerable length or of great diameter, required in the ordinary works of the engineer; but these are admirably produced by the screw-cutting lathes, in which the traverse of the tool is effected by a long guide-screw, connected with the mandrel that carries the work by a system of change wheels after the manner employed a century back, as in Fig. 490. The accuracy of the result now depends almost entirely upon the perfection of the guide-screw, and which we will suppose to possess very exactly 2, 4, 5, 6, or some whole number of threads in every inch, although we shall for the present pass by the methods employed in producing the original guide-screw, which thus serves for the reproduction of those made through its agency.

The smaller and most simple application of the system of change wheels for producing screws is shown in Fig. 494. The work is attached to the mandrel of the lathe by means of a chuck, to which is also affixed a toothed-wheel marked M, therefore the mandrel, the wheel and the work partake of one motion in common. The tool is carried by the slide-rest, the principal slide of which is placed parallel with the axis of the lathe as in turning a cylinder, and upon the end of the screw near the mandrel is attached a tooth wheel S, which is made to engage in M, the wheel carried by the mandrel.

As the wheels are supposed to contain the same number of teeth, they will revolve in equal times, or make continually turn for turn; and therefore in each revolution of the mandrel and work, the tool will be shifted in a right line, a quantity equal to *one* thread of the guide-screw, and so with every coil throughout its extent of motion. Consequently the motion of the two axes being always equal and continuous, the screw upon the work will become an exact copy of the guide-screw contained in the slide-rest, that is, as regards the interval between its several threads, its total length, and its general perfection.

Fig. 494.



But the arrows in M and S denote that adjoining wheels always travel in *opposite* directions; when, therefore, the mandrel and slide-rest are connected by only one pair of wheels, as in Fig. 494, the direction of the copy screw is the reverse of that of the guide. The right-hand screw being far more generally required in mechanism, when the combination is limited to its most simple form, of two wheels only, it is requisite to make the slide-rest screw left-handed, in order that the one pair of wheels may produce right-hand threads.

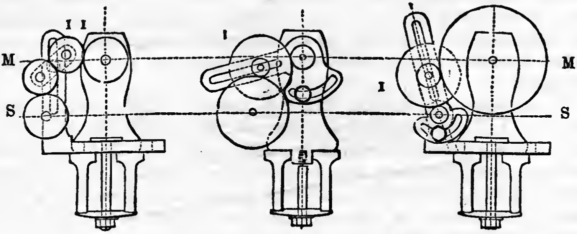
But a right-hand slide-rest screw may be employed to produce at pleasure both right and left-hand copies, by the introduction of either one or two wheels, between the exterior wheels M and S, Fig. 494. Thus, one intermediate axis, to be called I, would produce a right-hand thread; two intermediate axes, I I, would produce a left-hand thread, and so on alternately; and this mode, in addition, allows the wheels M and S to be placed at any distance asunder that circumstances may require.

In making double thread screws the one thread is first cut, the wheels are then removed out of contact, and the mandrel is moved exactly half a turn before their replacement, the second thread is then made. In treble threads the mandrel is twice disengaged, and moved one-third of a turn each time, and so on.

When the intermediate wheels are employed, it becomes necessary to build up from the bearers some description of pedestal, or from the lathe-head some kind of bracket, which may serve to carry the axes or sockets upon which the intermediate wheels revolve. These parts have received a great variety of modifications, three of which are introduced in the diagrams Figs. 495 to 497; the wheels supposed to be upon the mandrel are situated on the dotted line M M, and those upon the slide-rest on the line S S.

The rectangular bracket in Fig. 495 has two straight mortises; by the one it is bolted to the bearers of the lathe, and by the other it carries a pair of wheels, whose pivots are in a short piece, which may be fixed at any height or angle in the mortise, so that one or both wheels, I I, may be used according to circumstances. In Fig. 496, the intermediate wheel, or wheels, are carried by a radial arm, which circulates around the mandrel, and is fixed to the lathe head by a bolt passed through the circular mortise. In Fig. 496, a similar radial arm is adjustable around the axis of the slide-rest screw, in the fixed bracket.

Figs. 495 496 497.



Sometimes the wheel supposed to be attached to the slide-rest, is carried by the pedestal or arm, fixed to the bed or headstock of the lathe; in order that a shaft or spindle may proceed from the wheel S, and be coupled to the end of the slide rest screw, by a hollow square or other form of socket, so as to enable the rest to be placed at any part of the length of the bearer, and permit a screw to be cut upon the end of a long rod.

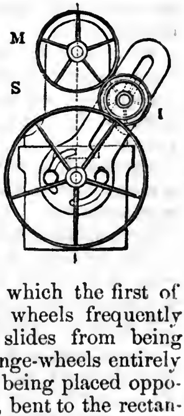
The shaft sometimes terminates at each end in universal joints, in order to accommodate any trifling want of parallelism in the parts; if, however, the shaft be placed only a few degrees oblique, the motion transmitted ceases to be uniform, or it is accelerated and retarded in every revolution, which is fatal in screw cutting.

This change in the position of the slide-rest is also needful in cutting a screw which exceeds the length the rest can traverse, as such long screws may then be made at two or more distinct operations; before commencing the second trip the tool is adjusted to drop very accurately into the termination of that portion of the screw cut in the first trip, which requires very great care, in order that no falsity of measurement may be discernible at the parts where the separate courses of the tool have met. This method of proceeding has, however, from necessity been followed in producing some of the earliest of the long regulating screws, which have served for the production of others by a method much less liable to accident, namely, when the cut is made uninterruptedly throughout the extent of the work.

In the larger application of the system of change-wheels, the entire bed of the lathe is converted into a long slide-rest, the tool carriage with its subsidiary slides for adjusting the position of the tool, then traverses directly upon the bed; this mode has given rise to the name "traversing or slide-lathe," a machine which has received, and continues to receive, a variety of forms in the hands of different engineers. It would be tedious and unnecessary to attempt the notice of their different constructions, which necessarily much resemble each other; more especially as the principles and motives, which induce the several constructions and practices, rather than the precise details of apparatus, are here under consideration.

The arrangement for the change-wheels of a screw-cutting lathe given in Fig. 498, resembles the mode frequently adopted. The guide-screw extends through the middle of the bed, and projects at the end; there is a clasp nut, so that when required, the slide-rest may be detached from the screw and moved independently of the same. The train of wheels is placed at the left extremity of the lathe; there is a radial arm which circulates around the end of the main screw, the arm has one or two straight mortises, in which are fixed the axes of the intermediate wheels, and there are two circular mortises, by which the arm may be secured to the lathe bed, in any required position, by its two binding screws.

Fig. 498.



On comparing the relative facilities for cutting screws, either with the slide-rest furnished with a train of wheels, or with the traversing or screw-cutting lathe, the advantage will be found greatly in favor of the latter; for instance:—

With the slide-rest arrangement, Fig. 494, the work must be always fixed in a chuck to which the first of the change-wheels can be also attached; the wheels frequently prevent the most favorable position of the slides from being adopted; and in cutting hollow screws the change-wheels entirely prevent the tool carriage of the slide-rest from being placed opposite to the centre, and therefore awkward tools, bent to the rectangular form, must be then used. The slide-rest also requires frequent attention to its parallelism with the axis of the lathe, or the screws cut will be conical instead of cylindrical.

With the traversing lathe, from the wheels being at the back of the mandrel, no interference can possibly arise from them, and consequently the work may be chucked indiscriminately on any of the chucks of the lathe; every position may be given to the slide carrying the tool, and therefore the most favorable, or that nearest to the work, may be always selected, and the tools need not be crooked. As the tool carriage traverses at once on the bearers of the lathe, the adjustment for parallelism is always true, and the length of traverse is greatly extended.

The system of screw-cutting just explained is very general and practical: for instance, one long and perfect guide-screw (which we will call the *guide*), containing 2, 4, 6, 8, 10, or any precise number of threads per inch having been obtained, it becomes very easy to make from it subsequent screws, (or *copies*) which shall be respectively coarser and finer in any determined degree. The principle is, that whilst the copy makes one revolution, the guide must make so much of one revolution, or so many, as shall traverse the tool the space required between each thread of the copy; and this is accomplished by selecting change-wheels in the proportions of these quantities of motion, or in other words, in the proportion required to exist between the guide-screw and the copy.

In explanation, we will suppose the guide to have 6 threads per inch, and that copies of 18, 14, 12½, 8, 3, 2, 1, threads per inch are required; the two wheels must be respectively in the proportions of the fractions $\frac{6}{18}$, $\frac{6}{14}$, $\frac{6}{12}\frac{1}{2}$, $\frac{6}{8}$, $\frac{6}{3}$, $\frac{6}{2}$, $\frac{6}{1}$, the guide being constantly the numerator. The numerator also represents the wheel on the mandrel, and the denominator that on the guide-screw; any multiples of these fractions may be selected for the change-wheels to be employed.

For example, any multiples of $\frac{6}{18}$, as $\frac{12}{36}$, $\frac{18}{54}$, $\frac{24}{72}$, etc., will produce a screw of 18 threads per inch, the first and finest of the group; and any multiples of $\frac{6}{1}$, as, $\frac{90}{15}$, $\frac{120}{20}$, etc., will produce a screw of 1 thread per inch, which is the last and coarsest of those given.

Screws 2, 4, or 6 times as *fine* will result from the interposing a *second pair* of wheels, respectively multiples of $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{6}$, and placed *upon one axis.*

For instance, the pair of wheels $\frac{24}{72}$, used for producing a screw of 18 threads per inch, would, by the combination A, produce a copy three times as *fine*, or a screw of 54 threads per inch. Fig. 496 represents the wheels referred to in combination A, and Fig. 497 those in combination B.

Combination A.			Combination B.			Combination C.		
M	Interm.	S	M	Interm.	S	M	Interm.	S.
24	60		120	24		27	53	
	20	72		72	20		39	107

And the wheels $\frac{120}{20}$ used for the screw of one thread per inch, would by the combination B, produce a copy three times as *coarse*, or of three inches rise. Whatsoever the value of the intermediate wheels, whether multiplies of $\frac{3}{4}$, $\frac{7}{8}$, $\frac{9}{4}$, etc., they produce screws respectively of $\frac{3}{4}$, $\frac{7}{8}$, $\frac{9}{4}$, the pitches of those screws, which would be otherwise obtained by the two exterior wheels alone; and in this manner a great variety of screws, extending over a wide range of pitch, may be obtained from a limited number of wheels.

For instance, the apparatus Holtzapffel and Co. have recently added to the slide rest, after the manner of Figs. 494 and 496, has a series of about fifteen wheels, of from 15 to 144 teeth, employed with a screw of 10 threads per inch: several hundred varieties of screws may be produced by this apparatus, the finest of which has 320 threads per inch, the coarsest measures $7\frac{1}{5}$ inches in each coil or rise: and the screws may be made right or left-handed, double, triple, quadruple, or of any number of threads. The finest combinations are only useful for self-acting turning; those of medium coarseness serve for all the ordinary purposes of screws; whilst the very coarse pitches are much employed in ornamental works, and in cutting these coarse screws the motion is given to the slide-rest screw, and by it communicated to the mandrel.

The value of any combination of wheels may be calculated as vulgar fractions, by multiplying together all the driving wheels as numerators, and all the driven wheels as denominators, adding also the fractional value, or pitch, of the guide-screw; thus in the first example A:—

$$\frac{24}{60} \times \frac{20}{72} \times \frac{1}{6} = \frac{480}{25920} \text{ or reduced to its lowest terms } \frac{1}{54}.$$

The fraction denotes that $\frac{1}{54}$th of an inch is the *pitch of the screw*, or the interval from thread to thread; also that it has 54 threads in each inch, and which is called the rate of the screw.

And in C, the numbers in which example were selected at random, the screw would be found to possess rather more than 35 threads per inch.

The fractions should be reduced to their lowest terms before calculation, to avoid the necessity for multiplying such high numbers. Thus the first example would become reduced to $\frac{1}{3} \times \frac{1}{3} \times \frac{1}{6} = \frac{1}{54}$, and would be multiplied by inspection alone, as the numerators and denominators may be taken crossways if more convenient; thus $\frac{24}{72}$ is equal to $\frac{1}{3}$, and $\frac{20}{60}$ is also equal to $\frac{1}{3}$, fractions which are smaller than $\frac{2}{5}$ and $\frac{5}{18}$, the lowest terms respectively of $\frac{24}{60}$ and $\frac{20}{72}$; the second case could not be thus treated, and the whole numbers must there be multiplied, as they will not admit of reduction. Other details will be advanced, and tables of the combinations of the change-wheels will be also given, in treating of the practice of cutting screws.

$$\frac{27}{53} \times \frac{39}{107} \times \frac{1}{6} \quad \frac{1114}{39026} \text{ or reduced to its lowest terms } \frac{1}{35\frac{71}{1113}}.$$

In imitation of the method of change-wheels, the slide-rest screw is sometimes moved by an arrangement of catgut bands, resembling that represented in Besson's screw-lathe, page 442.

One band proceeds from the pulley on the mandrel to a spindle overhead having two pulleys, and a second cord descends from this spindle to a pulley on the slide-rest. This apparatus has been applied to cutting the expanding horn snakes. See *Manuel de Tourneur,* first edit., 1796, vol. ii., plate 21; and second edit., 1816, vol. ii., plate 16.

The method offers facility in cutting screws of various pitches, by changing the pulleys, and also either right or left-hand screws, by crossing or uncrossing one of the bands.

The plan is unexceptionable, when applied for traversing the tool slowly for the purpose of turning smooth cylinders, or surfaces (which is virtually cutting a screw or spiral of about 100 coils in the inch); and in the absence of better means, pulleys and bands are sometimes used in matching screws of unknown or irregular pitches, by the tedious method of repeated trials; as on slightly reducing, with the turning tool, the diameter of either of the *driving* pulleys, the screw or the work becomes gradually *finer;* and reducing either of the *driven* pulleys makes it *coarser;* but the mode is scarcely trustworthy, and is decidedly far inferior to its descendant, or the method of change-wheels.

The screw tools, or chasing tools, employed in the traversing lathes for cutting external and internal screws, resemble the fixed tools generally, except as regards their cutting edges; the following figures, 499 to 501, refer to angular threads, and 502 and 503 to square threads.

Angular screws are sometimes cut with the single point, Fig. 499, a form which is easily and correctly made; the general angle of the point is about 55° to 60°, and when it is only allowed to cut on one of its sides or bevels, it may be used fearlessly, as the shavings easily curl out of the way and escape. But when both sides of the single point tool are allowed to cut, it requires very much more cautious management; as in the latter case, the duplex shavings being disposed to curl over opposite ways, they pucker up as an angular film, and in fine threads they are liable to break the point of the tool, or to cause it to dig into, and tear the work. Sometimes, also, a fragment of the shaving is wedged so forcibly into the screw by the end of the tool, that it can only be extricated by a sharp chisel and hammer.

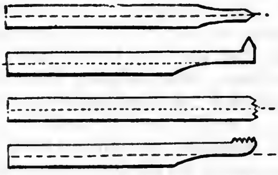
In cutting angular screws, it is very much more usual and expeditious to employ screw tools with many points, which are made in the lathe by means of a revolving cutter or hob, Figs. 447 and 448, page 427. Screw tools with many points, are always required for those angular threads which are rounded, at the top and bottom, and which are thence called *rounded* or *round* threads.

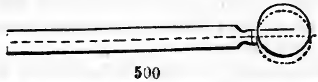
To the screw tool for rounded threads is given the profile of Fig. 500, which construction allows the tool to be *inverted,* so that the edges may be alternately used for the purpose of equalizing the section of the thread. In making the tool 500, the hob (which is *dotted*) is put between centres in the traversing lathe, and those wheels are applied which would serve to cut a screw of the same pitch as the hob; the bar of steel is then fixed in the slide-rest, so that the dotted line or the axis of the tool intersects the centre of the hob. The tool is afterwards hollowed on both sides with the file, to facilitate the sharpening, and it is then hardened. In using the tool, it is depressed until either edge comes down to the radius, proceeding from the (*black*) circle, which is supposed to represent the screw to be cut; the depression gives the required penetration to the upper angle, and removes the lower out of contact.

In the chasing tool represented in Fig. 501, the cutter, *c*, is made as a ring of steel which is screwed internally to the diameter of the bolt, and turned externally with an undercut groove, for the small screw and nut by which it is held in an iron stock, *s*, formed of a corresponding sweep; for distinctness the cutter and screw are also shown detached. The centre of the curvature of the tool is placed a little below the centre of the lathe, to give the angle of separation or penetration; and after the tool has been ground away in the act of being sharpened, it is raised up, until its points touch a straight-edge applied on the line *a a* of the stock; this denotes the proper height of centre, and also the angle to which the tool is intended to be hooked, namely, 10 degrees: each ring makes four or five cutters, and one stock may be used for several diameters of thread.

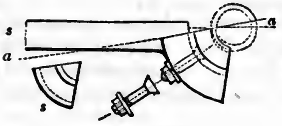
Screw Tools for Angular Threads.

Figs. 499





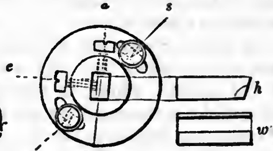
500



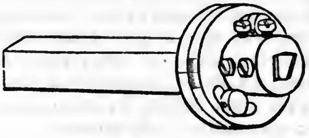
501

Screw Tools for Square Threads.

502



503



Angular thread screws are fitted to their corresponding nuts simply by reduction in diameter; but square thread screws require attention both as to diameter and width of groove, and are consequently more troublesome. Square thread screws are in general of twice the pitch, or double the obliquity, of angular screws of the same diameters; and, consequently, the interference of angle before explained as concerning the die-stocks, refers with a two-fold effect to square threads, which are in all respects much better produced in the screw-cutting lathe.

The ordinary tool for square thread-screws is represented in two views in Fig. 502; the shaft is shouldered down so as to terminate in a rectangular part which is exactly equal to the width of the groove. In general the end alone of the tool is required to cut, and the sides are beveled according to the angle of the screw, to avoid rubbing against the sides of the thread. Tools which cut upon the side alone are also occasionally used for adjusting the width of the groove. In either case it requires considerable care to maintain the exact width and height of the tool—the *inclination* of which should also differ for every change of diameter.

To obviate these several inconveniences, the author several years back contrived a tool-holder, Fig. 503, for carrying small blades made exactly rectangular. In height, as at *h*, the blades are alike, in width, *w*, they are exactly half the pitch of the threads, and they are ground upon the ends alone. The parallel blades are clamped in the rectangular aperture of the tool socket by the four screws *c c*; and when the screws *s s*, which pass through the circular mortises in the sockets, are loosened, the swivel-joint and graduations allow the blades to be placed at the particular angle of the thread, which is readily obtained by calculation, and is estimated for the medium depth of the thread, or midway between the extreme angles at the top and bottom.

One blade, therefore, serves perfectly for all screws of the same pitch, both right and left-handed, and of all diameters. As the tool exactly fills the groove, it works steadily, and the width of the groove and the height of the centre of the tool are also strictly maintained with the least possible trouble. The depth of the groove, which is generally one-sixth more than its width, is read off with great facility by means of the adjusting-screw of the slide-rest; especially if, as usual, the screw and its micrometer agree with the decimal division of the inch.

The holder, Fig. 503, has been much and satisfactorily used for screws from about 20 to 2 threads per inch; but when the screw is coarse and oblique, compared with its diameter, the blade is ground away to the dotted line in *h*, and is sometimes beveled on the sides almost to the upper edge, to suit the obliquity of the thread, but without altering the extreme width of the tool.

The tools for external screws of very coarse pitch, are necessarily formed in the lathe by aid of the corresponding wheels and a revolving cutter bar resembling Fig. 415, p. 410. The soft tool is fixed in the slide-rest, and is thereby carried against the revolving cutter bar, 415, which has a straight tool, either pointed or square as the case may be. The end of the screw tool is thus shaped as part of an external screw, the counterpart of that to be cut. The face of the screw tool is filed at right angles to the obliquity of the thread, and the end and sides are slightly beveled for penetration previously to its being hardened.

Internal square threads of small size are usually cut with taps which resemble Fig. 445, p. 424, except in the form of the teeth. When internal square threads are cut in the lathe, the tool assumes the ordinary form of a straight bar of steel with a rectangular point standing off at right angles, in most respects like the common pointed tool for inside work.

For very deep holes, and for threads of very considerable obliquity, cutter bars, such as Fig. 415, p. 410, are used. The work and the temporary bearings of the bar are all immovably fixed for the time, and the bar advances through the bearings in virtue of its screw-thread; or otherwise a plain bar, having a cutter only, and not being screwed, may be mounted between centres in the screw lathe, and the work, fixed to the slide-rest, may traverse parallel with the bar by aid of the change-wheels. The cutter bar in some cases requires a ring to fill out the space between itself and the hole, to prevent vibration; and it is necessary to increase the radial distance of the cutter between each trip, by a set screw, or by slight blows of a hammer.

Very oblique inside cutters are turned to their respective forms with a fixed tool, in a manner the converse of that explained above; and some peculiarities of management are required in using them, in order to obtain the under-cut form of the internal thread.

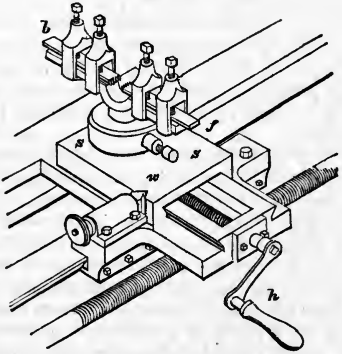
In cutting screws in the turning lathe, the tool only cuts as it traverses in the one direction; therefore whilst the cutter is moved backwards, or in the reverse direction, for the succeeding cut, it must be withdrawn from the work. Sometimes the tool is traversed backwards by reversing the motion of the lathe; and in lathes driven by power, the back motion is frequently more rapid than the cutting motion, to expedite the process; at other times the lathe is brought to rest, the nut is opened as a hinge, so as to become disengaged from the screw, and the slide-rest is traversed backwards by hand, or by a pinion movement, and the nut is again closed on the screw, prior to the succeeding cut. This mode answers perfectly for screws of the same thread as the guide, and for those of 2, 4, 6, 8 times as coarse or as fine; but for those of 2½, 4½, or any fractional times the value of the guide screw, the clasp nut cannot in general be employed advantageously.

The progressive advance of the tool between each cut, is commonly regulated by a circle of divisions or a micrometer on the slide rest screw, which should always correspond with the decimal division of the inch. The substance of the shaving may be pretty considerable after the first entry is made, but it should dwindle away to a very small quantity, towards the conclusion of the screw. To avoid the necessity for taxing the memory with the graduation at which the tool stood when it was withdrawn for the back stroke, the author has been in the habit of employing a micrometer exactly like that on the screw, which is set to the same graduation, and serves as a remembrancer; another method is to employ an arm or stop, which fits on the axis of the screw or handle with stiff friction, but nevertheless allows the tool to be shifted the two or three divisions required for each cut.

In the screw lathe used by Mr. Roberts, the nut of the slide-screw instead of being a fixture, is made with two tails as a fork, which embraces an eccentric spindle; by the half rotation of which spindle, the nut together with the adjusting screw, the slide, and the tool, are shifted, as one mass, a fixed distance to and from the centre, between each cut; so as first to withdraw and then to replace the tool. Whilst the tool is running back, the screw is moved by its adjusting screw and divisions, the minute quantity to set in the tool for the succeeding cut, and the continual wear upon the adjusting screw, as well as the uncertainty of its being correctly moved to and fro by the individual, are each avoided.

Sometimes, with the view of saving the time lost in running back, two tools are used, so that the one may cut as the tool slide traverses towards the mandrel, the other in the contrary direction. An arrangement for this purpose, as applied to the screwing of bolts in the lathe, is shown in Fig. 504; *f* represents the front, and *b* the back tool, which are mounted on the one slide *s s*, and all three are moved as one piece by the handle *h*, which does not require any micrometer.

Fig. 504.



In the first adjustment, the wedge *w*, is thrust to the bottom of the corresponding angular notch in the slide *s*, and the two tools are placed in contact with the cylinder to be screwed. For the first cut, the wedge is slightly withdrawn to allow the tool *f*, to be advanced towards the work; and for the return stroke, the wedge is again shifted under the observation of its divisions, and the slide *s s*, is brought forwards, towards the workman, up to the wedge; this relieves the tool *f*, and projects *b*, which is then in adjustment for the second cut; and so on alternately. The command of the two tools is accurately given by the wedge, which is moved a small quantity by its screw and micrometer, between every alternation of the pair of tools, by the screw *h*.

In cutting very long screws, the same as in turning long cylindrical shafts, the object becomes so slender, that the contrivance called a backstay is always required for supporting the work in the immediate neighborhood of the tool. The backstay is fixed to the slide plate, or the saddle of the lathe which carries the tool, and is brought as near to the tool as possible; sometimes the dies or bearings are circular, and fit around the screw; at other times they touch the same at two, three or four parts of the circle only. Some of the numerous forms of this indispensable guide or backstay will hereafter be shown.

In using the screw-lathe with a backstay for long screws, it is a valuable and important method, just at the conclusion, to employ a pair of dies in the place usually occupied by the tool; as they are a satisfactory test for exact diameter, and they remove trifling errors attributable to veins and irregularities of the material, which the fixed tool sometimes fails entirely to reduce to the general surface. The tool and backstay may be each considered to be built on the tops of pedestals more or less lofty, and therefore, more susceptible of separation by elasticity, than the pair of dies fixed in a small square frame. It has been judiciously proposed, in effect, to link the backstay and turning tool together, by the employment of a small frame carrying a semicircular die of lignum-vitæ, and a fixed turning tool, adjusted by a pressure screw; the frame to be applied either in the hand alone or in the slide rest, and to be inverted so that the shavings may fall away without clogging the cutter.

VARIOUS MODES OF ORIGINATING AND IMPROVING SCREWS.—The improvement of the screw has given rise to many valuable schemes and modes of practice, which have not been noticed in the foregoing sections, notwithstanding their collective length. These practices indeed could not consistently have been placed in the former pages of this subject because some of them must be viewed as refinements upon the general methods, the earlier notice of which would have been premature; and others exhibit various combinations of methods pursued by different eminent individuals with one common object, and are therefore too important to be passed in silence, notwithstanding their miscellaneous nature.

To render this section sufficiently complete, it appears needful to take a slight retrospective glance of the early and the modern modes of originating screws and screw apparatus; some account of the former may be found in the writings of Pappus, who lived in the fourth century.

In the works of Pappus Alexandrinus, a Greek mathematician of the fourth century, are to be found practical directions for making screws.

The process is simply to make a templet of thin brass of the form of a right-angled triangle, the angles of which are made in accordance with the inclination of the proposed screw. This triangle is then to be wrapped round the cylinder which is to be the desired screw, and a spiral line traced along its edge. The screw is subsequently to be excavated along this line. Minute practical directions are given not only for every step of this process, but also for the division, setting out, and shaping the teeth of a worm-wheel of any required number of teeth to suit the screw. (Vide *Pappi Math. Col.,* lib. viii. prob. xviii.)

The progressive stages which may be supposed to have been formerly in pretty general use for originating screws, may be thus enumerated:

1. The first screw-tap may be supposed to have been made by the inclined templet, the file, and screw tool. It was imperfect in all respects, and not truly helical, but full of small irregularities.

2. The dies formed by the above were considerably nearer to perfection, as the multitude of pointed edges of 1 being passed through every groove of the die, the threads of the latter became more nearly equal in their rake or angle, and also in their distances and form.

3. The screw cut with such dies would much more resemble a true helix than 1; but from the irregularities in the first tap, the grooves in the die 2 would necessarily be *wide,* and their sides, instead of meeting as a *simple angle,* would be more or less filled with ridges, and 3 would become the exact counterpart of 2.

4. A pointed tool applied in the lathe would correct the form of the thread or groove in 3 without detracting from its improved cylindrical and helical character, especially if the turning tool were gradually altered from the slightly rounded to the acute form in accordance with the progressive change of the screw. The latter is occasionally changed end for end, either in the die-stocks or in the lathe, to reverse the direction in which the tools meet the work, and which reversal tends to equalize the general form of the thread.

5. The corrected screw 4, when converted into a master-tap, would make dies greatly superior to 2; it would also serve for cutting up screw tools; and lastly,

6. The dies 5 would be employed for making the ordinary screws and working taps; and this completes the one series of screwing apparatus.

One original tap having been obtained, it is often made subservient to the production of others; for example, a screw tool with several points cut over the corrected original 4 would serve for striking in the lathe other master-taps of the same thread but different diameters. The process is so much facilitated by the perfection of the screw tool that a clever workman would thus, without additional correction, strike master-taps sufficiently accurate for cutting up other dies larger or smaller than 4. Sometimes also the dies 5 are used for marking out original taps a little larger or smaller than 4.

As a temporary expedient the screw tool may be somewhat spread at the forge fire to make a tool a little coarser, or it may be upset for one a little finer, and afterwards corrected with a file; or screw tools may be made entirely with the file, and then employed for producing, in the lathe, master-taps of corresponding degrees of coarseness and of all diameters.

These are in truth some of the progressive modes by which, under very careful management, great numbers of good useful screwing apparatus have been produced, and which answer perfectly well for all the ordinary requirements of "*binding*" or "*attachment*" screws; or as the cement by which the parts of mechanism and structures generally are firmly united together, but with the power of separation and reunion at pleasure.

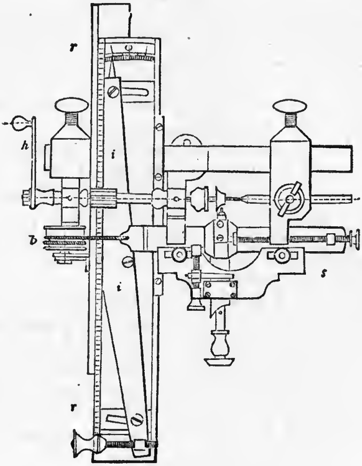
In this comparatively inferior class of screws considerable latitude of *proportion* may be allowed, and whether or not their pitches or rates have any exact relationship to the inch, is a matter of indifference as regards their individual usefulness; but in superior screws, or those which may be denominated "*regulating*" and "*micrometrical*" screws, it does not alone suffice that the screw shall be good in general character, and as nearly as possible a true helix; but it must also bear some defined proportion to the standard foot or inch, or other measure. The attainment of this condition has been attempted in various ways, to some of which a brief allusion was made, and a few descriptive particulars will now be offered.

The apparatus for cutting original screws by means of a wedge or inclined plane, appears to be derived from the old fusee engine, a drawing of which is given in Fig. 505. In principle it is perfect, and it is also universal within the narrow limitation of its structure.

The drawing is the half size of Fig. 1, Plate xvii., of Ferdinand Berthoud's *Essai sur L'Horlogerie,* Paris, 1763. M. Berthoud says, "The instrument is the most perfect with which I am acquainted; it is the invention of M. Le Lievre, and it has been reconstructed and improved by M. Gideon Duval." The templet or shaper plate determines the hyperbolical section of the fusee. The modification, with an inclined plane, is due to Hindley, of York.

The handle *h* gives rotation to the work; and at the same time, by means of the rack *r r*, and the pinion fixed on its axis, the handle traverses a slide which carries on its upper surface a bar *i*; the latter moves on a centre, and may be set at any inclination by the adjusting screw and divisions; it is then fixed by its clamping screws. The slide *s* carries the tool, and the end of this slide rests against the inclined plane *i* through the intervention of a saddle or swing piece. The slide and tool are drawn to the left hand by the chain which is coiled round the barrel *b*, by means of a spiral spring contained within it.

Fig. 505.



Supposing the bar *i i* to stand square or at zero, no motion would be impressed on the tool during its traverse, which we will suppose to require 10 revolutions of the pinion. But if the bar were inclined to its utmost extent, so that we may suppose the one end to project exactly one inch beyond the other, in reference to the zero line or the path of the slide, then during the 10 revolutions of the screw the tool would traverse one inch, or the difference between the ends of the inclined bar *i*; and it would thereby cut a screw of the length of one inch, or the total inclination of the bar, and containing ten coils or threads.

But the inclination of the bar is arbitrary, and may be any quantity less than one inch, and may lean either to the right or left; consequently the instrument may be employed in cutting all right or left-hand screws, *not exceeding* 10 *turns in length*, nor measuring in their total extent above *one inch*, or the maximum inclination of the bar.

The principle of this machine may be considered faultless; but in action it will depend upon several niceties of construction, particularly the straightness of the slide and inclined bar, the equality of the rack and pinion, and the exact contact between the tool slide and the inclined plane. These difficulties augment very rapidly with the increase of dimensions; and probably the machine made by Mr. Adam Reid exclusively for cutting screws, is as large as can be safely adopted. The inclined plane is 44 inches long, but the work cannot exceed 1$\frac{6}{10}$ths inch diameter, 2¼ inches long, or ten threads in total length. The application of the inclined plane to cutting screws is therefore too contracted for the ordinary wants of the engineer, which are now admirably supplied by the screw-cutting lathes with guide screws and change wheels.

The accuracy of screws has always been closely associated with the successful performance of engines for graduating circles and right lines, and the next examples will be extracted from the published accounts of the dividing engines made by Mr. Ramsden.

This eminent individual received a reward from the Board of Longitude, upon the condition that he would furnish for the benefit of the public a full account of the methods of constructing and using his dividing machines, and which duly appeared in the following tracts: "Description of an Engine for Dividing Mathematical Instruments, by Ramsden, 4to., 1777." Also, "Description of an Engine for Dividing Straight Lines, by Ramsden, 4to., 1779, from which the following particulars are extracted:

The circular dividing engine consisted of a large wheel moved by a tangent screw; the wheel was 45 inches diameter, and had 2160 teeth, so that six turns of the tangent screw moved the circle one degree; the screw had a micrometer, and also a ratchet-wheel of 60 teeth—therefore one tooth equalled one-tenth of a minute of a degree. The screw could be moved a quantity equal to one single tooth, or several turns and parts, by means of a cord and treadle, so that the circular works attached to the dividing wheel could be readily graduated into the required numbers by setting the tangent screw to move the appropriate quantities. The dividing knife or diamond point always moved on one fixed radial line by means of a swing-frame.

"In ratching or cutting the wheel," says Mr. Ramsden, "the circle was divided with the greatest exactness I was capable of, first into 5 parts, and each of these into 3; these parts were then bisected 4 times; this divided the wheel into 240 divisions, each intended to contain 9 teeth. The ratching was commenced at each of the 240 divisions by setting the screw each time to zero by its micrometer, and the cutter frame to one of the great divisions by the index; the cutter was then pressed into the wheel by a screw, and the cutting process was interrupted at the ninth revolution of the screw. It was resumed at the next 240th division (or nine degrees off), as at first, and so on.

This process was repeated three times round the circle, after which the ratching was continued uninterruptedly around the wheel about 300 times; this completed the teeth with satisfactory accuracy. The tangent screw was subsequently made, as explained in the text.

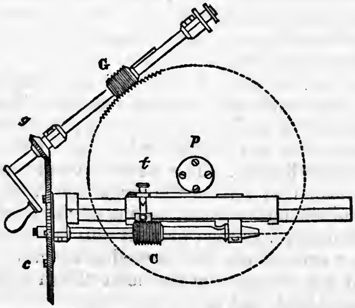
The *first* application of the tangent screw and ratchet to the purposes of graduation, appears to have been in the machine for cutting clock and watch wheels, by Pierre Fardoil; see plate 23 of

Thiout's *Traité d' Horlogerie*, etc. Paris, 1741. At page 55 is given a table of ratchets and settings for wheels with from 102 to 800 teeth.

In Mr. Ramsden's description of his dividing engines for circles, he says: "Having measured the circumference of the dividing wheel, I found it would require a screw about one thread in a hundred coarser than the guide-screw." He goes on to explain that the guide-screw moved a tool fixed in a slide carefully fitted on a triangular bar, an arrangement equivalent to a slide-rest and fixed tool: the screw to be cut was placed parallel with the slide, and the guide-screw and copy were connected by two change wheels of 198 and 200 teeth (numbers in the proportion required between the guide and copy), with an intermediate wheel to make the threads on the two screws in the same direction. As no account is given of the mode in which the guide-screw was itself formed, it is to be presumed it was the most correct screw that could be obtained, and was produced by some of the means described in the beginning of the present sections.

Mr. Ramsden employed a more complex apparatus in originating the screw of his dividing engine for straight lines, which it was essential should contain exactly 20 threads in the inch; a condition uncalled for in the circular engine, in which the equality of the teeth of the wheel required the principal degree of attention. This second screw-cutting apparatus, which may be viewed as an offspring of the circular dividing engine, is represented in plan, in Fig. 509, and may be thus briefly explained.

Fig. 509.



The guide-screw G is turned round by the winch, and in each revolution moves the larger tangent wheel one tooth: the tangent wheel has a small central box or pulley *p*, to which is attached the one end of an elastic slip of steel, like a watch-spring; the other end of the slip is connected with the slide *s*, that carries the tool *t*, in a right line besides the screw C, which latter is the piece to be cut; and C is connected with the guide-screw G, by a bevel pinion and wheel *g*, and *c*, as 1 to 6.

To proportion the traverse of the tool to the interval or pitch of the screw, two dots were made on the slide *s*, exactly five inches asunder; and in that space the screw should contain 100 coils, to be brought about by 600 turns of the handle. The guide-screw was moved that number of revolutions, and the diameter of *p* was reduced by trial, until the 600 turns traversed the slide exactly from dot to dot; these points were observed at the time through a lens placed in a fixed tube, and having a fine silver wire stretched diametrically across the same as an index.

See "Description of an Engine for Dividing Straight Lines."

In the construction of his dividing engine for straight lines, Ramsden very closely followed his prior machine for circular lines, if we conceive the wheel spread out as a rectangular slide. On the one edge of the main slide which carried the work, was cut a screw-form rack, with twenty teeth per inch, which was moved by a short fixed screw of the same pitch, by means of ratchets of 50, 48, or 32 teeth respectively; the screw could be moved a quantity equal to one single tooth, or to several turns and parts, by means of a treadle. To obtain divisions which were incompatible with the sub-division of the inch into 1000, 960 or 640 parts, the respective values of one tooth, the scale was laid on the slide at an *angle* to the direction of motion; when the swing frame was placed to traverse the *knife* at right angles to the *path* of the slide, the graduations were lengthened; when the *knife* was traversed at right angles to the *oblique* position of the scale being divided, they were shortened. This was to a small degree equivalent to having a screw of variable length. In cutting the screw-form teeth of the rectilinear dividing engine, the entire length, namely, 25.6 inches, was first divided very carefully by continual bisection into spaces of eight-tenths of an inch, by hand as usual, and the screw-cutter was placed at zero at each of these divisions, pressed into the edge of the slide, and revolved sixteen times; after three repetitions at each of the principal spaces, the entire length was ratched continuously until the teeth were completed.

With the view of producing screws of exact values, engineers have employed numerous modifications of the chain or band of steel, the inclined knife, the inclined plane, and indeed each of the known methods, which, however, were remodelled as additions to the ordinary turning-lathe with a triangular bar.

Some give a preference to the inclined knife, applied against a cylinder revolving in the lathe, by means of a slide running upon the bar of the lathe; which, besides being very rapid, reduced the mechanism to its utmost simplicity. This made the process to depend almost alone on the homogeneity of the materials, and on the relation between the diameter of the cylinder and the inclination of the knife; whereas in a complex machine, every part concerned in the transmission of motion, such as each axis, wheel and slide, entails its risk of individual error, and may depreciate the accuracy of the result; and to these sources of disturbance, must be added those due to change of temperature, whether arising from the atmosphere or from friction, especially when different metals are concerned.

A rod of wood, generally of alder and about two feet long, was put between the centres, and reduced to a cylinder by a rounder or *witchet*, attached to a slide running on the bar; the slide with the inclined knife was then applied, and the angle of the knife was gradually varied by adjusting screws, until several screws made in succession, were found to agree with some fixed measure. The experiment was then repeated with the same angle, upon cylinders of the same diameter, of tin, brass, and other comparatively soft metals, and hundreds, or it might almost be said, thousands of screws were thus made.

From amongst these screws were selected those which, on trial in the lathe, were found to be most nearly true in their angle, or to have a quiescent gliding motion; and which would also best endure a strict examination as to their pitch or intervals, both with the rule and compasses, and also when two were placed side by side, and their respective threads were compared, as the divisions on two equal scales.

The most favorable screw having been selected, it was employed as a guide-screw, in a simple apparatus which consisted of two triangular bars fixed level, parallel, and about one foot asunder, in appropriate standards with two apertures; the one bar carried the mandrel and popit-heads as in the ordinary bar lathe. The slide rest embraced both bars, and was traversed thereupon by the guide-screw placed about midway between the bars; the guide screw and mandrel were generally connected by three wheels, or else by two or four, when the guide and copy were required to have the reverse direction. The mandrel was not usually driven by a pulley and cord; but on the extremity of the mandrel was fixed a light wheel, with one arm serving as a winch handle for rapid motion in running back; and six or eight radial arms (after the manner of the steering wheels of large vessels), by which the mandrel and the screw were slowly handed round during the cut.

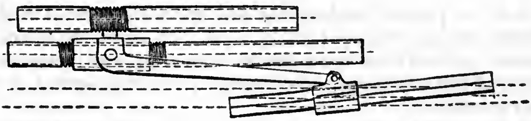
In a subsequent and stronger machine the bar carrying the mandrel stood lower than the other, to admit of larger change wheels upon it, and the same driving gear was retained. And in another structure of the screw-cutting lathe, the triangular bar was placed for the lathe heads in the centre, whilst a large and wide slide-plate, moving between chamfer bars attached to the framing, carried the sliding rest for the tool; in this last machine, the mandrel was driven by steam-power, and the retrograde motion had about double the velocity of that used in cutting the screw.

The relations between the guide-screw and the copy were varied in all possible ways: the guide was changed end for end, or different parts of it were successively used; sometimes, also, two guide-screws were yoked together with three equal wheels, their nuts being connected by a bar jointed to each, and the centre of this link (whose motion thus became the *mean* of that of the guides) was made to traverse the tool. Steel screws were also cut, and converted into original taps, from which dies were made, to be themselves used in correcting the minor errors, and render the screws in all respects as equable as possible. In fact, every scheme that he could devise, which appeared likely to benefit the result, was carefully tried, in order to perfect to the utmost, the helical character and equality of subdivision of the screw.

The change of the thousandth part of the total length, was therefore given to the tool as a supplementary motion, which might be added to, or subtracted from, the total traverse of the tool, in the mode explained by the diagram, Fig. 507, in which all details of construction are purposely omitted. The copy C, and the guide-screw G, are supposed to be connected by equal wheels in the usual manner; the guide-screw carries the axis of the bent lever, whose arms are as 10 to 1, and which moves in a horizontal plane; the short arm carries the tool, the long arm is jointed to a saddle which slides upon a triangular bar *i i*.

In point of fact, the tool was mounted upon the upper of two longitudinal and parallel slides, which were collectively traversed by the guide-screw G. In the lower slide was fixed the axis or fulcrum of the bent lever, the short arm of which was connected by a link with the upper slide, so that the compensating motion was given to the upper slide relatively to the lower.

Fig. 507.



The triangular bar *i i*, when placed exactly parallel with the path of the tool, would produce no movement on the same, and C, and G, would be exactly alike; but if *i i* were placed out of the parallelism one inch in the whole length, the tool, during its traverse to the left by the guide-screw G, would be moved to the right by the shifting of the bent lever, one-tenth of the displacement of the bar, or one-tenth of an inch.

Therefore, whilst the guide-screw G, from being coarser than required, moved the principal slide the one-thousandth part of the total length in excess; the bent lever and inclined *straight* bar *i i*, pulled back the upper or compensating slide, the one-thousandth part, or the quantity in excess; making the absolute traverse of the tool exactly seven feet, or the length required for the new screw C, instead of seven feet and one-sixteenth of an inch, the length of G. To have lengthened the traverse of the tool, the bar *i i* must have been inclined the reverse way; in other words, the path of the tool is in the diagram the *difference* of the two motions; in the reverse inclination, its path would be the *sum* of the two motions, and *i i* being a straight line, the correction would be evenly distributed at every part of the length.

Other experimentalists preferred, however, the method of the chain, or flexible band, for traversing the tool the exact quantity; because the reduction of a diameter of the pulley or drum, afforded a very ready means of adjustment for total length; and all the wheels of the mechanism being individually as perfect as they could be made, a near approach to general perfection was naturally anticipated on the first trial. This mode, however, is subject to the error introduced by the elasticity or elongation of the chain or band, and which is at the maximum when the greatest length of chain is uncoiled from the barrel.

About the year 1820, Mr. Clement put in practice a peculiar mode for originating the guide-screw of his screw-lathe, the steps of which plan will be now described.

1. He procured from Scotland some hand-screw tools cut over a hob with concentric grooves; and to prevent the ridges or points of the screw tools from being cut square across the end, the rest was inclined to compensate for the want of angle in the hob or cutter.

2. A brass screw was struck by hand, or chased with the tool 1.

3. The screw 2, was fixed at the back of a traversing mandrel, and clipped between two pieces of wood or dies to serve as a guide, whilst,

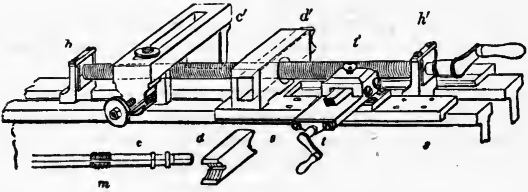
4. A more perfect guide-screw was cut with a fixed tool, and substituted on the mandrel for 3; as Mr. Clement considered the movement derived from the opposite sides of the one screw, became the mean of the two sides, and corrected any irregularities of angle, or of drunkenness.

5. A large and a small master-tap *m*, Fig. 508, were cut on the traversing mandrel with a fixed tool, the threads were about an inch long and situated in the middle of a shaft eight or ten inches long; the small master-tap was of the same diameter as the finished screw, the large master-tap measured at the bottom of the thread the same as the blank cylinder to be screwed. The master-taps *m*, were used in cutting up the rectangular dies required in the apparatus shown in Fig. 508, and now to be described.

6. On the parallel bed of a lathe were fitted two standards or collar-heads *h h'*, intended to receive the pivots of the screw to be cut, on the extremity of which was placed a winch handle, or sometimes an intermediate socket was interposed between the screw and the winch, to carry the latter to the end of the bed. The bed had also an accurate slide plate *s s'*, running freely upon it, the slide plate had two tails which passed beside the head *h'*, and at the other end, a projection through which was made a transverse rectangular mortise for the dies, the one end of the mortise is shown by the removal of the front die *d*, and the back die *d'* is seen in its

proper situation; one extremity of each die was cut from the large master tap *m*, and the other from the small. The clamp or shackle *c c′*, was used to close the two dies upon the screw simultaneously; it is shown out of its true position in order that the dies and mortise may be seen, but when in use the shackle would be shifted to the right, so as to embrace the dies *d d′*. The plain extremity *c′* rested against the back die, whilst the screw *c* bore against the front die, through the intervention of the washer loosely attached to the clamp to save the teeth from injury; the pressure screw *c* had a graduated head and an index, to denote how much the dies were closed.

Fig. 508.



7. A cylinder about two feet long, prepared for the screw, was placed between the heads *h h′*, and the large dies, whose inner edges were of the same diameter as the cylinder, were closed upon it moderately tight, and the screw was turned round with the winch, to trace a thread from end to end; this was repeated a few times, the dies being slightly closed between each trip.

8. A screw-tool was next fixed on the slide *s s′*, in a chamfer slide *t t′*, with appropriate adjusting screws, so as to follow the dies and remove a shaving, much the same as in turning. The dies having arrived at one end of the screw, the same screw tool or a second tool was placed on the opposite side of the side-plate so as to cut during the return movement. With the progress of the screw the screw-tool was applied at a variety of distances from the pair of dies, as well as on opposite sides of the screw, so that the metal was cut out by the tool, and the dies were used almost alone to guide the traverse. Of course the dies were closed between each trip, and when the screw was about half cut up the small dies were substituted for the large ones used at the commencement of the process.

9. The screw thus made, which was intended for a slide-rest, was found to be very uniform in its thread, and it was used for some time for the ordinary purposes of turning. When, however, it was required to be used for cutting other screws, it was found objectionable that its rate was nearly nine, whereas it was required to have eight threads per inch. It was then used in cutting a new guide-screw by means of a pair of change wheels of 50 and 56

teeth, which upon calculation were found to effect the conversion with sufficient precision.

10. From 9, the screw of 24 inches in length, one of 8 feet in length was obtained. The thread was cut one-third of its depth, with the wheels, successive portions being operated upon and the tool being carefully adjusted to the termination of the part previously cut. The general truth of the entire length was given by a repetition of the tedious mode of correction represented in the figure, with the dies and tool applied upon a bearer rather exceeding the full length of the screw.

Fig. 509.

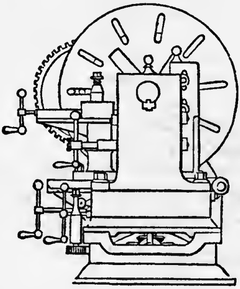
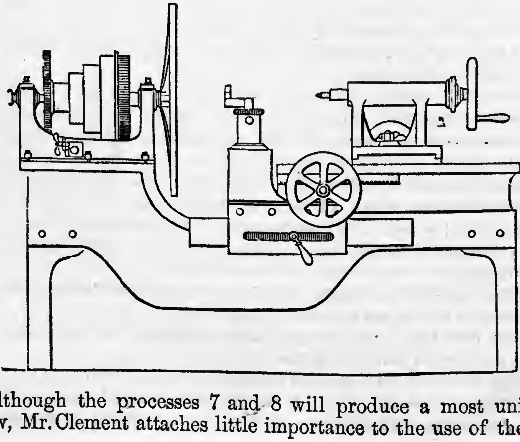
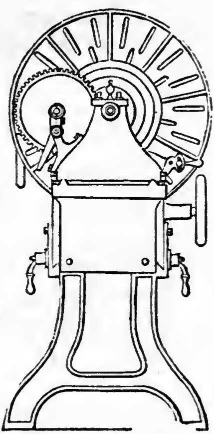


Fig. 510.



Although the processes 7 and 8 will produce a most uniform screw, Mr. Clement attaches little importance to the use of the dies and guide-frame alone when *several* screws are wanted strictly of the *same length.* Of some few thus made as nearly as possible under equal circumstances two screws were found very nearly to agree, and a third was above a tenth of an inch longer in ten inches. This difference he thinks to have arisen in marking out the threads, from a little variation in the friction of the slide, or a difference in the first penetration of the dies.

Fig. 511.



The friction of the slide, when sufficient to cause any retardation, he considers to produce a constant and accumulative effect; first, as it were, reducing the screw of 15 threads per inch, say to the fineness of 15¼, then acting upon that of 15¼, reducing it to 15½, and so on; and that to such an extent, as occasionally to place the screw entirely beyond the correctional process. This cannot be the case when the thread is first marked out with the change-wheels instead of the dies.

One very important application of the screw is to the graduation of mathematical scales. The screw is then employed to move a platform, which slides very freely and carries the scale to be graduated; and the swing frame, for the knife or diamond point, is attached to some fixed part of the framing of the machine. Supposing the screw to be absolutely perfect, and to have fifty threads per inch, successive movements of fifty revolutions would move the platform and graduate the scale exactly into true inches; but on close examination some of the graduations will be found to exceed, and others to fall short of, the true inch.

The scales assume, of course, the relative degree of accuracy of the screw employed. No test is more severe; and when these scales are examined by means of two microscopes under a magnifying power of ten or twenty times, the most minute errors become abundantly obvious from the divisions of the scales failing to intersect the cross wires of the instrument; the result clearly indicates corresponding irregularities in the coarseness of the screw at the respective parts of its length. An accustomed eye can thus detect, with the microscope, differences not exceeding the one thirty-thousandth part of an inch, the twenty-five-thousandth part being comparatively of easy observation.

Figs. 509 and 512 show a large chucking and reaming lathe built at Lowell, Massachusetts.

Figs. 510 and 511 show a chucking and reaming lathe manufactured at Lowell. This instrument is geared with a rest for holding drills and reamers moved by a toothed rack, backhead stock, adjustable sideways, cast-iron cone-pulleys, gun metal bearings, and cast-steel spindle.

Fig. 512.

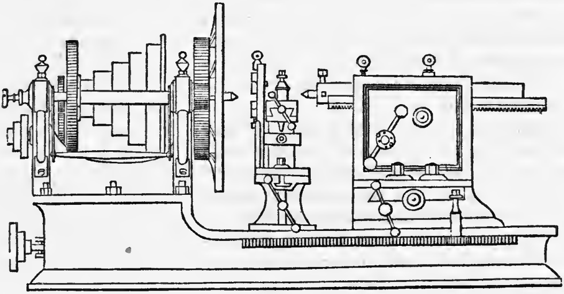
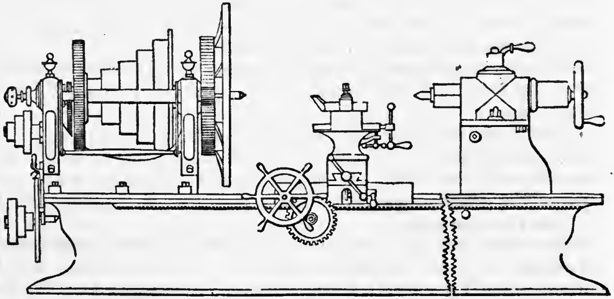


Fig. 513 is an engine lathe manufactured at the Lowell Machine Shop, Lowell, Massachusetts. Its swing is 50 inches over the sills, and 32 over the rest.

Fig. 513.



The bed of this lathe is cast in one piece, the feed motion is carried by a screw, the tool rest held down by gibs under the slides, and moved on a toothed rack and pinion by hand.

Screw Threads Considered in Respect to their Proportions, Forms, and General Characters.—The proportions given to screws employed for attaching together the different parts of works are in nearly every case arbitrary, or, in other words, they are determined almost by experience alone rather than by rule, and with little or no aid from calculation, as will be shown.

In addition to the ordinary binding screws, which, although arbitrary, assume proportions not far distant from a general average, many screws, either much coarser or finer than usual, are continually required for specific purposes; as are likewise other screws of some definite number of turns per inch—as 2, 10, 12, 20, etc.—in order to effect some adjustment or movement having an immediate reference to ordinary lineal measure. But all these must be considered as still more distant than common binding screws from any fixed proportions, and not to be amenable to any rules beyond those of general expediency.

Neither the pitch, diameter, nor depth of thread, can be adopted as the basis from which to calculate the two other measures, on account of the different modes in which the three influence the effectiveness of the screw; nor can the proportions suitable to the ordinary ¾ inch binding screw be doubled for the 1½ inch screw, or halved for that of ⅜ inch, as every diameter requires its individual scale to be determined in great measure by experiment in order to produce something like a mean proportion between the dissimilar conditions, which will be separately explained in various points of view.

The reasons for the uncertainty of measure in the various fixing screws required in the constructive arts are sufficiently manifest; as first, the force or strain to which a screw is exposed, either in the act of fixing or in the office it has afterward to perform, can rarely be told by calculation; and secondly, a knowledge of the strain the screw itself will safely endure without breaking in two, or without drawing out of the nut, is equally difficult of attainment; nor thirdly, can the deduction for friction be truly made from that force the screw should otherwise possess from its angle or pitch when viewed as a mechanical power, or as a continuous circular wedge.

The force required in the fixing of screws takes a very wide range, and is faintly indicative of the strain exerted on each. The watchmaker, in fixing his binding screws, employs with great delicacy a screw-driver the handle of which is smaller than an ordinary drawing pencil; while for screws, say of five inches diameter, a lever of six or seven feet long must be employed by the engineer, with the united exertions of as many men. But in neither case do we arrive at any available conclusion, as to the precise force exerted upon, or by each screw; nor of the greatest strain that each will safely endure.

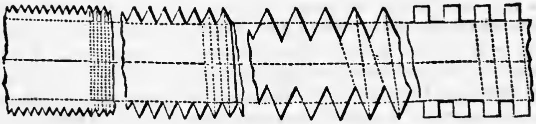
The *absolute* measures of the strength of any individual screw being therefore nearly or quite unattainable, all that can be done to assist the judgment, is to explain the *relative* or *comparative* measures of strength in different screws, as determined by the three conditions which occur in *every screw;* whether it be right or left-handed, of single or of multiplex thread, or of any section whatever; and which three conditions follow *different* laws, and *conjointly,* yet *oppositely* determine the fitness of the screw for its particular purpose, and therefore tend to perplex the choice.

The three *relative* or *comparative* measures of strength in different screws are: first, *the mechanical power of the thread,* which is derived from its pitch; secondly, *the cohesive strength of the bolt,* which is derived from its transverse section; thirdly, *the cohesive strength of the hold,* which is derived from the interplacement of the threads of the screw and nut.

These conditions will be first considered, principally as regards ordinary binding screws, and screw bolts and nuts, of angular threads, and which indeed constitute by far the largest number of all the screws employed; screws of angular and square threads will be then compared.

The comparative sections, Figs. 514 to 517, represent screws of the same diameters, and in all of which the depth of the thread is equal to the width of the groove; Figs. 515 and 517 show the ordinary proportions of ¾ inch angular and square thread screws; 514 and 516 are respectively as fine and as coarse again as 515.

Figs. 514 515 516 517.



Various measures of the screws which require little further explanation are subjoined in a tabular form; and the relative degrees of strength possessed by each screw under three different points of view, are added.

MEASURES AND RELATIVE STRENGTHS OF THE SCREWS.	Fig. 514.	Fig. 515.	Fig. 516.	Fig. 517.
External diameters in hundredths of an inch	.75	.75	.75	.75
Internal diameters in hundredths of an inch	.65	.55	.35	.55
Number of threads per inch, or *rates* of the screws	.20	10.	5.	5.
Depths and widths of the threads in hundredths	.05	.10	.20	.10
Angles of the threads on the external diameters*	1°16′	2°33′	5° 5′	5° 5′
Angles of the threads on the internal diameters*	1°28′	3°28′	10°47′	6°55′
Relative mechanical powers of the threads	20	10	5	5
Relative cohesive strengths of the bolts	4	3	1	3
Relative cohesive strengths of hold of the screws	65	55	35	27½
Relative cohesive strengths of hold of the nuts	75	75	75	37½

Square thread screws, have about twice the pitch of angular threads of similar diameters, and Fig. 517 estimated in the same manner as the angular, will stand by comparison as follows. The

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* The angles of the threads of screws are calculated trigonometrically, the circumference of the bolt being considered as the base of a right-angled triangle, and the pitch as the height of the same.

The author has adopted the following mode, which will be found to require the fewest figures; namely, to divide the pitch by the circumference, and to seek the product in the table of tangents; decimal numbers are to be used, and it is sufficiently near to consider the circumference as exactly three times the diameter.

square thread, Fig. 517, will be found to be equal in power to Fig. 516, the pitch being alike in each. In strength of bolt to be equal to Fig. 515, their transverse areas being alike. And in strength of hold, to possess the half of that of Fig. 515, because the square thread will from necessity break through the bottom of the threads, or an interrupted line exactly like the dotted line in Fig. 516, that denotes just half the area or extent of base, of the thread of Fig. 515; which latter covers the entire surface of the contained cylinder, and not the half only.

The mechanical power of the thread is derived from its pitch. The power, or the force of compression, is directly as the number of threads per inch, or as the *rate;* so that neglecting the friction in both cases, Fig. 514 grasps with four times the power of Fig. 516, because its wedge or angle is four times as acute.

When, however, the angle is very great, as in the screws of fly-presses, which sometimes exceed the obliquity of 45 degrees, the screw will not retain its grasp at all; neither will a wedge of 45 degrees stick fast in a cleft. Such coarse screws act by impact; they give a violent blow on the die from the momentum of the *fly* (namely, the loaded lever, or the wheel fixed on the press-screw) being suddenly arrested; they do not wedge fast, but on the contrary, the reaction upwards unwinds and raises the screw for the succeeding stroke of the fly-press.

Binding screws which are disproportionately coarse, from leaning towards this condition, and also from presenting less surface-friction, are liable to become loosened if exposed to a jarring action. But when, on the contrary, the pitch is very fine, or the wedge is very acute, the surface friction against the thread of the screw is such, as occasionally to prevent their separation when the screw-bolt has remained long in the hole or nut, from the adhesion caused by the thickening of the oil, or by a slight formation of rust.

The cohesive strength of the bolt is derived from its transverse section. The screw may be thus compared with a cylindrical rod of the some diameter as the bottom of the thread, and employed in sustaining a load; that is, neglecting torsion, which if in excess may twist the screw in two. The relative strengths are represented by the squares of the smaller diameters: in the screws of 20, 10, and 5 angular threads, the smaller diameters are 65, 55, and 35; the squares of these numbers are 4225, 3025, and 1225, which may be expressed in round numbers as 4, 3, 1; and, therefore, the coarsest screw, Fig. 516, has transversely only one-fourth the area, and conse-

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For the external angle of Fig. 516 say $.20+2.25=.0888$, and this quotient by Hutton's Tables gives 5 deg. 5 min.

For the internal angle of Fig. 514 say $.05+1.95=0.2564$, and by Hutton's Tables, 1 deg. 28 min.

In this method the pitch is considered as the tangent to the angle, and the division effects the change of the two sides of the given right-angled triangle, for two others, the larger of which is 1 or unity, for the convenience of using the tables.

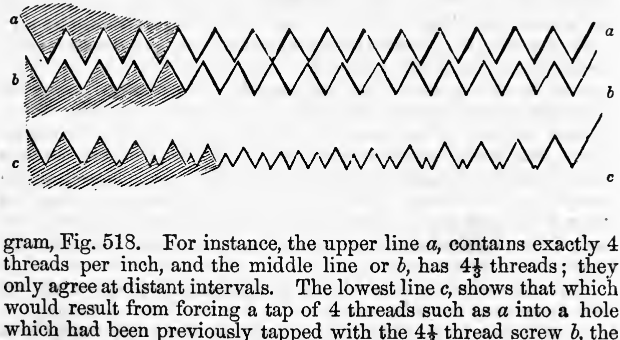
quently one-fourth the strength of the finest, represented in the three diagrams.

The cohesive strength of the hold is derived from the helical ridge of the external screw, being situated within the helical groove of the internal screw. The two helices become locked together with a degree of firmness, approaching to that by means of which the different particles of solid bodies are united in a mass; as one or both of the ridges must be in a great measure torn off in the removal of the screw, unless it be unwound or twisted out.

A slight difference in the diameter or the section of a screw and nut, is less objectionable than any variation in the coarseness or pitch; as the latter difference, even when very minute, will prevent the screw from entering the hole, unless the screw is made considerably smaller than it ought to be, and even then it will bear very imperfectly, or only on a few places of the nut.

To attempt to alter a screwed hole by the use of a tap of a different pitch, is equally fatal, as will be seen by the annexed diagram, Fig. 518. For instance, the upper line *a*, contains exactly 4 threads per inch, and the middle line or *b*, has 4⅓ threads; they only agree at distant intervals. The lowest line *c*, shows that which would result from forcing a tap of 4 threads such as *a* into a hole which had been previously tapped with the 4⅓ thread screw *b*, the threads would be said to cross, and would nearly destroy each other; the same result would of course occur from employing 4 or 5 thread dies on a screw of 4⅓ threads per inch.

Fig. 518.



Therefore, unless the screw tackle exactly agree in pitch with the previous thread, it is needful to remove every vestige of the former thread from the screw or hole; otherwise the result drawn at *c*, must ensue in a degree proportionate to the difference of the threads, and a large portion of the bearing surface, and consequently, of the strength and durability of the contact, would each be lost. Some idea may thence be formed of the real and irremediable drawback frequently experienced from the dissimilarity of screwing apparatus; *nearly to agree* will not suffice, as the pitch should be identical.

The nut of a ¾-inch screw bolt is usually ¾ inch thick, as it is considered that when the threads are in good contact, and collectively equal to the diameter of the bolt, that the mutual hold of the threads exceeds the strength either of the bolt or nut; and therefore that the bolt is more likely to break in two, or the nut to burst open, rather than allow the bolt to draw out of the hole, from the thread stripping off.

When screws fit into holes tapped directly into the castings or other parts of mechanism, it is usual to allow still more threads to be in contact, even to the extent of two or more times the diameter of the screw, so as to leave the preponderance of strength greatly in favor of the hold; that the screw, which is the part more easily renewed, may be nearly certain to break in two, rather than damage the castings by tearing out the thread from the tapped hole.

Should the internal and external screws be made in the same material, that is both of wood, brass or iron, the nut or internal screw is somewhat the stronger of the two. For example, in the screw Fig. 515, the base of the thread is a continuous angular ridge, which occupies the whole of the cylindrical surface represented by the dotted line. Therefore the force required to strip off the thread from the bolt, is nearly that required to punch a cylindrical hole of the same diameter and length as the bottom of the thread; for in either case the whole of the cylindrical surface has to be stripped or thrust off laterally, in a manner resembling the slow, quiet action of the punching or shearing engine.

But the base of the thread in the nut, is equal to the cylindrical surface measured at the *top* of the bolt, and consequently, the materials being the same, and the length the same, considering the strength of the nut for Fig. 515 to be 75, the strength of the bolt would be only 55, or they would be respectively as the diameters of the top and bottom of the thread; although when the bolt protrudes through the nut, the thread of the bolt derives a slight additional strength, from the threads situated *beyond* the nut, and which serve as an abutment.

It is however probable that the angular thread will not strip off at the base of the threads, either in the screw or nut, but will break through a line somewhere between the top and bottom: but these results will occur alike in all, and will not therefore materially alter the relation of strength above assumed.

Comparing Figs. 514, 515, and 516, upon the supposition that the bolts and nuts exactly fit or correspond, the strengths of the three nuts are alike, or as 75, and those of the bolts are as 65, 55, and 35, and therefore the advantage of hold lies with the bolt of finest thread; as the finer the thread, the more nearly do the bolt and nut approach to equality of diameter and strength.

Supposing, however, for the purpose of explanation, that instead of the screws and nuts being carefully fitted, the screws are each one-tenth of an inch smaller than the diameters of the respective taps employed in cutting the three nuts; Fig. 514 would draw entirely out without holding at all; the penetration and hold of Fig. 515 would be reduced to half its proper quantity; and that of Fig. 516 to three-fourths; and the last two screws would strip at a line more or less elevated above the base of the thread, and therefore the more easily than if the diameters exactly agreed.

The supposed error, although monstrous and excessive, shows that the finer the thread, the greater also should be the accuracy of contact of such screws; and it also shows the impolicy of employing fine threads in those situations where they will be subjected to frequent screwing and unscrewing, and also to much strain. As although when they fit equally well, fine threads are somewhat more powerful than coarse, in hold as well as in mechanical power; the fine are also more subject to wear, and they receive from such wear, a greater and more rapid depreciation of strength, than threads of the ordinary degrees of coarseness.

In a screw of the same diameter and pitch, the ultimate strength is diminished in a twofold manner by the increase of the *depth* of the thread; first it diminishes the traverse area of the bolt, which is therefore more disposed to break in two; and secondly, it diminishes the individual strength of each thread, which becomes a more lofty triangle erected on the same base, and is therefore more exposed to fracture or to be stripped off.

But the durability of machinery is in nearly every case increased by the enlargement of the *bearing surfaces*, and therefore as the thread of increased depth presents more surface-bearing, the deep screw has constantly greater durability against the friction or wear, arising from the act of screwing and unscrewing. The durability of the screw becomes in truth a fourth condition, to be borne in mind collectively with those before named.

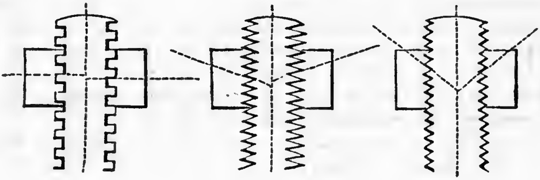
It frequently happens that the diameters of screwed works are so considerable, that they can neither break nor burst after the manner of bolts and nuts; and if such large works yield to the pressures applied, the threads must be the part sacrificed. If the materials are crystalline, the thread crumbles away, but in those which are malleable and ductile, the thread, instead of stripping off as a wire, sometimes bends until the resisting side presents a perpendicular face, then overhangs, and ultimately curls over: this disposition is also shown in the abrasive wear of the screw before it yields.

Comparing the square with the angular thread in regard to friction, the square has less friction, because the angular edges of the screw and nut, mutually thrust themselves into the opposite angular grooves in the manner of the wedge. The square thread has also the advantage of presenting a more direct thrust than the angular, because in each case the resistance is at right angles to the side of the thread, and therefore in the square thread the resistance is very nearly in the line of its axis, whereas in the angular it is much more oblique.

From these reasons, the square thread is commonly selected for presses, and for regulating screws, especially those in which rapidity of pitch, combined with strength, is essential; but as regards the ordinary attachments in machinery, the grasp of the angular thread is more powerful, from its pitch being generally about as fine again, and, as before explained, angular screws and nuts are somewhat more easily fitted together.

The force exerted in bursting open a nut, depends on the angle formed by the sides of the thread, when the latter is considered as part of a cone, or as a wedge employed in splitting timber. For instance, in the square thread screw, the thread forms a line at right angles to the axis, and which is dotted in the figure 519; it is not therefore a cone, but simply compresses the nut, or attempts to force the metal before it. In the deep thread, Fig. 520, the wedge is obtuse, and exerts much less bursting effort than the acute cone represented in the shallow thread screw, Fig. 521; therefore, the shallower the angular thread, the more acute the cone, and the greater the strain it throws upon the nut. The transverse measure of nuts, whether they are square or hexagonal, is usually about twice the diameter of the bolt, as represented in the figures, and this in general suffices to withstand the bursting effort of the bolt.

Figs. 519 520 521.



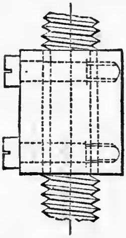
In the table of dimensions of nuts, in "Byrne's Engineer's Pocket Companion," the traverse measures decrease in the larger nuts; the breadth of a nut for a ½ inch bolt is stated as 1 inch, that for a 2½ inch bolt as four inches.

Those nuts, however, which are not used for grasping, but for the regulating screws of slides and general machinery, are made much thicker, so as to occupy as much of the length of the screw as two, three, or more times its diameter. This greatly increases their surface-contact and durability.

Should it be required to be able to compensate the nut, or to re-adapt it to the lessened size of the screw when both have been worn, the nut is made in two parts and compressed by screws, or it is made elastic so as to press upon the screw. The nuts for angular threads are divided diametrically and reunited by two or more screws, as in Fig. 522—in fact, like the semi-circular bearings of ordinary shafts; as then by filing a little of the metal away from between the two halves of the nut, they may be closed upon the angular ridges of the thread.

The nuts of square threads by a similar treatment would, on being closed, fit accurately upon the outer or cylindrical surface of the square thread screw; but the lateral contact would not be restored; these nuts are, therefore, divided transversely, as shown in Fig. 523, or they are made as two detached nuts placed in contact. When, therefore, a small quantity is removed from between them with the file, or that they are separated by one or more thicknesses of paper, the one-half of the nut bears on the right hand side of the square worm, the other on the left.

Figs. 522



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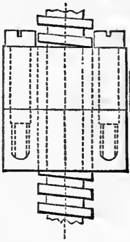

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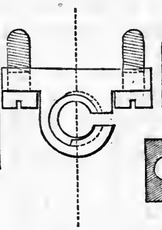

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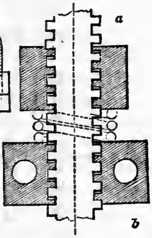


Either of these methods removes the "*end play*," or the "*loss of time*," by which expression is meant that partial revolution to and fro which may be given to a worn screw without producing any movement or traverse in the slide upon which the screw acts. It is usual, before cutting the nuts in the lathe or with screw traps, to divide the nuts, and to reunite them with soft solder, or it is better to hold them together with the permanent screws whilst cutting the thread.

But the screws of slides are very apt to become most worn in the middle of their length, or at the one end, leaving the other parts nearly of their original size. It is then best to replace them by new screws, as the former method of adjusting the nuts cannot be used; although recourse may occasionally be had to some of the various methods of *springing*, or the elastic contrivances commonly employed in delicate mathematical and astronomical instruments. Although these should be perfectly free from shake or uncertainty of motion, they do not in general require the firm, massive, unyielding structure of engineering works and machinery.

Two kinds of the elastic nuts alone are shown; in Fig. 524 the saw-cut extends throughout the length of the nut, but sometimes a portion in the middle is left uncut; the nut is usually a little *set-in*, or bent inwards with the hammer, so as to press upon the screw. In Fig. 525 the two pieces *a* and *b* bear against opposite sides of the threads, and *b* only is fixed to the slide as in Fig. 523; the correction is now accomplished by interposing loosely around the screw and between the halves of the nut, a spiral spring sufficiently strong to overcome the friction of the slide upon the fittings; the same contrivance is variously modified, sometimes two or four spiral springs are placed in cavities parallel with the screw.

The slide resists firmly any pressure from *a* to *b*, as the fixed half of the nut lies firmly against the side of the thread presented in that direction, but the pressure from *b* to *a* is sustained alone by the spiral spring; when, therefore, the pressure exceeds the strength of the spring, the slide nevertheless moves endways to the extent of the misfit in the piece *b*, and which, but for the spring, would allow the slide to shake endways. In absolute effect the contrivance is equivalent to a single nut such as *b* alone, which, although possessing end play if pulled towards *b* by a string and weight, would always keep in contact with the one side of the worm, unless the resistance were sufficient to raise the weight. The method is therefore only suited to works requiring delicacy rather than strength, and the spring, if excessively strong, would constantly wear the two halves of the nut with injudicious friction and haste.

The several threads represented in Figs. 526 to 538 may be considered to be departures from the angular thread Fig. 526 and the square thread Fig. 535, which are by far the most common.

The choice of section is collectively governed: First, by the facility of construction, in which the plain angular thread excels. Secondly, by the best resistance to strain, which is obtained in the square thread. Thirdly, by the near equality of strength in the internal and external screw. For similar materials the space and thread should be symmetrical, as in the square thread, and in Figs. 526 to 530, which screws are proper for metal works generally; whereas in dissimilar materials the harder of the two should have the slighter thread, as in the iron screws, Figs. 531 to 534, intended to be screwed into wood; the substance of the screw is supposed to be below the line, and the head to the right hand. Fourthly, by the resistance to accidental violence, either to the screws, or to the screwing tools, which is best obtained by the rejection of sharp angles or edges, as in the several rounded threads. This fourfold choice of section, like every other feature of the screw, is also mainly determined by experience alone.

Fig. 526, in which the angle is about 60 degrees, is used for most of the screws made in wood, whether in the screw-box or the turning lathe; and also for a very large proportion of the screw bolts of ordinary mechanism. Sometimes the points of the screw tool measure nearly 90 degrees, as in the shallow thread, Fig. 527, used for the thin tubes of telescopes; or at other times they only measure 45 degrees, as in the very deep thread, Fig. 528, used for some mathematical and other instruments. The angles represented may be considered as nearly the extremes.

In originating accurate screws, the angular thread is always

Sections derived from the ANGULAR THREAD.

Figs.

526


527


528

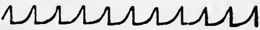

529


530


531


532


533


534


Sections derived from the SQUARE THREAD.

535


536


537


538


selected, because the figure of the thread is still maintained, whether the tool cut on one or on both sides of the thread, in the course of the correctional process.

Fig. 529 is the angular thread in which the ridges are more or less truncated to increase the strength of the bolt; it may be viewed as a compound of the square and angular thread.

Fig. 530 is the angular thread in which the tops and bottoms are rounded; it is much used in engineering works, and is frequently called a round thread.

In Fig. 531 the thread is more acute, and truncated only at the bottom of the screw. This is used for joinery-work, and greatly increases the hold upon the wood. Fig. 532 is obviously derived from Fig. 531, and is used for the same purpose.

In Fig. 533, which is also a screw for wood, the face that sustains the hold is rectangular, as in the square thread—the other is beveled.

Fig. 534 is the form of the patent wood screw sometimes called the German screw. It is hollowed, to throw the advantage of bulk in favor of the softer material, or the wood, the head of which is supposed to be on the right hand. In the last four figures, the substance of the screw is imagined to be situated below the line, and that of the wood above.

The screws which are inserted into wood are generally made taper, and not cylindrical, in order that they may cut their own nut or internal thread. Some of them are pointed, so as to penetrate without any previous hole being made—they merely thrust the fibres of wood on one side. Screws hold the most strongly in wood when inserted horizontally as compared with the position in which the tree grew, and least strongly in the vertical position.

Fig. 535 represents the ordinary square thread screw. The space and thread are mostly of equal width, and the depth is either equal to the width, or a trifle more, say one-sixth.

Fig. 536 is a departure from Fig. 535, and has been made for presses; and Fig. 537 has obviously grown out of the last from the obliteration of the angles. Various proportions intermediate between Figs 537 and 530 are used for round threads.

In some cases where the screw is required to be rapid, one single shallow groove is made of angular, square, or circular section, leaving much of the original cylinder standing, as in Fig. 538. For very slight purposes a pin only is fitted to the groove to serve as the nut. Should the resistance be greater, many pins, or a comb may be employed, and this was the earliest form of nut; otherwise a screwed nut may be used with a single thread. But when the greatest resistance is required the surface bearing of the nut is extended by making the thread double, triple, etc., by cutting one or more intermediate grooves and a counterpart nut.

The nuts or boxes of very coarse screws for presses are now mostly cut in the lathe, although, when the screwing tools were less perfectly understood, the nuts were frequently cast. Sometimes lead, or alloys of similar fusibility, were poured in betwixt the screw and the framework of the machinery; but for nuts of brass and gun-metal, sand moulds were formed. The screw was always warmed to avoid chilling the metal; and for brass, it was sometimes heated to redness and allowed to cool, so as slightly to oxidize the surface and lessen the disposition to a union or natural soldering of the screw and nut. It was commonly necessary to stretch the brass by an external hammering, to counteract the shrinkage of the metal in the act of cooling, and to assist in releasing from the screw the nut cast upon it in this manner. The mode is by no means desirable, as the screw is exposed to being bent from the rough treatment, and to being ground by particles of sand adhering to the brass.

The tangent screws used for screw wheels have mostly angular or truncated angular threads, Fig. 529, as screws absolutely square cannot be fitted with good contact and freedom from shake between the thread and teeth; and probably the same rules by which the teeth of ordinary wheels and racks are reciprocally set out, should be also applied to the delineation of the teeth of worm wheels, and the threads or teeth of their appropriate screws.

Tangent screws are occasionally double, triple, or quadruple, in order that 2, 3, or 4 teeth of the wheel may be moved during each revolution of the screw. In the Piedmont silk-mills, this principle is carried to the extreme, as the screw and wheel become alike, and revolve turn for turn; the teeth, supposing them to be 20, are then identical with those of a 20 thread screw, the *angular* coils of which cross the axis at the angle of 45°, that is, when the shafts lie at right angles to each other; other proportions and angles may be adopted. In reality they fulfil the office of bevel wheels, or rather of skew-bevel wheels, in which latter also, the axes, from being in different planes, may cross each other; so that the skew-bevel wheels may be in the centre of long shafts, but which cannot be the case in ordinary bevel wheels, the teeth of which lie in the same plane as the axis of the wheel. The Piedmont wheels act with a very reduced extent of bearing or contact surface, and a considerable amount of the sliding action of screws, which is disadvantageous in the teeth of wheels, although inseparable from all those with inclined teeth, and which are indeed more or less distant modifications of the screw.

When the obliquity of the teeth of worm wheels is small, it gives a very smooth action, but at the expense of friction; but in ordinary toothed wheels, the teeth are exactly square across or in the plane of the axis, and the aim is to employ rolling contact, with the greatest possible exclusion of sliding, from amongst the teeth.

Having treated somewhat in detail the different forms of screws, and the circumstances which adapt them to their several purposes, I have now to consider some of the inconveniences which have unavoidably arisen from the indefinite choice of proportions in ordinary screws, and also some of the means that have been proposed for their correction. The slight discussion of the more important of these topics will permit the introduction of various additional points of information on this almost inexhaustible subject, the screw.

No inconvenience is felt from the dissimilarities of screws, so long as the *same* screwing tools are always employed in effecting repairs in, or additions to, the *same* works. But when it is considered, how small a difference in either of the measures will mar the correspondence of the screw and nut; and further, the very arbitrary and accidental manner, in which the proportions of screwing apparatus have been determined by a variety of individuals, to suit their particular wants, and without any attempt at uniformity of practice (sometimes, on the contrary, with an express desire to be peculiar), it is perhaps some matter of surprise when the screws made in different establishments properly agree. Indeed their agreement can be hardly expected, unless they are derived from the same source, and that some considerable pains are taken not to depart from the respective proportions first adopted.

In a few isolated cases this inconvenience has been partially remedied by common consent and adoption, as in the so-called *air-pump thread*, which is pretty generally used by the makers of pneumatic apparatus; and to a certain degree also in some of the screws used in gas-fittings and in gun-work. But the non-existence of any common standard or scale, enhances both the delay and expense of repairs in general mechanism, and leads to the occasional necessity for making additional sizes of tools to match particular works, however extensive the supply of screw apparatus.

The perplexity is felt in a degree especially severe and costly, as regards marine and locomotive engines, which from necessity, have to be repaired in localities far distant from those in which they were made; and therefore require that the packet station, or railway depot, should contain sets of screwing tackle, corresponding with those used by every different manufacturer whose works have to be dealt with; otherwise, both the delay and expense are from necessity aggravated.

Some engineers suggested that for steam machinery and for the purpose of engineering in general, "an uniform system of screw threads" should be adopted. The following table may be considered as a mean between the different kinds of threads used by the leading engineers:

Table for Angular Thread Screws.

Diameters in inches	¼	5/16	⅜	7/16	½	⅝	¾	⅞	1″	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2″
Nos. of threads to the inch . .	20	18	16	14	12	11	10	9	8	7	7	6	6	5	5	4½	4½
Diameters in inches	2¼	2½	2¾	3″	3¼	3½	3¾	4″	4¼	4½	4¾	5″	5¼	6½	5¾	6″	
Nos. of threads to the inch . .	4	4	3½	3½	3¼	3¼	3	3	2⅞	2⅞	2¾	2¾	2⅝	2⅝	2½	2½	

In selecting this scale, the following very judicious course was adopted: An extensive collection was made of screw-bolts from the principal workshops, and the average thread was carefully observed for different diameters. The ¼ inch, ½ inch, 1 and 1½ inch, were particularly selected, and taken as the fixed points of a scale by which the intermediate sizes were regulated, avoiding small fractional parts in the number of threads to the inch. The scale was afterwards extended to 6 inches. The pitches thus obtained for angular threads were as above:

Above the diameter of 1 inch the same pitch is used for two sizes, to avoid small fractional parts. The proportion between the pitch and the diameter varies throughout the entire scale.

Thus the pitch of the ¼ inch screw is ⅕th of the diameter; that of the ½ inch ⅙th, of the 1 inch ⅛th, of the 4 inches 1/12th, and of the 6 inches 1/15th.

The depth of the thread in the various specimens is then alluded to. In this respect the variation was greater than in the pitch. The angle made by the sides of the thread being taken as an expression for the depth, the mean of the angle in 1 inch screws was found to be about 55°, which was also nearly the mean in screws of different diameters. Hence it was adopted throughout the scale, and a constant proportion was thus established between the depth and the pitch of the thread. In calculating the former, a deduction must be made for the quantity rounded off, amounting to ⅓d of the whole depth, *i. e.* ⅙th from the top, and ⅙th from the bottom of the thread. Making this deduction, the angle of 55° gives for the actual depth rather more than ⅗ths, and less than ⅔ds of the pitch.

As regards the smaller mechanism, made principally in brass and steel, such as mathematical instruments and many others, the screws in the above scale below half an inch diameter are admitted to be too coarse; and the acute angular threads which are not rounded are decidedly to be preferred, from their greater delicacy and durability,—that is, when their strengths are proportioned to the resistances to which they are exposed. In these respects the following table may be considered preferable:

Table for Small Screws of Fine Angular Threads.

Diameters in vulgar fractions of the inch . .	$\frac{1}{2}$	$\frac{15}{32}$	$\frac{7}{16}$	$\frac{13}{32}$	$\frac{3}{8}$	$\frac{11}{32}$	$\frac{5}{16}$	$\frac{9}{32}$	$\frac{1}{4}$	$\frac{7}{32}$	$\frac{1}{5}$
Diameters in hundredths of the inch nearly	.50	.47	.44	.41	.37	.34	.31	.28	.25	.22	.20
Number of threads to the inch	16	18	18	20	20	24	24	28	28	32	36
Diameters in hundredths of the inch	.18	.16	.14	.12	.10	.09	.08	.07	.06	.05	.04
Numbers of threads to the inch	36	40	40	48	48	56	56	64	72	80	100

The tables above given, and which have been *selected* and not *calculated*, will serve to explain the inapplicability of the mode of calculation proposed in various popular works,—namely, for angular thread screws, to divide the diameter by 8 for the pitch, when, it is said, such screws will all possess the angle of 3½ degrees nearly; and for square threads to divide by 4, thus giving an angle of 7 degrees nearly; therefore

Angular thread screws of	8	6	4	2	1	$\frac{1}{2}$	$\frac{1}{4}$	inches diameter
would have pitches of	1	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$	inches rise
or rates of	1	$1\frac{1}{3}$	2	4	8	16	32	threads per inch,
which differ greatly from		$2\frac{1}{2}$	3	$4\frac{1}{2}$	8	12	20	Whitworth's observational numbers.

By the use of the constant divisor 8, the one-inch screw agrees with Whitworth's table, the extremes are respectively too coarse and too fine; as instead of 8 being employed, the actual divisors vary from about 5 to 16, and therefore a theoretical mode would probably require a logarithmic scheme. But were this followed out with care, the adjustment of the fractional threads so obtained, for those of whole numbers, would completely invalidate the precision of the rule; and the result would not be in any respect better than when adjusted experimentally, as at present.

There is little doubt that if we could entirely recommence the labors of the mechanist, or if we could sweep away all the screwing tools now in use, and also all the existing engines, machines, tools, instruments, and other works, which have been in part made through their agency, these proposed scales, or others not greatly differing from them (as the choice is in great measure arbitrary), would be found of great general advantage; the former for the larger, the latter for the smaller works. But until all these myriads of objects are laid on one side, or that repairs are no longer wanted in them, the old tools must from absolute necessity be retained, in addition to those proposed in these or any other schemes. It would be of course highly judicious in *new* manufacturing establishments to adopt such conventional scales, as they would, to that extent, promote this desirable but almost impracticable end, namely, that of unity of system; but which, although highly fascinating and apparently tenable, is surrounded by so many interferences that it may perhaps be considered both as needless and hopeless to attempt to carry it out to the full, or to make the system absolutely universal; and some of the circumstances which affect the proposition will be now briefly given.

First, *agreement with* STANDARD MEASURE, *although convenient, is not indispensable.* It may be truly observed, that as regards the general usefulness of a screw such as Fig. 516, which was supposed to measure $\frac{3}{4}$ inch diameter, and to have 10 threads per inch, it is nearly immaterial whether the diameter be three or four hundredths of an inch larger or smaller than $\frac{3}{4}$ of an inch; or whether it have 9, $9\frac{1}{16}$th, $9\frac{3}{4}$, $10\frac{1}{2}$, or 11 threads per inch, or any fractional number between these; or whether the thread be a trifle more or less acute, or that it be slightly truncated or rounded; so long as the threads in the screw and nut are but truly helical and alike, in order that the threads mutually bear upon each other at every part; that is, as regards the simple purpose of the binding screw or bolt, namely, the holding of separate parts in firm contact. And as the same may be said of every screw, namely, that a small variation in diameter or pitch is commonly immaterial, it follows that the good office of a screw does not depend on its having any assigned relation to the standard measure of this or any other country.

Secondly, *The change of system would cause an inconvenient increase in the number of screwing tools used.* Great numbers of excellent and useful screws, of accidental measures, have been made by various mechanicians; and the author hopes to be excused for citing the example with which he is most familiar.

Between the years 1794 and 1800 I. I. Holtzapffel made a few varieties of taps, dies, hobs, and screw tools, after the modes explained at pages 457 and 458. These varieties of pitch were ultimately extended to twelve kinds, of each of which was formed a deep and shallow hob or screw tool-cutter. These, when measured many years afterwards, were found nearly to possess in each inch of their length the threads and decimal parts that are expressed in the following table:

Approximate Values of I. I. Holtzapffel's Original Screw Threads.

Number	1	2	3	4	5	6	7	8	9	10	11	12
Threads in 1 inch .	6.58	8.25	9.45	13.09	16.5	19.89	22.12	25.71	28.88	36.10	39.83	55.11

The angle of the deep threads is about 50 degrees: of the shallow 60 degrees.

This irregularity of pitch would not have occurred had the screw-lathe with change-wheels been then in use; but such was not the case. For a long series of years I. I. Holtzapffel (in conjunction with his partner, I. G. Deyerlein, from 1804 to 1827) made, as occasion required, a large or small screw, a coarse or fine, a shallow or deep thread, and so forth. By which accumulative mode, their series of working taps and dies, together with screw tools, gauges, chucks, carriers, and a variety of subordinate apparatus, became extended to not less than one hundred varieties of all kinds.

About one-third of these sizes have been constantly used, up to the present time, both by H. & Co., and by other persons to whom copies of these screw tackles have been supplied, and consequently many thousands of screws of these kinds have been made: this implies the continual necessity for repairs and alterations in old works, which can only be accomplished by retaining the original sizes.

Since the period at which H. & Co. made their screw lathe, they have employed the aliquot threads for all screws above half an inch; indeed, most of these have also been cut in the screw lathe. To have introduced the same method in small binding screws which are not made in the screw lathe, but with the diestocks and chasing tools, would have doubled the number of their working-screw tackle, and the attendant apparatus; with the risk of confusion from the increased number, but without commensurate advantage as regards the purposes to which they are applied.

Doubtless the same reasons have operated in numerous other factories, as the long existence of good useful tools has often lessened, if not annulled, the advantage to be derived from a change which refers more immediately to engineering works; and in which a partial remedy is supplied, as steam-engines, etc., are frequently accompanied with spare bolts and nuts, and also with corresponding screw apparatus, to be employed in repairs; the additional cost of such parts being insignificant, compared with the value of the machinery itself.

Thirdly: *Unless the standard sizes of screws become inconveniently numerous, many useful kinds must be omitted, or treated as exceptions.* For instance, in ordinary binding screws, more particularly in the smaller sizes, two if not three degrees of coarseness should exist for every diameter, and which might be denominated the coarse, medium, and fine series; and again, particular circumstances require that threads should be of shallow or of deep angular sections, or that the threads should be rounded, square, or of some other kinds; in this way alone, a fitness for all conditions would inconveniently augment the number of the standards.

In many cases besides, screws of *several* diameters are made of the *one* pitch. In order, for example, that the hole when worn may be tapped afresh, and fitted with screws of the same pitch or thread but a trifle larger; or that a partially worn screw may be corrected with the dies or in the lathe, and fitted with a smaller nut of the same pitch. A succession of taps of the same pitch also readily permits a larger screw to be employed, when that of smaller diameter has been found to break, either from an error of judgment in the first construction of the machine, or from its being accidentally submitted to a strain greater than it was intended ever to bear.

It is also in some cases requisite to have right and left-hand screws of the same pitch, that, amongst other purposes, they may effect simultaneous yet opposite adjustments in machinery, as in some universal chucks: and also some few screws, the threads of which are double, triple, quadruple, and so forth, for giving to screws of small diameters considerable rapidity of pitch or traverse, or a fixed ratio to other screws associated with them, in the same piece of mechanism.

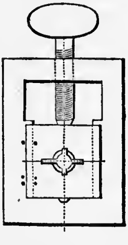
Under ordinary and proper management, the production of a number of similar pieces may be obtained with sufficient exactitude, by giving to the *tool* some constant condition. For example, a hundred nuts tapped with the same tap, will be very nearly alike in their thread; and a hundred screws passed through the hole of a screw-plate, will similarly agree in size, because of the nearly constant dimensions of the tools, for a moderate period.

In practice, the same relative constancy is given to the dies of die-stocks and bolt screwing engines, and partly so to the tools of the screw-cutting lathe. Sometimes the pressure or adjusting screw has graduations or a micrometer; and numerous contrivances of eccentrics, cams, and stops, are employed to effect the purpose of bringing the die or turning-tool to one constant position, for each succeeding screw; these matters are too varied and general to require more minute notice. Part of such modes may serve sufficiently well for ten, or even a hundred screws, provided that no accident occur to the tool; but if it were attempted to extend this mode to a thousand, or a hundred thousand pieces, the same tool could not, even without accident, endure the trial; it would have become not only unfit for cutting, but also so far worn away as to leave the last of the works materially larger than the first.

In respect to screws, the instrument, the size of which claims the most importance, is perhaps the plug-tap, or that which removes the last portion of the material, and therefore determines the diameter of the internal thread; but as the tap is continually, although slowly, wearing smaller, the first and the last nut made with it unavoidably differ a little in size. It is on account of the wearing of the tap, amongst other circumstances, that when screws and nuts are made in large numbers, and are required to be capable of being interchanged, it becomes needful to make a small allowance for error, or to make the screws a trifle smaller than the nuts.

In order to retain the size of the taps used by Holtzapffel & Co. they some years ago made a set of original taps exactly of the size of the proposed screws, and to be called A; these, when two or three times used to rub off the burrs, were employed for cutting regulating dies B, of the form of Fig. 539, with two shoulders, so that the dies could be absolutely closed, and yet leave a space for the shaving or cuttings. In making all their plug-taps, they are first prepared with the ordinary shop tools, until the taps are so nearly completed, that, grasped between the regulating dies B, the latter close within the fortieth or fiftieth of an inch, therefore leaving the dies B next to nothing to perform in the way of cutting, but only the office of regulating the diameter of the working plug-taps. Should the dies B meet with any accident, the taps A, which have to this stage been only used for one pair of regulating dies, exist for making repetitions of B. This method has been found to fulfil its intended purpose very effectually for several years, but at the same time it is not proposed to apply this or any other system universally.

Fig. 539.



In conclusion, it may be said that by far the most important argument in favor of the adoption of screws of aliquot pitches applies to steam-machinery and similar large works, and that, principally, because it brings all such screws within the province of the screw-lathe with change-wheels, which has become, in engineering establishments and some others, a very general tool. This valuable tool alone renders each engineer in a great measure independent of his neighbor, as screws of 2, 2¼, 2½, 3, 10, or 20 threads in the inch, are readily measured with the common rule, and copied with the screw-wheels, and a single-pointed tool, or an ordinary comb or chasing tool with many points.

And therefore, with the modern facility of work, were engineers severally to make their screw tackle from only the *written* measures of any conventional table, they would be at once abundantly within reach of the adjustment of the tools, and that without any standard guages; the strict introduction of which would almost demand that all the tools made in uniformity with them should emanate from one centre, or be submitted to some office for inspection and sanction—and this would be indeed to buy the *occasional* advantage at too dear a rate.

It must, however, be unhesitatingly granted, that the argument applies but little, if at all, to a variety of screws which from their smaller size are not made in the screw lathe, but with die-stocks and the hand-chasing tools only; and which are employed in branches of art that may be considered as almost isolated from one another, and therefore not to require uniformity.

For instance, the makers of astronomical, mathematical, and philosophical instruments, of clocks and watches, of guns, of locks and ironmongery, of lamps and gas apparatus, and a multitude of other works, possess, in each case, an amount of skill which applies specifically to these several occupations; so that unless the works made by each are returned to the absolute makers for reparation, they are at any rate sent to an individual engaged in the same line of business.

Under these circumstances, it is obvious that the gun-makers, watchmakers, and others, would derive little or no advantage from one system of threads prevailing throughout all their trades; in many of which, as before noticed, partial systems respectively adapted to them already exist. The means employed by the generality of artisans in matching strange threads, are, in addition, entirely independent of the screw lathe, and apply equally well to all threads, whether of aliquot measures or not; as it is usual to convert one of the given screws, if it be of steel, into a tap, or otherwise to file a screw tool to the same pitch by hand, wherewith to strike the thread of the screw or tap; and when several screws are wanted, a pair of dies is expressly made.

But at the same time that, from manifold considerations, it appears to be quite unnecessary to interfere with so many existing arrangements and interests, it must be freely admitted that advantage would ultimately accrue from making *all new screws of aliquot measures;* and which, by gradually superseding the old irregular threads, would tend eventually, although slowly, to introduce a more defined and systematic arrangement in screw tackle, and also to improve their general character.

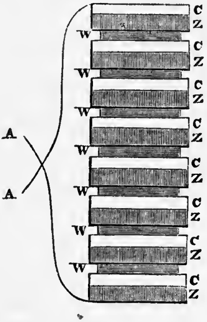
CHAPTER XXIV.

HISTORY OF THE ART OF ELECTRO-METALLURGY.

In reviewing the rise and progress of any discovery in the arts and sciences, particularly of one connected with the application of chemistry to manufacturing purposes, there are two circumstances which almost invariably demand especial notice. The first is, that the discovery has been the result of accidental observation—a fact eliminated during investigations undertaken for other purposes—rather than the result of a direct endeavor to make the discovery. The second is, that, after the discovery has been made known, it is found that many previously published experiments exhibited results which bore more or less directly upon the subsequent discovery, and which are consequently sometimes cited to detract from the merit of the discoverer, and the originality and value of his discovery. The following historical sketch will show that these observations directly apply to the discovery of the art of Electro-Metallurgy:

Volta's Discovery.—At the beginning of the year 1800, Professor Volta invented the apparatus which has been named after him, the *Voltaic Pile.* As originally constructed by Volta, it consisted of an equal number of round pieces of zinc, silver, and pasteboard—the zinc and silver pieces being each about the size of a penny, and those of pasteboard a little smaller; the pasteboard pieces were soaked in a solution of common salt, and then with the metals were piled in the following manner:—zinc, silver, pasteboard; zinc, silver, pasteboard; and so on, in the same order, till all the pieces, amounting to upwards of a hundred, were piled upon each other, the uppermost plate being of silver, and, as already stated, the undermost of zinc; these exterior plates, to each of which a wire is attached, form the terminals or poles of the pile. Fig. 540 shows the construction of the Pile.

Fig. 540



C—Silver Plate.
Z—Zinc Plate.
W—Pasteboard between.
AA—The Wires in connection with the Terminal Plates.

By this instrument all the phenomena of an ordinary battery can be produced.

Chemical Decompositions by the Pile.—This discovery placed in the hands of the philosopher an instrument by which he could make such investigations as had never previously been conceived to be possible. Nicholson, for example, effected the decomposition of water and of several metallic salts: and observed, as a general rule, that in the decomposition of the latter the metal of the salt was reduced upon the zinc terminal of the pile.

First Battery.—Cruikshanks, of Woolwich, with a view to facilitate the construction of the pile, employed square plates of copper and zinc, soldered together two and two; these were cemented, by means of pitch, into a wooden trough, at the distance of about a quarter of an inch from each other, and so arranged that the zinc plates all faced one end of the trough, and the copper plates the other end. The spaces or cells between every pair of plates were filled with a solution of common salt, or a mixture of acid and water, which produced the same effect as the moist cards in the pile. The trough thus charged with its metals and solution acted the same part as the Voltaic pile. This was the first of those instruments now so well known as the "*galvanic battery.*"

Decomposition by the Battery, and its Application.—Cruikshanks attached a silver wire to each terminal of his battery, and the other ends of these wires he placed in a glass tube. When this tube was filled with a solution of acetate of lead, and the electric current was allowed to pass through it for some time, metallic lead was found deposited upon the wire attached to the zinc terminal of the battery. Solutions of sulphate of copper, nitrate of silver, and several other salts, were tried with similar results. The metals, as Cruikshanks expressed it, were "*revived*," and that so completely, as to suggest to him the application of the battery to the analysis of minerals. While Cruikshanks, Nicholson, and several other gentlemen in this country were making investigations and applications of voltaic electricity, upon the Continent, Brugnatelli, Fourcroy, Vauquelin, and Thenard were making similar investigations, and obtaining similar results.*

DEPOSITION OF METALS UPON OTHERS.—Brugnatelli, in his Annals of Chemistry, gives a long list of experiments on the decomposition of salts by the pile. He observed the transfer of the elements of a decomposed compound from one pole to another—that silver, when deposited upon platinum, preserved all its metallic brightness—and that, when copper or zinc were used in connection with the silver terminal, or positive pole, of the pile for decomposing salts, these metals were dissolved, and deposited upon the negative pole. The researches of Fourcroy, Vauquelin, and Thénard gave the same results.

GILDING.—In 1805, Brugnatelli, in a letter to Van Mons, mentions, among other scientific facts, that "he had gilt in a complete manner two large silver medals, by bringing them, by means of a steel wire, into communication with the negative pole of a voltaic pile, and keeping them one after the other immersed in ammoniuret of gold newly made and well saturated."†

EARLY OPINIONS CONCERNING ELECTRO-DECOMPOSITION.—The above few instances are selected from a host of a similar kind upon electro-decomposition, to show that the fact of the deposition of metals by an electric current was familiar to philosophers at this early stage of the history of galvanism; that nevertheless, the phenomenon was never thought of further than as a curious action of electricity when passing through a solution containing metals; and that although these effects were produced again and again, it was only to prove and enforce certain speculative views respecting the electric fluid. As for example, Brugnatelli had formed an idea that the electric fluid had some relations to an acid which he called the *electric acid*, and he therefore viewed the decomposition of solutions, and the obtaining of the metal, which he termed an *electrate*, as the result of the combination of this electric acid with the metal of the solution. In one of his memoirs upon this subject, he says—"Gold and platinum are not sensibly altered by the electric matter which passes through them, though it often

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* **Wilkinson, Elements of Galvanism, vol. ii. 1804.**

† **Phil. Magazine, 1805.**

happens that the electric current deposits on gold a stratum of zinc, copper, mercury, or silver, according to whichever of these metallic bodies it traverses."* In the same paper it is several times stated that gold and platina do not seem sensibly affected by the *electric acid.* And, when he communicated the above experiment of gilding the two medals, his object was to show that he had now found that the electric acid had also the power of acting upon gold; and the publication of these results and observations excited no other idea in the minds of philosophers of that period than that they were mere scientific curiosities. The editor of the *Philosophical Magazine* appended the following note to the extract already quoted:—"The result here detailed reminds me of one, somewhat similar, which took place during some experiments performed some years ago in the Askesian Rooms. Some gold leaf was put loose upon a new piece of copper coin, which was then brought into the circuit of the pile. A part of the gold was inflamed, and other portions adhered to the surface of the copper, as completely as if they had been attached by any common gilding process."†

HOW THESE RESULTS AFFECT THE DISCOVERY.—We have been particular in thus noticing the observations of the first pioneers in electro-chemistry, because these and similar facts of later date have been brought prominently forward by writers upon electro-metallurgy, with the apparent intention to detract from the merit due to the discoverers of the new art; founding their objection on the ground that the *principle* upon which the discovery is founded is not new. "Electro-metallurgy," says Mr. Smee, "may be said to have its origin in the discovery of the constant battery by Professor Daniell, for in that instrument the copper is continually reduced upon the negative plate." And again, when speaking of Daniells' battery, he says—"Mr. M. De la Rue experimented on its properties, and found the copper plate also covered with a coating of metallic copper, which is continually being deposited; and so perfect is the sheet of copper thus formed, that being stripped off, it has the counterparts of every scratch of the plate on which it is deposited."‡

Doubtless these experiments border very closely upon the discovery; but yet they have no more claim to serve as dates to its origin than those we have been referring to. But if it be necessary that an originating experiment must have a resemblance to that which it suggests—such as Daniell's battery; and the single cell of electro-metallurgy—why omit to refer to Dr. Wollaston's earlier experiments of 1801? He says—"If a piece of silver, in connection with a more positive metal, be put into a solution of copper, the silver is coated over with the copper, which coating will stand the operation of burnishing."§ But in our opinion none

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* Brugnatelli, Annals of Chemistry, vol. xviii., and Wilkinson, vol. ii.
† Phil. Mag., 1805.
‡ Smee, Elements of Electro-Metallurgy, 2d Edition, 1843.
§ Philosophical Transactions, 1801.

of these results originated electro-metallurgy: the discovery of that art, although it is an application of such results as we have described, was as original on the part of the discoverers, and as unconnected with these results at the time it was made, as it would have been had the earlier observations never been published. The discovery seems to have been deduced from results which the discoverers had obtained in their own experiments, not even while searching for such a discovery but during investigations instituted for other purposes.

USE OF OBSERVED FACTS.—It must not be supposed that we depreciate the value of the published facts upon the decomposition of salts, nor that we overlook their relation to the discovery which followed; for the multiplication of facts, and the improvement of instruments for experimenting, enlarge our knowledge of the principles to be investigated or applied; they facilitate inquiry, and increase the number of observers. The circumstances connected with the discovery of ELECTRO-METALLURGY—of the application of the decomposing force of an electro current passing through a solution, will illustrate these observations.

SPENCER'S FIRST EXPERIMENTS.—Mr. Thomas Spencer, of Liverpool, states that, in 1837, while experimenting with a modification of a Daniell's battery, he used a penny piece instead of a plain piece of copper, as a pole. Copper was deposited from the solution upon it, and on removing the wire which attached the penny to the zinc plate he also pulled off a portion of the deposited copper, which he found to be an exact counterpart or mould of a part of the head and letters of the coin *as smooth and sharp as the original.* But this did not suggest to him any useful application, until sometime after he dropped, accidentally, a little varnish upon a slip of copper which he was about to use in the same way as he had used the penny piece. On finding that no deposit of copper took place on the parts where the varnish had dropped, he *then* conceived the idea of applying this principle to the arts, by coating a piece of copper with varnish or wax, and cutting a design through the wax or varnish, leaving the copper bare, and then depositing upon these parts, so that upon removing the varnish the design would be left in relief.

JACOBI'S EXPERIMENTS.—While Mr. Spencer was following up these ideas, the following paragraph appeared in the *Athenæum* for 4th May, 1839:

"*Galvanic Engraving in Relief.*—While M. Daguerre and Mr. Fox Talbot have been dipping their pencils in the solar spectrum, and astonishing us with their inventions, it appears that Professor Jacobi, at St. Petersburgh, has also made a discovery which promises to be of little less importance to the arts. He has found a method—if we understand our informant rightly—of converting any line, however fine, engraved on copper, into a relief, by galvanic process. The Emperor of Russia has placed at the Professor's disposal, funds to enable him to perfect his discovery."

In consequence of this announcement, Mr. Spencer, on the 8th of May, 1839, gave notice to the Liverpool Polytechnic Institution, that he should make a communication to them of his process for effecting results similar to those of Professor Jacobi. But Mr. Spencer appears to have changed his design of reading it to the above Institution, in order to have it read at the meeting of the British Association, which was to take place a short time after.

JORDAN'S EXPERIMENTS.—Meanwhile the announcement of the *Athenæum* was quoted in the *London Mechanics' Magazine* for May 11th, 1839, which brought forth a letter from Mr. C. J. Jordan, a book-printer, dated 22d May, 1839, and published on the 8th June of the same year in the *London Mechanics' Magazine*. In this letter Mr. Jordan describes his experiments upon the same subject, detailing the method of procuring electrotypes, and offering hints for their application which have since been acted upon with considerable success. The following is a copy of Mr. Jordan's letter, which was, no doubt, the first published description of the art in this country:

"*Engraving by. Galvanism.*

"Sir:—Observing in the last page of a recent Number of your Magazine, a notice extracted from the *Athenæum*, relative to a discovery of Professor Jacobi, its perusal occasioned the recollection of some experiments performed about the commencement of last summer, with the view of obtaining impressions from engraved copper plates, by the aid of galvanism, which led me to infer some analogy in principle with those of the Russian Professor, and may probably give me the right to claim priority in its discovery and application. These experiments were abandoned from the want of that most important element in pursuits of this nature—time; the writer's share of the said element being occupied in a manner more imperative than pleasing. I regret, however, not having made it the subject of an earlier communication, as this would have placed my pretensions beyond doubt; but, inasmuch as the notice alluded to is given from memory, and is undescriptive, while I may be enabled to exhibit the *modus operandi*, my assertion may be at least partially substantiated.

"It is well known to experimentalists on the chemical action of voltaic electricity, that solutions of several metallic salts are decomposed by its agency, and the metal procured in a free state. Such results are very conspicuous with copper salts, which metal may be obtained from its sulphate (blue vitriol), by simply immersing the poles of a galvanic battery in its solution, the positive wire becoming gradually coated with copper. This phenomenon of metallic reduction is an essential feature in the action of sustaining batteries, the effect, in this case, taking place on more extensive surfaces. But the form of voltaic apparatus which exhibits this result in the most interesting manner, and relates more immediately to the subject of the present communication, may be thus described:—It consists of a glass tube, closed at one extremity with a plug of plaster of Paris, and nearly filled with a solution of sulphate of copper; this tube and its contents are immersed in a solution of common salt. A plate of copper is placed in the first solution, and is connected, by means of a wire and solder, with a zinc plate which dips into the latter. A slow electric action is thus established through the pores of the plaster, which it is not necessary to mention here—the result of which is the precipitation of minutely crystallized copper on the plate of that metal, in a state of greater or less malleability according to the slowness or rapidity with which it is deposited. In some experiments of this nature, on removing the copper thus formed, I remarked that the surface in contact with the plate equalled the latter in smoothness and polish, and mentioned this fact to some individuals of my acquaintance. It occurred to me, therefore, that if the surface of the plate was engraved, an impression might be obtained. This was found to be the case; for, on detaching the precipitated metal, the most delicate and superficial markings, from the fine particles of powder used in polishing, to the deeper touches of a needle or a graver, exhibited their correspondent impressions in relief, with great fidelity. It is, therefore, evident that this principle will admit of improvement, and that casts and moulds may be obtained from any form of copper.

"This rendered it probable that impressions may be obtained from those other metals having an electro-negative relation to the zinc plate of the battery. With this view, a common printing-type was substituted for the copper plate, and treated in the same manner. This also was successful; the reduced copper coated that portion of the type immersed in the solution. This, when removed, was found to be a perfect matrix, and might be employed for the purpose of casting, where time is not an object.

It appears, therefore, that this discovery may be turned to some practical account. It may be taken advantage of in procuring casts from various metals, as above alluded to; for instance, a copper die may be formed from a cast of a coin or medal, in silver, type metal, or lead, etc., which may be employed in striking impressions in soft metals. Casts may probably be obtained from a plaster surface surrounding a plate of copper; tubes or any small vessels may also be made by precipitating the metal around a wire, or any kind of surface, to form the interior, which may be removed mechanically, by the aid of an acid solvent, or by heat.

"C. J. Jordan."

"*To the Editor of the London Mechanics' Magazine.*"

Clear and perspicuous as this letter is, it did not attract the slightest notice. And a few weeks after, we find that its existence was forgotten even by the editor of the magazine in which it appeared.

Spencer's First Printed Paper upon Electrotype.—Mr. Spencer's communication, referred to above, was, in consequence of some misunderstanding, not read at the meeting of the British Association, but it was immediately afterwards read before the Polytechnic Institution of Liverpool, at their meeting on the 13th September, 1839, which was upwards of three months after the publication of Mr. Jordan's letter in the *London Mechanics' Magazine.* Mr. Spencer's paper was accompanied with specimens both of electrotypes and of printing from electrotypes. The publication of this paper acted like an electric shock upon society, and men both of science and art became active competitors in this new field of application; the one class anxious to bear away the honors arising from some important improvement; the other, the profits which might follow some novel application of the process to their own or some other branch of manufacture. Indeed, thousands of all classes and ages, who had never previously given science a passing thought, became fascinated with the new art, and—the process being simple and easy to perform—the amateurs soon became excellent electrotypists. With these combined efforts, it need not be wondered at that in a very short time improvements of great scientific interest were pointed out, and applications of the greatest importance to the arts and manufactures of this country were introduced. In consequence, some of our old and standard manufactures, as we shall subsequently have occasion to notice at some length, have already been revolutionized.

HISTORICAL ANOMALY.—During a period of nearly five years —while the country was passing through an electrotyping mania —Mr. Spencer held the undivided honor of being the first to apply the deposition of metals to practical purposes in this country, but early in 1844, Mr. Henry Dircks, in a letter to the *London Mechanics' Magazine,* revived Mr. Jordan's letter, and told us that he was aware of its existence from the time of its first publication. We cannot eulogise either the policy, or the love of scientific truth, which induced Mr. Dircks to remain silent so long, and see the claims of Mr. Jordan set aside by one whom he considered to be a mere pretender to the merit of the discovery. Nor, after a careful and impartial examination of all the details published on the subject, can we agree to his condemnation of Mr. Spencer's prior claims; as he, Mr. Spencer, upon the 8th of May, as already noticed, stated to a public meeting of the Polytechnic Society of Liverpool, that he had made a similar discovery previous to any knowledge of either what Jordan or Jacobi had done, and which was a publication as much as if printed in the *Times* or *Athenæum,* and especially when followed by a detailed description of the discovery.

It is to be regretted that Mr. Jordan's diffidence, which in this case was far from being commendable, prevented his setting the public right upon this important matter. As a consequence, he must now be content with a much smaller share of the honor of the discovery than he might have enjoyed.

In reviewing the circumstances of this discovery, it strikes us as being a remarkable instance of the unity of intellectual perception in reference to the general principles of Nature and their applications; for we believe that Professor Jacobi, Mr. Spencer, and Mr. Jordan, viewed the subject of electro depositions in the same light, and about the same time; and each, according to their several abilities, presented to the public the same discovery, independent of the other, excepting the announcement made by one having hastened the publication of the observations of the others.

The following is Mr. Spencer's original paper on electro-metallurgy, which we give at length, trusting that its importance in connection with the history of the art, and the lucid description of its practice, will serve as a sufficient apology for not abridging it:

"*On Working in Metal by Voltaic Electricity, reprinted from the Paper Published by the Liverpool Polytechnic Society, and read at the Meeting of September the* 12*th*, 1839, *Notice being given May the* 8*th: Henry Booth, Esq., President, in the Chair.*

"In the paper that I have the honor to lay before the society, I do not profess to have brought forward a perfect invention. My only object is to point out a means by which, I hope, practical men may be enabled to apply a great and universal principle of Nature to the useful and ornamental purposes of life. In this I may be considered sanguine—an error, I am aware, too often fallen into by those who, like myself, imagine they have discovered a useful application of an important principle; but however this may fall out, I shall lay an account of its results, with specimens, successful and unsuccessful, before the members and the public—previously stating, however, that all my first experiments were made on a small scale—a method of procedure attended with many advantages to the experimentalist himself, but having its disadvantage when laid before the public. In this first respect, perhaps, the chemical experimenter has an advantage over the mechanical one, as the success of his experiment, when tried on a small scale, doubly guarantees it if conducted on a still larger scale: with mechanical results I believe in most instances it is the reverse. But when the chemist produces his microscopic proofs, the public are generally slow to believe that such minute appearances should warrant him in coming to any general conclusion.

"In the latter part of September, 1837, I was induced to make some electro-chemical experiments, with single pairs of plates, consisting of small pieces of zinc and equal-sized pieces of copper, connected together with wires of the latter metal. It was intended that the action should be slow: the fluids in which the metallic electrodes were immersed were in consequence separated by thin discs of plaster of Paris. In one cell thus formed was placed sulphate of copper in solution—in the other, a weak solution of common salt. I need scarcely add that the copper electrode was placed in the cupreous solution, the other being in that of the salt.

I mention these experiments briefly—not because they are *directly* connected with what I shall have to lay before the society, but because, by a portion of their results, I was induced to come to the conclusions I have done in the following paper. I was desirous that no action should take place on the wires by which the electrodes were held together; and to attain this object I varnished them with sealing-wax varnish: but, in one instance, I dropt a portion on the copper electrode that was attached. I thought nothing of this circumstance at the moment, but put the experiment in action.

"This operation was conducted in a glass vessel; I had consequently an opportunity of occasionally examining its progress from the exterior. After the lapse of a few days, metallic crystals had covered the copper electrode—*with the exception of that portion* which had been spotted with the drops of varnish. I at once saw that I had it in my power to guide the metallic deposition in any shape or form I chose, by a corresponding application of varnish or other non-metallic substance.

"I had been aware of what every one who uses a sustaining galvanic battery with sulphate of copper in solution must know—that the copper plates acquire a coating of copper from the action of the battery; but I had never thought of applying it to a useful purpose, except to multiply the plates of a species of battery, which I did in 1836. My present attempt was with a piece of thin copper plate, having about four inches of superfices, with an equal sized piece of zinc, connected as before by a piece of copper wire. I gave the copper a coating of soft cement, consisting of beeswax, resin, and a red earth. It was compounded in the manner recommended by Dr. Faraday, in his work on Chemical Manipulation, but with a larger proportion of wax. The plate received its coating while hot. When it was cold, I scratched the initials of my name rudely on the plate, taking special care that the cement was quite removed from the scratches, that the copper might be thoroughly exposed. This was put in action in a cylindrical glass vessel, about half filled with a saturated solution of sulphate of copper. I then took a common gas glass, similar to that used to envelope an argand burner, and filled one end of it with plaster of Paris, to the depth of three-quarters of an inch. Into this I put water, adding a few crystals of sulphate of soda to excite action, the plaster of Paris acting as a partition to separate the fluids, but, at the same time, being sufficiently porous to allow the electro-chemical action to permeate its substance.

"I now bent the wire in such a manner that the zinc end of the arrangement should be in the saline solution, while the copper end, when in its place, should be in the cupreous solution. The gas glass, with the wire, was then placed in the vessel containing the sulphate of copper.

"It was then suffered to remain at rest, when in a few hours I perceived that action had commenced, and that the portion of the copper rendered bare by the scratches had become gradually coated with pure bright deposited metal, whilst all the surrounding portions were not at all acted on. I now saw my former observations realized; but whether the deposition so formed would retain its hold on the plate, and whether it would be of sufficient solidity or strength to bear working if applied to a useful purpose, became questions which I now determined to solve by experiment. It also became a question—should I be successful in these two points—whether I should be able to produce lines sufficiently in relief to print from. This latter appeared to depend entirely on the nature of the cement or etching-ground I might use.

"This I endeavored to solve at once; and, I may state, it appeared at the time to be the main difficulty, as my impression then was, that little less than one-eighth of an inch of relief would be requisite to print from.

"I now procured a piece of copper, and gave it a coating of a modification of the cement I have already mentioned, and having covered it to about one-eighth of an inch in thickness, I took a steel point and endeavored to draw lines in the form of net-work, that should entirely penetrate the cement, and leave the surface of the copper exposed. But in this I experienced much difficulty, from the thickness I deemed it necessary to use; more especially when I came to draw the cross lines of the net-work. The cement being soft, the lines were pushed as it were into each other, and when it was made of harder texture, the intervening squares of the net-work chipped off the surface of the metallic plate. However, those that remained perfect I put in action as before.

"In the progress of this experiment I discovered that the solidity of the metallic deposition depended entirely on the weakness or intensity of the electro-chemical action, which I knew I had in my power to regulate at pleasure, by the thickness of the intervening wall of plaster of Paris, and by the coarseness or fineness of the material. I made three similar experiments, altering the texture and thickness of the plaster each time, by which I ascertained that if the partitions were *thin* and *coarse*, the metallic depositions proceeded with great *rapidity*, but the crystals were friable and easily separated; on the other hand, if I made them thicker and of a little finer material, the action was slower, but the metallic deposition was as solid and ductile as copper formed by the usual methods—indeed, when the action was exceedingly slow, I have had a metallic deposition apparently much harder than common sheet copper, but more brittle.

"There was one most important and, to me, discouraging circumstance attending these experiments, which was, that when I heated the plates to get off the covering of cement, the meshes of copper net-work occasionally *came off with it*. I at one time imagined this difficulty inseparable, as it appeared that I had cleared the cement entirely from the surface of the copper that I meant to have exposed; and I concluded that there must be difference in the molecular arrangement of copper prepared by heat and that prepared by voltaic action, which prevented their chemical combination. However, I determined, should this prove so, to turn it to account in another manner, which I shall relate in the second portion of the paper.

"I now occupied myself for a considerable period in making experiments on this latter section of the subject.

"In one of them I found, on examination, that a portion of the copper deposition, which I had been forming on the surface of a coin, adhered so strongly that I was quite unable to get it off—indeed, a chemical combination had apparently taken place. This was only on one or two spots on the prominent parts of the coin. I immediately recollected that, on the day I put the experiment in action, I had been using nitric acid for another purpose, on the table I was operating on, and that in all probability the coin might have been laid down where a few drops of the acid had accidentally fallen. Bearing this in view, I took a piece of copper, coated it with cement, made a few scratches on its surface until the copper appeared, and immersed it for a short time in dilute nitric acid, until I perceived, by an elimination of nitrous gas, that the exposed portions were acted upon sufficiently to be slightly corroded. I washed the copper in water, and put it in action as before described. In forty-eight hours I examined it, and found the lines were entirely filled with copper, I applied heat, and then spirits of turpentine, to get off the cement, and, to my satisfaction, I found that the voltaic copper had completely combined itself with the sheet on which it was deposited.

"I then gave a plate a coating of cement to a considerable thickness, and sent it to an engraver; but when it was returned I found the lines were cleared out so as to be wedge-shaped, or somewhat in the form of a V, leaving a hair line of the copper exposed at the bottom, and a broad space near the surface; and where the turn of the letters took place, the top edges of the lines were galled and rendered rugged by the action of the graver. This, of course, was an important objection, which I have since been able to remedy in some degree by an alteration in the shape of the graver, which should be made of a shape more resembling a narrow parallelogram than those in common use: some engravers have many of their tools so made. I did not put this plate in action, as I saw that the lines, when in relief, would have been broad at the top and narrow at the bottom. I took another plate, gave it a coating of the wax, and had it written on with a mere point. I deposited copper on the lines, and afterwards had it printed from.*

"I now considered part of the difficulties removed: the principal one yet remaining was to find a cement or etching-ground, the texture of which should be capable of being cut to the re-

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* This plate was shown to friends, and also specimens of printing from it, in 1838.

quired depth, without raising what is technically termed *a burr*, and, at the same time, of sufficient toughness to adhere to the plate, when reduced to a small isolated point, which would necessarily occur in the operation which wood-engravers term cross-hatching.

"I have since learned, from practical engravers, that much less relief is necessary to print from than I had deemed indispensable, and that, on becoming more familiar with the cutting of the wax-cement, they would be enabled to engrave in it with great facility and precision.

"I tried a number of experiments with different combinations of wax, resins, varnishes, earths, and metallic oxides, all with more or less success. One combination that exceeded all others in its texture was principally composed of beeswax, resin, and white lead. This had nearly every requisite, so that I was enabled to polish the surface of the plate with it until it was nearly as smooth as a plate of glass. With this compound I had two plates, five inches by seven, coated over, and portions of maps cut on the cement, which I had intended should have been printed off. I applied the same process to these as to the others, immersing them into dilute nitric acid before putting them in action; indeed I suffered them to remain about ten minutes in the solution. I then put them into the voltaic arrangement. The action proceeded slowly and perfectly for a few days, when I removed them. I applied heat as usual, to remove the cement, but *all* came away, as in a former instance—the voltaic copper peeling off the plate with the greatest facility. I was much puzzled at this unexpected result; but, on cleaning the plate, I discovered a delicate trace of *lead*, exactly corresponding to the lines drawn on the cement previous to the immersion in the dilute acid. The cause of this failure was at once obvious: the carbonate of lead I had used to compound the etching-ground had been decomposed by the dilute nitric acid, and the metallic lead thus reduced had deposited itself on the exposed portions of the copper plates, preventing the voltaic copper from chemically combining with the sheet copper. I was now with regret obliged to give up this compound, and to adopt another, consisting of beeswax, common resin, and a small portion of plaster of Paris. This seems to answer the purpose tolerably, though I have no doubt, by an extended practice, a better may still be obtained by a person practically acquainted with the etching-grounds in use among engravers.

"I now proceed to the second, and I believe the most satisfactory portion of the subject. Although I have placed these experiments last, some of them were made at the same time with the others already described, and some of them before; but, to render the subject more intelligible, I have placed them thus.

"The members of the society will recollect that, on the first evening it met, I read a paper on the 'production of metallic veins in the crust of the earth,' and that among other specimens of cupreous crystallization which I produced on that occasion, I exhibited three coins—one wholly covered with metallic crystals, the other on one side only. It was used under the following circumstances. When about to make the experiment, I had not a slip of copper at hand to form the negative end of my arrangement, and, as a good substitute, I took a penny and fastened it to one end of the wire, and put it, in connection with a piece of zinc, in the apparatus already described.

"Voltaic action took place, and the copper coin became covered with a deposition of copper in a crystalline form. But, when about to make another experiment, and being desirous of using the piece of wire used in the first instance, I pulled it off the coin to which it was attached. In doing this, a piece of the deposited copper came off with it; on examining the under portion of which, I found it contained an exact mould of a part of the head and letters of the coin, as smooth and sharp in every respect as the original on which it was deposited. I was much struck with this at the time; but, on examination, the deposition metal was very brittle. This, and the fact that it would require a metallic nucleus to aggregate on, made me apprehensive that its future usefulness would be materially abridged; but it was reserved for future experiment, and in consequence laid aside for a time, until my attention was recalled to the subject in a subsequent experiment, already detailed, by the drops of varnish on a slip of copper. Finding in that instance that the deposit would take the direction of any non-conducting material, and be, as it were, guided by it, I was induced to give the previous branch of the subject a second trial, because I had, in the first instance, supposed that the deposition would only take place continuously, and not on isolated specks of a metallic surface, as I now found it would; but the principal inducement to investigate the subject was the fact of finding that deposited copper had much more tenacity than I at first imagined.

"Being aware of the apparent natural law which limits metallic deposition by voltaic electricity, excepting in the presence of a metallic body, I perceived that the uses of the process would, in consequence, be extremely limited, except in the multiplication of already engraved plates, as, whatever ornament it might produce, it would only be done by adhering to the condition of a metallic mould.

"I accordingly determined to make an experiment on a very prominent copper medal. It was placed in a voltaic circuit, as already described, and deposited a surface of copper on one of its sides to about the thickness of a shilling. I then proceeded to get the deposition off. In this I experienced some difficulty, but ultimately succeeded. On examination with a lens, every line was as perfect as the coin from which it was taken. I was then induced to use the same piece again, and let it remain a much longer time in action, that I might have a thicker and more substantial mould, in order to test fairly the strength of the metal. It was accordingly put again in action, and let remain until it had acquired a much thicker coating of the metallic deposition; but on attempting to remove it from the medal I found I was unable. It had, apparently, completely adhered to it.

"I had often practised, with some degree of success, a method of preventing the oxidation of polished steel, by slightly heating it until it would melt fine beeswax; it was then wiped, apparently completely off, but the pores or surface of the metal became impregnated with the wax.

"I thought of this method, and applied it to a copper coin.

"I first heated it, applied wax, and then wiped it so completely off, that the sharpness of the coin was not at all interfered with. I proceeded as before, and deposited a thick coating of copper on its surface. Being desirous to take it off, I applied the heat of a spirit-lamp to the back, when a sharp crackling noise took place, and I had the satisfaction of perceiving that the coin was completely loosened. In short, I had a most complete and perfect copper mould of one side of a half-penny.

"I have since taken some impressions from the mould thus taken, and, by adopting the above method with the wax, they are separated with the greatest ease.

"By this experiment it would appear that the wax impregnates the surface of the metal to an inconsiderable depth, and prevents a chemical adhesion from taking place on the two surfaces; and I can only account for the crackling noise, on separation, by supposing it probable that the molecular arrangement of the voltaic metal is different from that subjected to percussion, and this difference causes an unequal degree of expansibility on the application of heat.

"I became now of opinion, that this latter method might be applied to engraving much better than the method described in the first portion of this paper. Having found in a former experiment that copper in a voltaic circuit deposited itself on lead with as much rapidity as on copper, I took a silver coin, and put it between two pieces of clean sheet-lead, and placed them under a common screw-press. From the softness of the lead, I had a complete and sharp mould of both sides of the coin, without sustaining injury. I then took a piece of copper wire, soldered the lead to one end, and the piece of zinc to the other, and put them into the voltaic arrangement I have already described. I did *not*, in this instance, *wax* the mould, as I felt assured that the deposited copper would easily separate from the lead by the application of heat, from the different expansibility of the two metals.

"In this result I was not disappointed. When the heat of a spirit-lamp was applied for a few seconds to the lead, the copper impression came easily off. So complete do I think this latter portion of the subject, that I have no hesitation in asserting that *fac-similies* of any coin or medal, no matter of what size, may be readily taken, and as sharp as the original. To test further the capabilities of this method, I took a piece of lead plate, and stamped some letters of its surface to a depth sufficient to print from, when in relief. I deposited the copper on it, and found it came easily off, the letters being in relief.

"Finding from this experiment that the extreme softness of lead allowed it to be impressed on by type metal, I caused a small portion of ornamental letter-press to be set up in type, and placing it on a planed piece of sheet lead, it was subjected to the action of a screw press.

"After considerable pressure, it was found that a perfectly sharp mould of the whole had been obtained in the lead. A wire was now soldered to it, and it was placed in an apparatus similar in principle, but larger than the one already described. At the end of eight days from this time, copper was deposited to one-eighth of an inch in thickness; it was then removed from the apparatus, and the rough edges of the deposited copper being filed off, it was subjected to heat, when the two metals began to loosen. The separation was completed by inserting a piece of wedge-shaped wood between them.

"I had now the satisfaction of perceiving that I had by these means obtained a most perfect specimen of stereotyping in copper, which had only to be mounted on a wooden block to be ready to print from.

"From the successful issue of this experiment, which was mainly due to the susceptibility of the lead, I was induced to attempt to copy a wood engraving by a similar method, provided the wood would bear the requisite pressure. Knowing that wood engravings are executed on the *end* of the block, I had better hopes of succeeding, the wood being less likely to sustain injury.

"I accordingly procured a small wood block, and placed its engraved surface in contact with a piece of sheet lead made very clean, and subjected it to pressure, as in the former instance. I had now, as before, the gratification of perceiving that a perfect mould of the little block had been obtained, and no injury done to the original. Several wood engravings and copperplates were subjected to similar treatment, and are now in process of being deposited on in the apparatus before me.

"I now come to the third and concluding portion of the experiments on this subject. The object being to deposit a metallic surface on a model of clay, wood, or other *non*-metallic body—as, otherwise, I imagined the application of this principle would be extremely limited. Many experiments were made to attain this result, which I shall not detail, but content myself with describing those which were ultimately most successful.

"I procured two models of an ornament, one made of clay, and the other of plaster of Paris, soaked them for some time in linseed-oil, took them out, and suffered them to dry—first getting the oil clean off the surface. When dry, I gave them a thin coat of mastic varnish. When the varnish was nearly dry, *but not thoroughly so*, I sprinkled some bronze powder on that portion I wished to make a mould of. This powder is principally composed of mercury and sulphur, or it may be chemically termed a sulphuret of mercury. There is a sort that acts much better, in which is a portion of gold. I had, however, a complete metalliferous coating on the surface of the model, by which I was enabled to deposit a surface of copper on it, by the voltaic method I have already described. I have also gilt the surface of a clay model with gold leaf, and have been successful in depositing copper on its surface. There is likewise another, and as I trust it will prove, a simpler method of attaining this object; but as I have not yet sufficiently tested it by experiment, I shall take another opportunity of describing it."

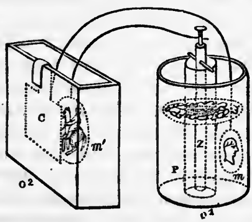
[At the close of the paper, several specimens of coins, medals, and copper plates, some of them in the act of formation by the voltaic process, were exhibited by Mr. Spencer to the Society.]

PLUMBAGO AS A COATING.—Shortly after Mr. Spencer's paper was published, several important improvements were introduced, one or two of which we will refer to here, and will give the others when detailing the processes to which the improvements were applied. The first was the use of plumbago or black lead, to give the surface of non-metallic bodies a conducting property. This was the discovery of Mr. Robert Murray, a gentleman of high attainments and unassuming manners, who communicated the process to the members of the Royal Institution orally. The Society of Arts afterwards awarded to Mr. Murray a silver medal, as an expression of their sense of the value of the discovery. Seldom was reward more deserving, or a discovery more important to the purposes to which it was to be applied, for this application at once freed electro-metallurgy from every bond: it was no longer necessary to use either metallic moulds, or moulds having metal reduced upon their surfaces by chemical means—which, according to the processes then known, was both tedious and uncertain, and only applicable to certain substances. Plumbago possessed all the requisite properties: it was convenient, plentiful, and cheap, easily applied, and equally effective for every substance on which the electrotypist desired to obtain a deposit, or which he could wish to cover with metal, either for useful or ornamental purposes.

SEPARATE BATTERY.—The second improvement to be noticed is one that must have followed the original discovery very soon, namely, the application of a *separate battery* for the purposes of deposition. This was suggested by Mr. Mason. Although those instances of deposition of metals which have been referred to in the early history of galvanism were effected by means of separate batteries, namely, by placing the ends of the wires attached to the terminals of the battery in the solution to be decomposed, still the discovery under consideration was made by means of what is termed the *single cell.* It consisted in simply attaching by a wire the article upon which a deposition was to be made to a piece of zinc, and immersing the zinc in diluted acid, and the other article in a solution of the metal to be deposited; the two liquids being separated by a porous partition, or diaphragm, such as moist bladder, or unglazed porcelain. In this case, the whole electricity was expended within the cell, to deposit the metal within or upon the mould. By Mr. Mason's discovery, the electricity generated in the cell could be made to do an equivalent of work in a separate cell as well—making the original arrangement the generating cell or battery to the second cell. In this last cell was also a solution of a metal having in it a sheet of similar metal attached to the copper of the first cell, and the mould to be covered was attached to the zinc of the first cell. Fig. 541 is an illustration of Mason's improvement, which consisted in causing a medal, in the act of being deposited, to serve as part of a battery for the deposition of another medal.

O^2, Outer vessel filled with sulphate of copper; O^1, another vessel, with P, a porous cell filled with dilute acid, in which is placed Z, a zinc plate, which is connected by a wire with a medal *m'* in the second vessel charged with sulphate of copper. The medal, *m*, in the first cell, is connected by a wire to a piece of copper, C, in the second cell: the electricity passes from the zinc Z to *m*, and by the wire to C, then to *m'*, and by the wire back to the zinc Z.

Fig. 541.



The use of a separate battery, however self-evident, was a valuable addition to the electro-metallurgist for many of his operations; although for some purposes the original single cell is to be preferred.

Laws of Deposition.—As might have been expected in the excitement occasioned by the announcement of a new art, every individual experimenter became so engrossed by his own investigations and their results, as to overlook the labors of others, and at last to lay claim to the honor of originating *all* the discoveries they announced; while the truth is, that nearly all the important facts of electro-metallurgy appear to have occurred almost simultaneously to various experimenters. We shall quote one or two instances of these absorbing claims, as it is important to rectify the errors they contain, because no successful laborer, however humble, in the field of science or art, should be overlooked by his fellow-laborer whose opportunities for research may be much more favorable.

Extract from Smee's "Electro-Metallurgy."

"The laws regulating the reduction of all metals in different states were first given in this work as the result of my own discoveries. By these we can throw down gold, silver, platinum, palladium, copper, iron, and almost all other metals, in three states, namely, as a black powder, as a crystalline deposit, or as a flexible plate. These laws appear to me at once to raise the isolated facts known as the electrotype into a science, and to add electro-metallurgy as an auxiliary to the noble arts of this country."

That Mr. Smee discovered the laws referred to we have not the slightest doubt: they were published as laws in his book, and they are commonly quoted as Mr. Smee's; nevertheless, he was not the first who discovered them; the same laws were pointed out by Mr. Spencer, in his original paper just quoted, published eighteen months previously to the appearance of Mr. Smee's work, as will be seen from the following extracts:

Laws given by Smee.	*Laws given by Spencer.*
"Law I.—The metals are invariably thrown down as a black powder, when the current of electricity is so strong, in relation to the strength of the solution, that hydrogen is evolved from the negative plate of the decomposition cell. "Law II.—Every metal is thrown down in a crystalline state, when there is no evolution of gas from the negative plate, or no tendency thereto. "Law III.—Metals are reduced in the reguline state, when the quantity of electricity, in relation to the strength of the solution, is insufficient to cause the production of hydrogen in the negative plate of the decomposition trough, and yet the quantity of electricity very nearly suffices to induce that phenomenon."	"I discovered that the solidity of the metallic deposition depended entirely on the weakness or intensity of the electro-chemical action, which I knew I had in my power to regulate at pleasure, by the thickness of the intervening wall of plaster of Paris, and by the coarseness or fineness of the material. I made three similar experiments, altering the texture and thickness each time, by which I ascertained, that if the partitions were *thin* and *coarse*, the metallic deposition proceeded with great *rapidity*, but the crystals were friable and easily separated; on the other hand, if I made them thicker, and of a little finer material, the action was slower, but the metallic deposition was as solid and ductile as copper formed by the usual methods. Indeed, when the action was exceedingly slow, I have had a metallic deposition much harder than common sheet copper, but more brittle."

The identity of these deductions or laws requires no comment; and, comparing the circumstances of the one having nothing but the rude apparatus of a new-born art suggested by himself, to that of the other, enjoying the advantage of eighteen months improvements, Mr. Spencer is astonishingly correct, and his name should be identified with the discovery of these laws. The claim of originality involved in the inference drawn by Mr. Smee, though formidable at first sight, is nevertheless, without foundation. Mr. Smee says: "These laws appear to me at once to raise the isolated facts known as the electrotype into a science, *and to add electro-metallurgy as an auxiliary to the noble arts of this country.*" Unfortunately for the validity of Mr. Smee's claim, patents were taken out long previous, both in England and France, for the application of the electro-depositions to the arts. And Messrs. Elkington's patent for silvering and gilding by this process—a patent which has not yet been superseded—was not only published in full detail, but was in extensive operation months before the publication of Mr. Smee's book. Nevertheless, the publication of Mr. Smee's book did good service to the art of electrotyping; and the invention of his battery has so identified his name with the science, that it will go down to posterity as that of an active and successful laborer in the field of electricity: to Mr. Smee we owe, moreover, the very appropriate name for the art, *Electro-metallurgy.*

WORKS PUBLISHED ON ELECTRO-METALLURGY.—Besides many interesting papers in journals and magazines, several separate works were published on this art. Some months previously to the publication of Mr. Smee's work, Mr. Spencer had given the world "*Instructions for the multiplication of works of art in metal by voltaic electricity;*" and shortly after Mr. Smee's work appeared, we had, in rapid succession, Walker's *Electrotype Manipulation,* Sturgeon's *Art of Electrotyping,* Shaw's *Manual of Electro-metallurgy,* etc., all showing much practical knowledge of the subject. Walker's *Manipulation,* from its practical nature and its concise form, became the favorite of the amateur, and did more to popularize the art than all the others put together; and although little pretensions were made to originality, the author will not fail to have an honorable remembrance in the history of the art.

PATENTS TAKEN OUT FOR ELECTRO-METALLURGY.—The application of the art to useful purposes was so self-evident and so eagerly sought after, that no less than ten patents were taken out for useful applications, between the discovery of the art and the close of 1841; and not a year has passed since, without adding patents for certain improvements, and applications of Electro-metallurgy to some particular branch of manufacture, several of which will be noticed in their proper places, as many of them, although based upon right principles, were commercially speaking, entire failures.

CHAPTER XXV.

DESCRIPTION OF GALVANIC BATTERIES, AND THEIR RESPECTIVE PECULIARITIES.

Nomenclature.—The terms that are employed to denote the various parts of a galvanic battery, and of other electrotype arrangements, frequently puzzle the student, and lead him into difficulties. Before we proceed to describe the various forms of the battery, we shall, for this reason, give a preliminary account of the nomenclature of galvanism.

The two extremities of a battery have long been called *Poles*—one of them the *Positive*, and the other the *Negative*, Pole. But objections have been taken to the use of the terms *negative*, *positive*, and *pole*, on the ground that such terms do not convey a correct idea of the circumstances or of the effects produced. Before connecting the two metals or extremities of a battery, there is no electricity evolved, nor is there any electrical tension on any part of the arrangement; and when the connection is formed the electricity simply makes a circuit, it is therefore supposed that no particular portion of that circuit can be said to be either negative or positive to another portion.

Proposed Terms.—Various terms have been suggested as substitutes for negative and positive, and also for pole. Dr. Faraday has proposed the following: for pole, he substitutes *electrode*, which signifies *a way;* for the negative pole, *cathode*, signifying *downwards;* and for the positive pole, *anode* or *upwards*. To understand these terms properly, we must suppose a battery lying upon the ground with its copper (positive) end to the east, and the wire connecting the ends of the battery bent into an arch similar to the course of the sun; the electric current will thus flow up from the east end of the battery, and descend into it at the west end. The fluid that is decomposed by a current of electricity passing through it is termed by Faraday an *electrolyte;* the elements liberated by this decomposition he terms *ions*, distinguishing those liberated at the cathode as *cations*, which in sulphate of copper would be the metal, and those liberated at the anode as *anions*, which would be the acid portion of the sulphate of copper.

The late Professor Daniell, disapproving of the terms cathode and anode, substitued *platinode* for the negative, and *zincode* for the positive, pole. We think these terms are better adapted for electro-metallurgy than cathode and anode, which have no direct reference to ordinary conditions; while zincode distinctily expresses the substance dissolved, and platinode the element not acted upon.

Professor Graham adopts the terms *zincous* and *chlorous* poles, as synonymous with zincode and platinode, or positive and negative.

Although the terms positive, negative, and pole, may not be the best, still, under all the conditions of electro-metallurgy, we deem them as appropriate as any of the proposed substitutes, some of which are based on supposed conditions which have not been proved, and may be found incorrect.

When we shall have occasion to use the two terms *pole* and *electrode*, these will be used synonymously: positive and negative electrode are synonymous with positive and negative pole.

Electrolyte will be applied to a solution when undergoing decomposition by the electric current passing through it.

The *positive electrode*, or pole, is that metal in the electrolyte which is being dissolved, or, if not capable of being dissolved, at which the acid or solvent of the electrolyte is being liberated, as when sulphate of copper forms the electrolyte, the sulphuric acid is liberated. The *negative electrode*, or pole, is that metal or substance in the electrolyte upon which the metal is being deposited by the influence of the electric current, such as a medal upon which copper is being deposited in an electrotype process.

BATTERIES.

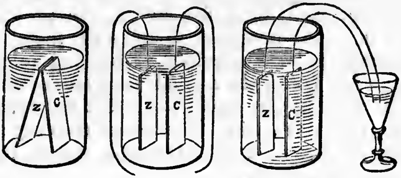
SINGLE PAIR OF PLATES.—If a piece of ordinary metallic zinc be put into dilute sulphuric acid, it is speedily acted upon by the acid, and hydrogen gas is at the same time evolved from its surface, having a disagreeable smell arising from impurities contained in the zinc or acid. If the zinc be taken out, and a little mercury be rubbed over its surface, an amalgamation takes place between the two metals: the plate becomes of a beautiful bright silver appearance. If the zinc thus amalgamated be again put into the dilute acid, there is no action, for the mercury retains the zinc with sufficient force to protect it from the acid. If a piece of copper be immersed along with the zinc, and the two metals be made to touch each other, a particular influence is induced among the three elements, zinc, copper, and acid; the acid again acts upon the zinc as if no mercury was upon it, but the hydrogen is now seen to escape from the surface of the copper; this action will go on as long as the two metals are kept in contact. Or if, instead of causing the two metals to touch, a wire be attached to each, and their opposite ends are placed in a little dilute acid in another vessel, the same action will take place between the zinc and copper as when they were in contact; but in this instance, the ends of the two wires which dip into the vessel containing acid will undergo a change: the one attached to the zinc will give off a quantity of hydrogen gas, while the one attached to the copper, supposing it to be also copper, will rapidly dissolve.

Figure 542. Represents the zinc and copper, placed in dilute sulphuric acid, brought into contact; in this experiment, gas will be seen escaping from the copper.

Figure 543. Zinc and copper, placed in dilute acid, and wires attached, which, when connected, will exhibit the same effects as in the first case.

Figure 544. Shows the wires connected by means of a liquid, such as acid and water, sulphate of copper, etc.

Figs. 542 543 544.



The copper and zinc, c and z, with the acid in the first vessel, Figure 544, constitute a battery of one pair. The wine glass *e*, wi acid, in which the wires are placed, is termed the decomposition cell.

Best kind of Zinc.—The zinc used for the battery should be *milled* or rolled zinc, not thinner than $\frac{1}{8}$th of an inch, otherwise the waste will be very great; for amalgamated zinc, when it becomes thin, is so tender and brittle, that the utmost care cannot preserve it whole. The best thickness for the zincs, when their size is upwards of four inches square, is $\frac{1}{4}$th of an inch; but if under this size, $\frac{1}{8}$th to $\frac{3}{16}$th of an inch is the proper thickness. Cast plates of zinc should not be used, as they are negative to rolled zinc, and give less electrical power: they are so porous that no amalgamation will protect them from the action of the acid—producing "local action," as it is termed, which is not only a waste of zinc and acid, but prevents, to a great extent, the production of the quantity of electrical force which the surface of the zinc in use is calculated to give.

Amalgamation of the Zinc Plates.—The amalgamation of zinc is a process exceedingly simple; nevertheless, if care be not taken, a very great loss in mercury and zinc is soon effected. A stoneware pan is best to use, and should be sufficiently capacious to allow the zinc plate to lie flat within it: a mixture of eight parts water, and one part sulphuric acid, should be put into the pan, sufficient in quantity to cover the zinc plate, which should lie in it till the surface is perfectly bright. The pan is now raised on the one side, and a little mercury put into the lower part, care being taken that the zinc does not touch the mercury, to prevent which is the object of raising the pan on one side. A little coarse tow, tied to the end of a piece of wood, is dipped into the mercury, which lifts small portions of the metal mechanically, which is then rubbed with considerable pressure upon both sides of the zinc plate, over which the mercury flows easily: the plate is then washed, by dipping it into clean water, and is next made to stand upon its edge in another pan, with two small pieces of wood under it, so as to allow the mercury to drain from it. Instead of tow, an old scratch brush is generally used in plating factories: this is a brush made of fine brass wire, tied upon a piece of wood; but we prefer tow, when carefully employed, as the brass wire amalgamates with the mercury, and causes a loss of that metal. After the zincs have drained for a few hours, the process should be repeated, only it is not necessary to allow the metal to lie in the acid in the second process previous to rubbing in the mercury: after draining a few hours the second time, amalgamation is completed. In the first process a plate, of a foot square, amalgamated on both sides, will retain three ounces of mercury; but for the second process, or any time after, the same size of plate will only retain 1½ ounces of mercury.

Zinc rapidly absorbs mercury, which permeates the whole metal. If the mercury was in quantity, the zinc would dissolve in it; hence the propriety of rubbing the mercury into the zinc, only in small portion, for if allowed to imbibe as much as it is capable of doing, it would not only be a loss of mercury, but the plate would become exceedingly brittle. When too much mercury is used, a portion of it will filter out from the plate by standing, but it carries with it some zinc dissolved, which tends to deteriorate the quality of the metal for the battery.

The zinc in the battery, after being used, should never be allowed to lie in the acid when the battery is not in use, but should be taken out, and the surface carefully brushed with a *hard* hair brush, in water, and then laid by in a safe place. The matter thus brushed off, being an amalgam of zinc, is to be carefully collected, and kept in dilute sulphuric acid, or in the waste acid from the batteries: most of the zinc in this amalgam will dissolve out, so that a great portion of the mercury may be recovered, or by placing these brushings in a coarse cloth bag, and subjecting it to pressure in a screw-press, most of the mercury may by this means be recovered.

ECONOMY IN AMALGAMATION.—If the battery is to be used seldom, and only for a short period at a time, another method of amalgamation may be adopted. The zinc plate, after lying in the dilute acid till the surface is bright, may be rubbed over with a solution of nitrate of mercury, which gives a very thin amalgamation; but this method is unsuitable if the battery is to be in use for several hours together.

When a battery is being worked daily, it will be advisable to repeat the amalgamation from time to time, otherwise local action will begin, and the working power of the battery be weakened, while the loss in zinc will be increased.

The following is the proportional rate which we have found on the large scale under the most favorable circumstances. A new zinc plate, amalgamated as described, working continuously—

24 hours, zinc lost 12½ ounces—copper deposited 12 ounces;
48 hours, zinc lost 20½ ounces—copper deposited 17 ounces;
60 hours, zinc lost 34 ounces—copper deposited 24½ ounces.

From these and similar data we found that the most economical way of using zincs is the following: after being in the battery twenty-four hours, they are to be taken out, brushed, and laid aside; after working other twenty-four hours, they are to be again brushed and *immediately* re-amalgamated: if these directions are attended to, ½ ounce of mercury will be sufficient for one foot square of zinc, both sides.

The advantages of proper amalgamation will be made more evident in the sequel. We have only to add here, in consequence of an oft-expressed fear of the danger of working with quicksilver, that no apprehension need be felt: the skin does not absorb it, and there being no heat required in the operation that could convert the mercury into vapor, the only state in which it is dangerous, no salivation can take place.

DISTANCE BETWEEN THE BATTERY PLATES.—To return again to the battery-cell. It will be found that if the two metals—the zinc and copper in acid, Fig. 544—be put very close to each other, the action will be much more rapid than when they are far apart. It will also be found that, allowing the zinc and copper to be kept at one distance, but the wires in the decomposition-cell to be put at different distances, similar results will take place. When the wires are close the action in the battery-cell will be more powerful than when the two wires are put farther apart: these properties are applicable to all batteries and decomposition-cells of every kind. The following results will give an idea of the relations of these several conditions:

1st. One pair of copper and zinc plates, measuring superficially 6 square inches, were immersed in a solution consisting of 1 acid to 35 water: plates of copper of equal size to those of zinc and copper were laid in the decomposition-cell, which was then filled with a liquid of equal strength to that in the battery-cell; the plates in the battery-cell and the decomposition-cell were then placed one inch apart: in four hours

The zinc in the battery-cell lost by dissolving 10½ grains;
The copper dissolved in decomposition-cell 10 grains.

2d. The battery-plates were put 12 inches apart, and the plates in decomposition-cell 1 inch apart: in four hours

There were dissolved in the battery-cell, zinc 7 grains;
In decomposition-cell, copper 6 grains.

3d. The battery plates were placed 1 inch apart, and the plates in decomposition-cell 12 inches apart: in four hours

The zinc in battery-cell lost 4½ grains;
The copper in decomposition-cell lost 3½ grains.

These results show the importance of attending to the conditions of the respective agents, and also, that distance in the decomposition-cell offers greater resistance than distance in the battery-cell.

DIFFERENT ELEMENTS OF BATTERIES.—Although our observations have been made on zinc, copper, and dilute sulphuric acid in the battery-cell, still these are not the only essential elements in a battery, as almost any two metals with a liquid similarly arranged will produce an electric current; but the current will vary according to the nature of the metals employed, and the effects produced upon them by the solution in which they are placed. If the exciting solution has the power of acting upon both metals, as when zinc and copper are immersed in dilute nitric acid, the current of electricity produced by the action of the acid upon the zinc will be neutralized to an extent corresponding to the relative action of the acid upon the copper. To have any effective electrical power, it is necessary that one of the metals employed be capable of combining easily with one of the elements of the solution in which they are placed, and forming a soluble salt, while the other does not; and the power obtained under proper circumstances has an intimate relation with these two properties in contrast. The metal which undergoes solution is termed the positive metal, the other the negative metal. Metals are not considered to possess any intrinsic negative or positive principle; their relations in this respect are governed solely by the circumstances in which they may be placed. For instance, if we connect a piece of copper and a piece of iron, and immerse them in acidulated water, the iron is dissolved, and is positive in relation to the copper; but if the same metals are immersed in a solution of yellow hydro-sulphuret of potassium, the copper is dissolved, and is positive relatively to the iron. Hence, to obtain a galvanic battery, the conditions are simply to provide two metals, and immerse them in a solution capable of acting upon the one and not upon the other. The first table shows the order in which the common metals stand to each other, in respect of their relative negative and positive properties, when immersed in water acidulated with sulphuric acid. The second table is given by Gmelin as the relations of the metals, in water and sea water, the most intensely negative metal standing highest, and the metal which acts most positively standing lowest:

Platinum
Gold
Antimony
Silver
Nickle
Bismuth
Copper
Lead
Iron
Tin
Cadmium
Zinc

Platinum
Gold
Silver
Copper
Bismuth
Antimony
Iron
Tin
Lead
Cadmium
Zinc

According to this arrangement, each metal is positive with respect to all that stand before it, and the electrical conditions of any pair become the more contrasted the further apart they stand in the scale. Thus, a battery composed of zinc and platinum is much more powerful than one composed of zinc and copper; and again, copper and iron make a very weak battery.

A battery may also be formed by having one metal and two kinds of solutions, separated by a porous diaphragm. For example, we may have strong nitric acid in one division, and dilute sulphuric or muriatic acid in the other; and by putting into each a piece of clean iron, a powerful current is obtained. These and several other arrangements of solutions and metals, are expensive and troublesome to keep in order, and are therefore never used for practical purposes in the art of electro-metallurgy.

PROPERTIES OF METALS FIT FOR BATTERIES.—In looking to the above table, it may be asked, "Since lead stands next to copper, and is so much cheaper, why should it not be used instead?" The reason is, that there are other properties which a metal, especially that used as the negative element, ought to possess to fit it for use in a voltaic arrangement; such as the power of freely conducting an electric current, of keeping a bright surface, and not becoming oxidized; none of which properties belong to lead. Could that metal be kept from oxidizing, a very powerful current of electricity might be obtained by using it with zinc; but its surface soon gets coated with an oxide possessing none of the properties of the metal, and hence the arrangement becomes zinc and oxide of lead, which produces but a weak current of electricity. These remarks refer to any metal that is subject to oxidization—an incident which is often a source of annoyance to the electrotypist when using copper plates.

Lead slightly amalgamated, and used as the negative metal with zinc, produces a very constant current for a time.

Lead is also a very bad conductor of the electric current, which renders it unsuitable for an element in the battery, the negative metal being considered as only acting the part of a conductor: this property materially affects the available power of an arrangement.

The following table shows the *relative Conducting power* of the respective metals:

Silver . . .	120
Copper . . .	120
Gold . . .	80
Zinc . . .	40
Platinum . .	24
Iron . . .	24
Tin . . .	20
Lead . . .	12

We have just stated that a battery composed of zinc and platinum will be more powerful than one composed of zinc and copper, so far as regards their negative and positive tendencies; but so much does the conducting power of the negative metal affect the practical usefulness of a battery, that notwithstanding the fact that platinum is much more negative than copper, there is so much of the effective electricity expended in overcoming the resistance which the inferior conductibility of the platinum offers to the progress of the current, that a battery of zinc and copper proves to be a more effective and useful battery for electro-metallurgy than one made of zinc and platinum. Hence also the reason that iron and copper, or iron and any other metal, make but an indifferent battery—iron being a bad conductor; while lead, which will be seen in the table, stands lowest in this property, is therefore unfit for batteries.

In fitting up a voltaic arrangement with a negative metal that is not a good conductor, such as platinum, the closer it is placed to the exciting liquid, in connection with another metal that is a good conductor, the better; because the current obtained will be the more effectual.

The following experiments will illustrate these remarks with a few of the common metals used as negative electrodes. There were, in each battery, six square inches of each metal exposed to the action of the acid, which was sulphuric acid diluted with 25 parts of water. The poles were of the same size, of copper, placed in sulphate of copper; and the quantity of copper deposited was taken as the data, each trial being of a different length of time:

FIRST, IN ACTION HALF AN HOUR.

BATTERY.	DEPOSITED.
Tin and zinc	1·7 grains.
Copper and zinc . . .	1·8 "
Platinum and zinc . . .	·5 "
Platinized silver and zinc .	2·0 "

SECOND, IN ACTION TWO AND A-HALF HOURS.

Tin and zinc	5·9 grains.
Copper and zinc . . .	8·8 "
Platinum and zinc . . .	4·5 "
Platinized silver and zinc .	9·7 "

THIRD, IN ACTION SIXTEEN HOURS.

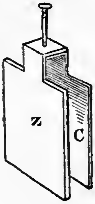
Tin and zinc	64·5 grains.
Copper and zinc . . .	50·5 "
Platinum and zinc . . .	43·0 "
Platinized silver and zinc .	67·3 "

From these few experiments it appears that tin and zinc, when used for a long time, constitute a very effective battery. It is very constant in its action, and thus suited for time. It stands next to platinized silver. The whole, in nineteen hours, gave respectively—

Platinized silver	79·	grains.
Tin	72·1	"
Copper	61·1	"
Platinum	48·0	"

Babington's Battery.—If we look back to the description given of the voltaic pile (page 489), and the improvement made upon it by Cruikshanks, we perceive the relation they bear to the pieces of copper and zinc mentioned in page 510; but the relation is more apparent in Babington's improvement upon Cruikshank's battery. When working with this battery, it was found that the energy of the battery did not depend, as was supposed, upon the extent of surface of the zinc and copper which were in contact, but upon the extent of surface of these metals in contact with the liquid with which the battery was excited; and that it was sufficient if the zinc and copper touched each other in a single point;—provided that the plates were plunged into the liquid, and that the copper plate should be exactly opposite to a zinc plate in the same cell, a space between them. Hence, instead of soldering the zinc and copper together, as Mr. Cruikshanks did, it was enough to effect a communication by turning over a portion of the copper plate at the top, and soldering it to the upper extremity of the zinc. Thus—c, the copper, is bent over to touch and be soldered to the zinc plate z. For this arrangement, the wooden trough was divided, by plates of glass or varnished wood, into as many cells as there were pairs of zinc and copper. The cells being filled with the acid, or exciting solution, the metals were then placed into them in such a manner that each pair of

Figs. 545



546.

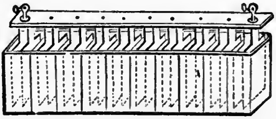
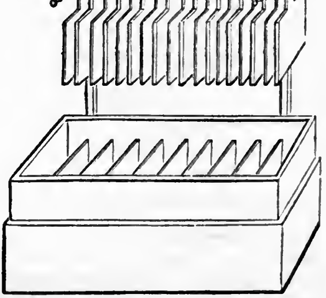


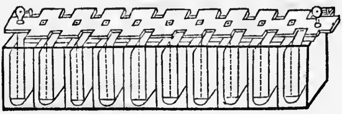
Fig. 547.



zinc and copper plates had a partition between. By this arrangement the zinc of one pair faced the copper of the next pair in the cell, as shown in Figures 546 and 547. The former represents the plates immersed in the solution; the latter, the plates suspended on a rack over the solution. This arrangement was termed Babington's Battery.

Wollaston's Battery.—Although we have spoken of the great value of amalgamated zinc for batteries, still at the period when the arrangement just described was introduced, amalgamation was not known; and the zinc plates were, therefore, always liable to be destroyed by the acid. It was, consequently, of importance that no zinc should be exposed to the action of the acid that was not calculated to give electricity, as the energy of each pair of plates depends upon the extent of surface of the two metals *exactly opposite to each other*. It will be evident that in Babington's arrangement only one side of the zinc was effective in giving electricity, while both sides were exposed to the action of the acid. To obviate this defect, Dr. Wollaston caused the copper plate to *surround the zinc*, by which the whole surface of the zinc exposed to the acid was made effective in producing electricity, and thereby doubling its quantity without further cost. The accompanying figure (Fig. 548) shows the manner in which this battery was originally constructed.

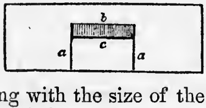
Fig. 548.



This improvement, if we except several modifications of construction for the facility of taking the plates asunder for cleaning, etc., did all for this kind of battery that could be done.

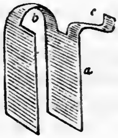
Modification of Wollaston's Battery now in use.—Wollaston's battery is still generally used in large factories for depositing metals; and it is found by experience to be the most convenient and economical of all the batteries yet contrived. The modification we have found to be very suitable, and practically useful, may be thus described. In the arrangement represented above, when amalgamated zincs are used, small quantities of amalgam fall from the zinc plates upon the copper, which not only occasion local action, but the mercury amalgamates with the copper, spreads over it, and to a great extent lessens its efficiency; and as the copper must be red hot to expel the mercury, much loss of copper as well as mercury is the result. To obviate this defect, the copper is connected above the zinc and left open at bottom; as, for example, a thin sheet of copper, of dimensions according with the size of the cells in the battery, is cut thus: This copper is bent in the middle at *b*, the ends *a a* dip into the cells, while

Fig. 549.

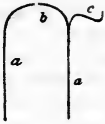


c is bent over to connect with the zinc plate of the neighboring cell, thus:

Figs. 550

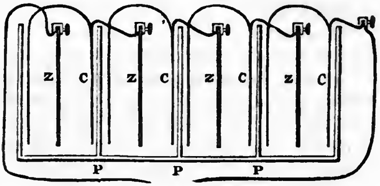


551.



The zinc plates are placed between the bent copper *a a*. The following diagram of a battery of several pairs of plates will illustrate these observations:

Fig. 552.



Z Z Z Z, The zinc plates.
C C C C, Copper plates.
P P P, Partitions of trough, which are generally made of thin wood.
w w, Wires from battery.

The zinc and copper are connected together by a binding screw. To construct this battery the zinc plates are put in first, being made to slide in grooves, cut in the sides of the trough, the plates standing in the centre of their respective cells: the copper plates are put in, and the copper bands marked *c* are made fast to the zincs by binding screws, care being taken that the parts where they are connected are clean and bright, and that the copper and zinc touch nowhere else. A battery of nine pairs of plates can be fitted up and made ready for action in ten minutes.

In fitting up batteries of this sort, we are aware that sometimes great care is taken that the partitions in the trough be perfectly water-tight, and also formed of some non-conducting material, such as glass, or of wood, either pitched or saturated with some non-conducting substance; but we have found in practice that these precautions are not required, the principal thing to attend to being, that the metals should not be allowed to touch, except in their proper connections.

Defects of Common Acid Batteries.—Although we have spoken thus favorably of the principles upon which Wollaston's battery is constructed, still as a philosophical instrument it is far from being perfect: hence the many modifications of it which have been recommended. Indeed, electro-chemists, since the time of Volta, have been endeavoring to invent an instrument free from the defects which attach to Wollaston's—one capable of giving, at the same time, a constant and powerful current, abundant in quantity, and of great intensity. The success and results of these endeavors are so closely connected with the art of electro-metallurgy, and the knowledge of them is so essential to a successful prosecution of the art, that we must not be sparing in our descriptive details.

In operating with a Wollaston's battery, or any other arrangement composed of similar elements, such as zinc, sulphuric or muriatic acid, and copper, silver or platinum, it will be found that the current of electricity obtained diminishes in quantity and strength in proportion to the time of action. This is the result of various causes:

1st. The hydrogen which is evolved at the surface of the negative metal in the battery, which we shall say is copper, adheres with considerable force to the surface of the metal, and consequently obstructs its superficial influence, so that the quantity of electricity which the surface of the two metals is calculated to give is much lessened.

2d. After the battery is in action a short time, a portion of the sulphate or chloride of zinc, formed in the battery by the solution of the zinc, becomes reduced upon the surface of the copper. This reduction is supposed to be owing to the electrolyzation of the zinc solution by the passage of electricity, but it is, more probably, caused by a galvanic action upon the copper plate and the solution in the battery. It generally begins at the lower edge of the copper plate, and spreads upwards. This weakens the electric current, both by inducing a galvanic action between the zinc and the copper, upon which it is deposited, and by its tendency to send a current of electricity in an opposite direction to the main current, thereby neutralizing to a great extent the original power of the circle.

3d. When copper is used it becomes gradually covered over with a thin, black, slimy coating of oxide and other impurities, which materially affects the regularity and strength of the current: this is a source of considerable annoyance in working, and necessitates a regular cleaning of the coppers, which should be done immediately on being taken out of the battery, by brushing with a hard hair brush in water; but when the battery has been long in action, this mode of cleaning is insufficient: the plates will then require to be rubbed over with a little dilute nitric acid, and then washed. If the black coating be allowed to dry upon the coppers, they must then be dipped into strong nitric acid till their surfaces are acted upon; or they may be moistened with a little urine, then brought to a dull red in the fire, and immediately plunged into water; but in both cases there is a loss of copper. A small quantity of the black matter, upon being tested, gave oxide of copper, with a trace of iron, antimony, and lead, which are the general impurities of sheet copper.

Max, Duke of Leuchtenberg,* has giving the following results

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* Progress of General Science, vol. ii.

of an analysis of the black matter found upon the copper plate forming the positive electrode in a copper solution.

Sand	1·90
Antimony	9·22
Tin	33·50
Arsenic	7·40
Platinum	0·44
Gold	0·98
Silver	4·45
Lead	0·15
Copper	9·24
Iron	0·30
Nickle	2·26
Cobalt	0·86
Vanadium	0·64
Sulphur	2·46
Selenium	1·27
Oxygen	24·82
	99·98

An analysis of this sort invests the subject with great interest. We wish there had also been given an analysis of the copper that was used as the electrode, and the quantity of black matter obtained, and the quantity of copper dissolved to yield that product: for the analysis indicates an amount and diversity of impurities in copper that has never hitherto been thought of. Both the number and the proportions are startling. However, it is a known fact, that the more impure the copper is that is used for a pole, the black matter is not only more easily, but more abundantly produced.

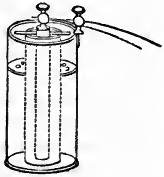
Another source of weakness to the electric current, and which affects more or less all batteries of whatever construction, arises from the action of the acid upon the zinc. The more freely this action is allowed to proceed the more constant and powerful is the battery. The acid in combining with the zinc forms a salt, which, if it adhered to the surface of the plate, would soon stop further action; but this salt being soluble in water, is dissolved from the surface of the plate as soon as formed, allowing a new surface to be exposed. But water can only dissolve a certain quantity of the salt, and its power of dissolving decreases as it approaches to the limit of saturation: hence there is a constant tendency to a decrease of power in the battery, and if means be not taken to withdraw the salt of zinc formed, the battery will continue to decrease in power, till at length it ceases to act. But long before the battery ceases to act, the presence of sulphate of zinc manifests itself in several ways, neutralizing the efficacy of the battery. The zinc salt, as it dissolves from the plate, being heavier than the acid solution, falls to the bottom; hence in a very short time the solution is formed of strata of different densities, and this induces a galvanic action between the lower and upper portions of the plates, both copper and zinc, and accounts for the deposition of zinc on the bottom part of the plates, as above referred to. This local galvanic action between the bottom and top parts of the zinc plate is sometimes so great when the battery has been long in action, as to double the thickness of the zinc plate at bottom, while the part near the surface of the solution is nearly penetrated by the acid; and when a battery is formed of a number of pairs, the terminal zincs are those most affected, the one forming the negative terminal or pole more so than the other. We have found a deposition of 6½ ounces of zinc upon the two lower inches of a plate terminal, which measured, in the solution, six inches by five, the battery having been in operation but eighteen hours. When this occurs, the quantity of electricity circulating through the battery is very small. Although this evil may not proceed to the extent of having quantities of zinc deposited upon the bottom part of the plates, still the tendency to deposition which every one who employs a battery must have observed, as also the more rapid action of the acid on the upper parts of the plates, shows that the action of the acid over the surface of the plate is very irregular, and consequently the quantity of electricity must be irregular in the same degree, often producing in the battery an intermittent action.

Various means have been devised for removing the sulphate of zinc, and adding corresponding quantities of new acid water; the most simple and effective of which, according to our experience, is to make the battery trough much deeper than is required for the plates, which may be supported either by grooves in the side of the trough, cut to the proper depth, or by a fillet of wood, or perforated false bottom; so that the zinc salt when formed may fall under the plates, and thus a much longer time elapse before its presence produces any decidedly bad effect.

There can be no doubt, we think, that some easy means will yet be devised for carrying off the dense solution of sulphate of zinc, before it rises to the plates, and for replacing it by acid water from above, thus giving to the battery a uniformity and steadiness of action it does not at present possess. There have been many ingenious contrivances tried for this purpose by the amateur, but we have seen none so simple and economical for manufacturing purposes, as that referred to.

DANIELL'S BATTERY.—A few years ago, some of the disadvantages now detailed were to a great extent overcome by a very ingenious arrangement discovered by the late Professor Daniell. The discovery consists in the separation of the zinc from the copper by a porous diaphragm, such as bladder, unglazed porcelain, etc., and the use of two distinct fluids. The portion of the battery containing the zinc is charged with dilute acid as before, but the portion containing the copper is filled with a solution of sulphate of copper. The action in this battery is similar to that described in the ordinary battery; the zinc is dissolved by the acid, but the hydrogen, instead of being evolved at the copper plate, combines with the acid of the sulphate of copper: metallic copper is thus set at liberty upon, and combines with, the copper plate of the battery, not only maintaining but improving its surface, during the evolution of a constant current of electricity. From the constancy of the current maintained the battery has been termed the *Constant Battery.* The construction of a single pair is described by Professor Daniell in the following terms:

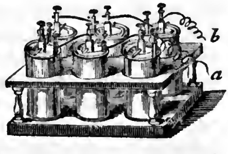
Fig. 553.



"A cell of this battery consists of a cylinder of copper 3½ inches in diameter, which experience has proved to afford the most advantages between the generating and conducting surfaces, but which may vary in height according to the power which it is wished to obtain. A membranous tube, formed of the gullet of an ox, is hung in the centre by a collar, and a circular copper plate, resting upon a rim, is placed near the top of the cylinder, and in this is suspended, by a wooden cross-bar, a cylindrical rod of amalgamated zinc, half an inch in diameter; the cell is charged with eight parts of water, and one of oil of vitriol, which has been saturated with sulphate of copper, and portions of the solid salt are placed upon the upper copper plate, which is perforated like a collander for the purpose of keeping the solution always in a state of saturation. The internal tube is filled with the same acid mixture without the copper. A tube of porous-earthenware may be substituted for the membrane with great convenience, but probably with some little loss of power.*

A number of such cells may be connected very readily, by attaching the zinc of the one to the copper of the other, and (as shown in Fig. 554) thus forming an intensity arrangement of great power and constancy.

Fig. 554.



This arrangement of battery is eminently suited to all kinds of electrical operations, and it may be borne in mind that it was by operating with this battery the idea of electro-metallurgy first occurred. In this battery we see that the evils arising from the slow liberation of the hydrogen from the surface of the negative metal, and the deposition of the zinc upon the copper, and also the blackening of the surface of the copper, are all surmounted. Nevertheless it is not used to any extent in the art of electro-metallurgy, it being much less economical than the ordinary batteries, from the quantity of copper salt necessary to keep it in a work-

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* Daniell's Chemical Philosophy, 2d edition, 1843, p. 504.

ing condition, and from the necessity of using porous diaphragms, which speedily wear out. If the diaphragm is made of animal membrane, the acid very soon destroys it; and although unglazed porcelain lasts a little longer, the acid acts upon the alumina, so that after a few days' working the diaphragm becomes too porous; and if the zinc plate touches the porous vessel, a circumstance very difficult to avoid, there is very soon formed in and upon the porous surface a deposit of copper which speedily renders the cell useless, besides producing a loss of copper. The saturation of the zinc solution, already spoken of, not unfrequently produces the same effects—the saturated portion of the bottom becomes reduced by the local action, and thus often a minute point of metallic zinc touches the cell, and forms a nucleus for a deposit of copper upon the porous cell, which spreads over the surface very rapidly. There are always pieces of amalgamated zinc, like fine scales, falling to the bottom of the cell, which also form nuclei for the deposition of copper upon the porous cell.

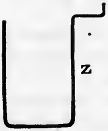
After the cells have been some time in use, if they are laid aside and allowed to dry, they are very liable to break. Care should be taken to keep them in clean water till the salts within the pores are dissolved out; but if this precaution is taken they may be preserved for a long time if only used occasionally.

The remarks upon the economy of the arrangement just described have reference to its use as an instrument, or separate battery, for the deposition of a metal in a separate cell (decomposition cell); but not to the arrangement known in electro-metallurgy as the *single cell* process, which is simply a modification of one pair of Daniell's arrangement; a description of which, with its comparative economy, will be given in another part of this treatise.

Professor Daniell says that any depth of cell may be used according to the power required, but this cannot be done with equal advantage, for a large surface of zinc in a cell is not the most economical, when a great quantity of electricity is required.

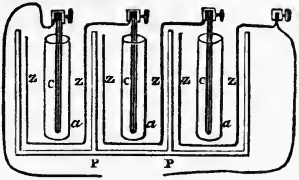
GROVE'S BATTERY.—Another battery, constructed upon the same principle as Daniell's, but differing in the arrangement of the metals, and the substances used to excite them, was invented by Mr. Grove, and is known as *Grove's Battery*. In this arrangement, platinum is used instead of copper, and strong nitric acid instead of the sulphate of copper of Daniell's battery. One pair may be fitted up conveniently in a tumbler or jelly-pot. A cylinder of zinc is placed inside the tumbler; within this cylinder is placed a porous vessel, in which is a slip of platinum either in sheet or foil; the porous vessel is filled with strong nitric acid, and the tumbler with dilute sulphuric acid: a wire is next attached to each metal, and the battery is complete. When a series of pairs is to be used, the form we have found most convenient is to arrange the metals in the same manner as we have

Fig. 555.



described for Wollaston's trough (page 518). The zinc is formed in the same shape as shown by Fig. 555. The zinc is placed in the cell of the trough, and the porous vessel which should be flat is placed within the zinc, so that the platinum in it may be connected with the zinc of the neighboring pair, as represented in figure 556.

Fig. 556.



zzz, Are the zinc plates of the form of figure 555.

aaa, Porous cells filled with nitric acid.

ccc, Plates of platinum united to the zinc at top by binding screws.

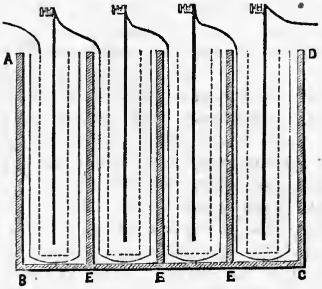
pp, Are partitions. The divisions of the battery trough need not be water tight, but merely such as will prevent the zincs from touching one another.

It will be seen that by this means any number of pairs may be easily arranged. Care, however, must be taken, when fitting up such an arrangement, that the platinum be kept closely connected with the zinc by a large surface, otherwise the platinum will be fused at the connections. A flat piece of wood, with a groove to fit the zinc, is often made the means of keeping the two metals together, but we prefer flat binding screws of brass, for if kept clean they assist the connection, being good conductors. The fusion of the platinum connections, a practical and often expensive annoyance, may, however, be completely prevented by coating about half an inch of the end of the platinum, either with copper or silver, which is easily effected by the electro-process: the coated part is then connected with the zinc by any convenient means without the risk of fusing.

Figure 557 represents a section of Mr. Grove's nitric acid battery, in a series of four pairs of zinc and platinum. The outer thick line, A B C D, is an earthenware trough, which is divided into four cells. The dotted lines represent four porous vessels, of a size sufficient to contain about double the quantity of liquid that is contained between the outer surfaces of the porous vessels and the earthenware cells. The dark central lines are the plates of amalgamated zinc; and the thinner lines, that bend round under the porous cells, show the position of the platinum foil, which is attached to the zinc plate by small screws.

This form of battery is also free from some of the objections to the common battery, but it is seldom or never used in the ordinary processes of electro-metallurgy. Its advantages over every other known form of battery are, its great activity of action, and intensity or power of current—a circumstance not generally sought after by electro-metallurgists. But if it were duly considered that a battery consisting of three pairs of zinc and platinum is far more effective than an ordinary battery of ten or twelve pairs (although the elements of its construction are more expensive), it would stand a fair chance of being adopted as the more economical battery of the two.

Fig. 557.



The porous cells have not the objection of being closed up by the deposition of metals upon or within them; but they are affected by the acids, and by long working they become too porous, the nitric acid passing through and causing rapid destruction of the zinc. It wants the constancy of Daniell's, its quantity declining rapidly when long in action—one feature we have often experienced which we have not seen observed by other experimenters. When working with a Grove's battery of from eight to twelve pairs, the platinum being six inches by seven inches, after the battery was in action for four or five hours, during which it diminished in quantity gradually, all of a sudden it seemed to recover its energy, giving a quantity and power not much less than it gave in the first hour, and then declined again rapidly, but occasionally renewing its vigor for short periods. We have thought it probable that this reaction may be caused by the formation of nitrate of ammonia in the rapid decomposition of the nitric acid during the first action of the battery, which, as it accumulates, may be reacted upon.

The prevailing and permanent objection to the use of this arrangement, not only for manufacturing purposes, but for many experimental purposes, is this, that it emits nitrous fumes which corrode every thing within their reach, and prove very disagreeable to every person breathing them. For a small single pair of Grove's battery it is very convenient to use a circular form, in which case a little cylinder of wood, bored so that its sides be about ¼th of an inch thick, does well for a porous cell, and will last a long time.

Bunsen's Battery is a modification of Groves' and much used on the continent for electrical purposes. Carbon is used instead of the platinum, and for convenience it is generally made cylindrical. The mode of construction is to form a hollow cylinder by coking pounded coal in an iron mould, then soaking the coke cylinder in a solution of sugar and calcining a second time, which gives great compactness. The porous cell containing the zinc and dilute acid is placed in this cylinder, and the whole put into a glass or stoneware vessel charged with nitric acid; of course the coke cylinder and zinc are connected, and thus the battery is completed.* Nitrous fumes are evolved from this battery also.

SMEE'S BATTERY.—Some of the defects in the common battery of zinc and copper were much lessened by an ingenious contrivance of Mr. Alfred Smee. This gentleman had observed that if the copper plate of the battery be roughened, either by corrosive acids or by rubbing the surface with sand paper, its action was made much more efficient, the rough surface evolving the hydrogen much more freely. Taking advantage, therefore, of this principle, he covered platinum foil with a finely divided black powder of platinum, deposited by electricity from a solution of that metal, and used this in place of the copper in the ordinary battery. Instead of platinum foil, Mr. Smee soon after adopted silver foil, which is much less expensive. The method of preparing these plates is given by Mr. Smee as follows:—"The silver to be prepared for this should be of a thickness sufficient to carry the current of electricity, and should be roughened by brushing it over with a little strong nitric acid, so that a frosted appearance is obtained. It is then washed and placed in a vessel with dilute sulphuric acid, to which a few drops of nitro-muriate of platinum has been added. A porous tube is then placed into this vessel with a few drops of dilute sulphuric acid; into this tube a piece of zinc is put, contact being made between the zinc and silver; the platinum will, in a few seconds, be thrown down upon the silver as a black metallic powder. The operation is now completed, and the platinized silver ready for use."† A simple method, which obviates the use of a battery is thus described: lay the silver between two pieces of sand paper, and press it with a common smoothing iron, then pull the silver out while under the pressure. The platinum solution is made very hot, and the silver dipped in it for some time, which effects the coating.

The nitro-muriate of platinum is easily prepared: take one part of nitric acid, and two parts of hydrochloric acid (muriatic acid); mix together and add a little platinum, either as metal or sponge; keep the whole at or near a boiling heat; the metal is then dissolved; forming the solution required.

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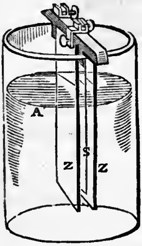
* A more simple and less expensive modification of this arrangement, is to put a solid bar of carbon or coke into a porous cell filled with nitric acid, which is placed in a stone or glass jar filled with dilute sulphuric acid, having a cylinder of zinc surrounding the porous cell, leaving about one inch of space between the porous cell and zinc, similar to a Daniell's, forming a modification of Grove's, having carbon instead of the platinum.

† Smee's Elements of Electro-Metallurgy, 2d edition, p. 24, 1843.

Several experiments have been tried with a view to substitute a cheaper metal than silver to deposit the platinum upon, but not with much success. Cheap metals have also been coated with silver by the electro-process, and been used for depositing the platinum upon. The most successful is a composition metal made of tin, lead, and a little antimony, rolled into sheet and plated by silver; this was found very convenient, because it could be easily bent into any required shape, and it keeps its place without the necessity of fixing in frames as required by thin silver; nevertheless, for constant work these plates are found not to present any permanent advantage, and have been abandoned; besides, to give a sufficient coating of silver, becomes as expensive as silver foil.

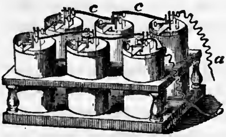
Mr. Smee, in constructing his battery, has been guided by the expense of the silver, and therefore reverses the order of arrangement introduced by Wollaston, by surrounding the platinized silver with the zinc. Fig. 558 represents a single cell of this form of battery. A, is the jar containing the solution. Z Z, the two amalgamated zinc plates. S, the platinized silver plate. The whole are suspended by a cross bar of wood; and as it is essential to the proper working of the battery that the plates be always parallel to one another, the wooden frame is generally extended round the edge of the thin silver plate, though it is not so represented in the figure. One of the clamps at the top of the wooden bar is connected with the platinized silver plate, and the other with a pair of zinc plates. Instead of a glass or stoneware jar, small square troughs, made of gutta percha, are often used for the Smee's battery, as they suit admirably, and are not liable to break.

Fig. 558.



When *intensity* of electricity is required, it is necessary to use a number of such cells, which may be arranged in a wooden frame, in the manner shown by Fig. 559, where *a b* represent the two poles of the battery, and *c c* the wires by which the cells are connected with one another.

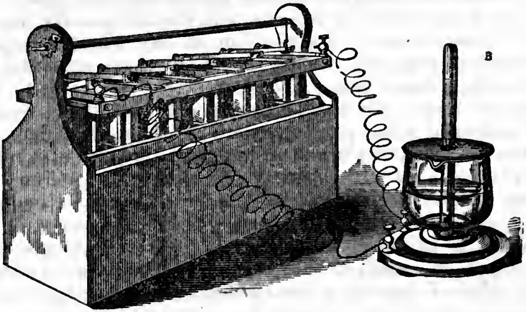
Fig. 559



A superior form of compound Smee's battery, contrived by Acland, is represented in Fig. 560. In this apparatus the plates are all connected to a frame that can be elevated or depressed by means of an iron rod and rachet wheel, so that the plates may be either partially or entirely immersed in the solution, or raised at pleasure out of it. The connections are so contrived, that by a slight alteration the battery is adapted to afford either *quantity* or *intensity* of electric power. It is usually made to contain six cells, any number of which can be used at once that a given process may require. The exciting fluid is contained in an incorrodible stoneware trough, placed in a mahogany box. A battery of this description, each silver plate of which measures 20 square inches, has sufficient power, when decomposing water, to disengage one cubic inch of mixed gases in 50 seconds, and will heat to redness 4 inches of platinum wire.

Letter B in Fig. 560 represents an apparatus for showing the decomposition of water into oxygen and hydrogen gas by the voltaic battery.

Fig. 560.



It will be observed in Smee's arrangement that there are two surfaces of zinc, in every pair exposed to the acid, which do not give off any electricity, but when long in use are much acted upon, forming a consideration of some value to a manufacturer.

The silver used is very thin, and liable to crack when taken from its frame, and therefore cannot be made into different constructions of battery in the same manner as we can do with copper. It is also liable to have zinc deposited upon its surface when long in action.

There is we believe no arrangement of battery better known and more used by amateur electrotypists than Smee's, and there are probably none better adapted for small operations; but it has not been introduced to any extent in the factory. When used in series, the advantages it possesses over Wollaston's do not counterbalance the extra labor and expense attending its use, and many who have tried it in the operations of the factory have for these reasons given it up.

Numerous modifications of these different batteries have been proposed from time to time, intended for different objects, but those given embrace all that are used for electro-metallurgical purposes. Owing to the apparent advantages of certain forms of battery, the following may be referred to:

Earth Battery.—The fact that when a piece of copper and a piece of zinc are imbedded in the earth and connected by a wire, there is a current of electricity obtained from them, in the same way as if they were placed in any battery trough, instantly suggested the application of the earth, or what is termed an earth battery, to the purposes of depositing. We need hardly say these trials were without success. The electricity obtained in this way is very weak, depending wholly upon the moisture of the earth, and the arrangement forming therefore simply a water battery. We have made electrotypes by this means, and also plated small articles, but the action or deposition is very slow. We have obtained a greater amount of deposition in five minutes from one square inch of zinc and copper placed in dilute sulphuric acid, than from four feet of zinc and copper placed in the earth in the space of an hour. An earth battery adapted to deposit from 150 to 200 ounces of silver per day, would require acres of land.

In this as in all other forms of battery the deposit is in relation to the zinc oxidated in the battery; there would therefore be no economy in using the earth battery, and to lessen the amount of surface required by an intensity arrangement, would not alter the law, but rather add to the expense, as it would require upwards of 100 pairs in the earth to be equal to 3 or 4 pairs of Wollaston's for the object of depositing; and would thus be adding to the cost of depositing one hundred times the equivalent of zinc instead of four times its equivalent.

MAGNETO-ELECTRIC MACHINE.—Several years ago, Mr. Woolrich, of Birmingham, patented a discovery for applying to the deposition of metals the electricity obtained from magnetism or the magneto-electric current, instead of voltaic electricity. We have never had an opportunity of operating with Mr. Woolrich's machine, nor of seeing it in operation for the purpose of deposition. We cannot speak of it from experience; but, from a statement made at the meeting of the British Association in 1850, by Mr. Elkington, of Birmingham, who is the proprietor of the patent, and a gentleman of most extensive experience, it would seem that he had up to that time never been induced to give up the ordinary battery in favor of magnetism or any other suggested improvement. We understand however that this means of obtaining the electricity for the purposes of electro-metallurgy has recently been much improved, by forms of magnets, etc., patented by Mr. Millward, and described by him as follows: "The first branch of the improvement is carried into effect by the employment of an electro-magnet formed by a current of electricity produced from a magneto-electric machine, instead of that generated in a voltaic battery; and such an electro-magnet may be very advantageously used for magnetizing large bars of steel, or for producing very powerful magnets. Any of the known forms of magneto-electric machines will serve thus to convert a bar of steel to an electro-magnet, but the patentee prefers to use one composed of four, eight, or any other number of permanent magnets, having double the number of armatures, and coiled with strong wire of about 60 feet in length. The machine about to be described has been found to answer well in practice. In this machine the steel magnets are composed of eight plates of a U form, weighing about 30 lbs. each plate, and there are eight such compound magnets, all the north poles of which are arranged on one side of the machine, and the south poles on the other side, although this precise arrangement is not essential, and may be varied. The armatures are of soft iron, weighing about 15 lbs., and are coiled about with 60 feet of copper wire of No. 4 gauge, and insulated in the usual manner. The armatures revolve in a brass wheel, and are caused to pass as near to the poles of the magnets as practicable, the commutator or break acting on the whole eight magnets at the same instant, so that the current of electricity shall always pass in one direction, and the surface of the whole of the 64 plates be in combination at the same time. The bar of soft iron used as the electro-magnet with this machine weighs about 500 lbs., and is coiled with bundles of about 30 copper wires of No. 16 gauge, and about 60 feet in length (the bundles are formed by binding a series of uncovered wires together into one covered strand or bundle), and the power of the electro-magnet will depend upon the power of the permanent magnets used in the machine, both as to the weight it will support from a keeper, and as to its capability of rendering bars of steel permanently magnetic by contact therewith. It will therefore be evident that by having two sets of the permanent magnets, and changing them in such machine, their supporting power may be increased by continued charges or passes from the electro-magnet thus produced. In one form of electro-magnetic machine represented and described under the second head of the invention, the steel bars or permanent magnets are eight in number (these bars may be of cast or soft iron, but when soft iron is employed, bars of steel permanently magnetized will have to be used in conjunction with them), of a U form, and arranged around a circle with their poles pointing towards the centre. Each arm of each of the magnets has attached to it straight bars of steel, also rendered permanently magnetic (of which any desired number, and of any length or size, may be employed, according to the strength of magnet required), which are so placed as to be out of the influence of the armatures when the latter are revolving. The poles of the U-shaped magnets are, on the contrary, as nearly as possible in contact with the armatures which revolve within the circle formed by them, either between the poles or in front of them. Instead of the bars which form the circle being of steel and magnetized, they may be made of soft iron, and depend for their magnetism upon the magnetic bars before named placed around them. In another form of machine both the magnets and armatures are stationary, and the commutator alone has motion between the poles of the horse-shoe magnets and the armatures, being mounted on a spindle and caused to revolve by a band from some driving machinery. The commutator, or break-piece, is composed of a brass centre, with four radial arms of soft iron, either solid or formed of two or more plates."—*See Repertory of Patent Inventions, vol.* 18, *for* 1851, *and Sketches therein.*

The quality of these machines for depositing depends much upon their sustaining power. Eight of these sets of plates or magnets, containing altogether about 12 cwt. of steel, in a proper state of working, are said to form a battery capable of depositing from 12 to 20 ounces of silver per hour, but it is not stated, however, upon what extent of surface this takes place. The relative economy of these magnets over the galvanic battery has not been so great as to recommend their general adoption. We have, however, no doubt that, as such a machine gives electricity of great intensity, it may be superior to the galvanic battery for some purposes, and may give properties to the deposited metals which the ordinary battery does not.*

Before concluding the description of batteries, we may briefly notice one or two little conveniences which are indispensable to the operation. The first of these is what are termed *binding screws*, by which the parts of batteries, as we have shown by numerous figures, are connected together, or by which their poles are connected to the objects through which the voltaic current is to be passed. They are usually made of brass, and of various forms, according to the shape of the objects that are to be connected.

Figures 561 to 566 represent some of the most useful kinds; Fig. 561 is used to connect wires together; Figs. 563 and 565 are required for Smee's battery (see Fig. 559); Fig. 565, to connect the plates of Grove's battery (Fig. 557); Figs. 563 and 564 are used for Daniell's battery; the latter for connection with a zinc rod, the

Figs

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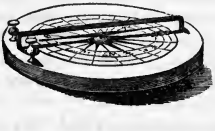
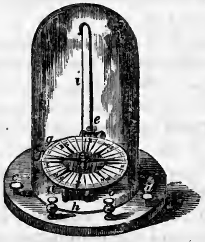
566.

Figs. 567



568.



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* For some particulars of the working of electro-magnetic machines, see Shaw's Manual of Electro-Metallurgy, 2d edition, 1843.

former to bind plates together. In all cases, the parts that touch the surfaces to be connected must be perfectly clear and bright.

In many cases, when a complicated apparatus has been put together, it is desirable to ascertain whether the connections are all perfect. This is best determined by means of a galvanometer, two varieties of which are represented by Figs. 567 and 568.

CHAPTER XXVI.

ELECTROTYPE PROCESSES.

SINGLE-CELL OPERATIONS.—We shall now proceed to detail the process of electrotyping, the materials for which are of the most simple nature. Let us suppose that the object of the student is to copy a copper medal—for example, the side of a penny-piece. Dissolve a quantity of the crystals of sulphate of copper in any convenient vessel; if distilled water can be had, the better. This is conveniently done by suspending the crystals in a coarse cloth on the surface of the water, or the crystals may be put into the water, and well stirred, till dissolved; crushing the crystals facilitates their solution. The water should be kept cold and be fully saturated with the salt, and the solution allowed to stand untouched for several hours. This last precaution is not always essential, but only necessary when the copper solution is not perfectly clear and transparent.

The sulphate of copper of commerce has often a large quantity of iron in it, a portion of which becomes per-oxidized, and will precipitate or fall to the bottom of the solution on standing; indeed, when it is known that the salt contains much iron, it is best to crush the salt very fine, and expose it to the air for some time; when dissolved, after this exposure, a great quantity of iron will settle at the bottom of the solution, which should be carefully decanted and the last portion filtered. The clear solution should now have about one-fourth of its quantity of water added to it, as a completely saturated solution is not the best. A newly-formed solution does not deposit so freely as one that has been in use for some time. The addition of a few drops of sulphuric acid, or, what we have found better, a little sulphate of zinc—about one ounce to the pound of sulphate of copper—improves the condition of a new solution.

Next, put the solution of sulphate of copper into the vessel intended for use, say it is a large jelly-pot, in which let a vessel of unglazed porcelain (porous vessel) be placed, filled to within half an inch of the mouth with a mixture of 24 parts water and 1 sulphuric acid, taking care that the copper solution is of the same depth as the solution in the porous cell.

Preparation of the Coin.—A fine copper wire must now be put round the edge of the coin and fastened by twisting. Then cover the back part, upon which the deposit is not required, with beeswax or tallow, or, what is better, imbed the back of the coin with gutta percha. Have the fore part or face well cleaned, and the surface moistened with sweet oil, by a camel's hair pencil, and then cleaned off by a silk cloth, till the surface appears dry; or, instead of oil, the surface may be brushed over with black lead, which will impart to it a bronze appearance. The use of the oil or black lead is to prevent the deposit adhering to the face of the coin. A very common and excellent method to prevent the copper deposit adhering to the copper mould is this:—Take a gill of rectified spirits of turpentine, and add to it about the size of an ordinary pea of beeswax. When this is dissolved, wet over the surface of the mould with it, and then allow it to dry: the mould is then ready to put into the solution. Medals taken from moulds so prepared retain their beautifully bright color for a long time. But when fine line engravings are to be coated, the little wax dissolved in the turpentine may be objectionable; so also is black lead, for both have a tendency to fill up the fine lines. In this case, let the wash with turpentine be wiped off by a silk handkerchief, instead of drying it: but for ordinary medals this objection will scarcely apply. This being done, the opposite end of the copper wire round the penny-piece is to be connected with a piece of amalgamated zinc, either by means of a binding screw or a hole in the zinc. Then place the zinc in the acid within the porous cell, and put the penny-piece into the copper solution: bring the face of the coin parallel to the zinc, at the distance of about half an inch or one inch from the porous vessel. Deposition immediately begins, and the metal thickens according to the length of time the action is kept up. In about twenty-four hours, the deposit will be of the thickness of a common card, and it may then be taken off. The zinc is to be brushed and washed, before it is put aside. The wire round the coin is now to be untwisted, and by a slight turn will come off easily. The deposit is also easily separated from the mould, which will be a perfect counterpart of the face of the penny-piece.

This mould is next to be treated exactly as described for obtaining it from the penny-piece, and the deposit from it will be a *fac-simile* of one side of the penny-piece. With care, any number of duplicates may be taken from this mould.

It need hardly be remarked, that as copper is deposited the solution becomes proportionally exhausted, and in a short time the current of electricity passing will be too much for the strength of the solution, which will then give a deposit of a sandy consistence, without tenacity.* It is therefore necessary, while the deposition is going on, to suspend some crystals of sulphate of copper at the

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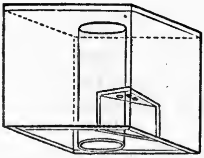
* **See Laws of Deposition, page 20.**

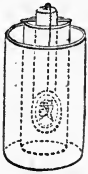
top of the solution, which, as they dissolve, will maintain its strength.

Forms of Apparatus.—It will be observed that no particular form of apparatus is required for electrotyping, but certain modifications may be adopted for convenience and economy. As every portion of the zinc in the acid is capable of giving off electricity, by placing the cell that contains the zinc in the centre of the copper solution, moulds may be suspended on each side of that cell. We have also observed that the zinc plate should not be allowed to touch the cell, as the copper will be reduced upon it and the cell destroyed. To avoid this, the zinc may be suspended by a small wooden peg, put through it and made to rest upon the edges of the cell. Figures 569, 570, 571, 572, represent several convenient forms of apparatus for electrotyping.

Figs. 569



570



571.

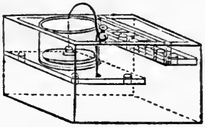
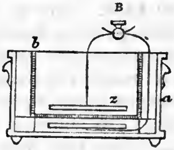


Fig. 572 is a form of the apparatus which the author has used for many years with great success, being both cheap and effective. *a* is a large jelly-pot holding the copper solution; *b* is a flat porous cell, about 4 inches square and half inch wide; *z* the zinc plate. Amalgamated metals may be suspended upon both sides, and the strength of the solution is maintained by suspending a few crystals of the salt in a little cloth bag upon the surface of the solution.

Fig. 572.



Instead of porous vessels made of earthenware, a bladder may be used, in which the acid and zinc are placed. We have also seen a vessel divided by a porous partition, being either a plate of biscuit porcelain, plaster of Paris, very thin sycamore wood, or dressed skin. The porcelain, as before mentioned, is the best: plaster is too porous, and the solution soon destroys it: wood is too close, and the deposit is consequently very slow: skin does very well for a short time, but it is soon destroyed. When porous cells were not convenient, we have made electrotypes by wrapping the zinc plates in two or three folds of stout cartridge paper, moistened with a solution of salt, and placing this in the copper solution with the mould. Of course, this is only to be adopted when a porous vessel cannot be obtained. The paper lasts but a short time, and has, therefore, to be frequently renewed; besides which, there is always a deposit of copper upon the paper, thus occasioning a loss.

Common coarse garden-pots answer excellently for porous vessels, closing the aperture at bottom by a cork.

The precautions that have been given (see Daniell's Battery, p. 39), as to the preserving of the porous cells when not in use, are applicable to the cells or partitions used in these processes, which, when not in use, should be kept in water, or should not be allowed to dry until they have been in water long enough to dissolve out the salts that were within the pores of the cell; otherwise the salts crystallize, and either crack the cell or cause it to scale off in small pieces. Porous cells, when not thoroughly washed and freed from salts, if laid aside for a few days, often thrown out an efflorescence, or crystalline growth, like mould, of a soft silky texture, and from one-half to one inch in length. An analysis of this efflorescent matter gave

Oxide of zinc	39·6
Sulphuric acid	26·0
Water	34·2
	99·8

Comparative Value of Exciting Solutions.—We have recommended the porous cell being filled by dilute sulphuric acid, which we consider best; but other saline solutions will serve the same purpose: solutions of common salt, sal ammoniac, sulphate of zinc, have been recommended, and each has been called best in its turn. The following results of experiments with these solutions in the porous cell will show their relative qualities, and enable the student to judge for himself. The size of the zinc plate in the cell used in these experiments measured 6 inches by 6 inches; the copper plates upon which the deposits were formed were the same size; the solution of copper was kept at the same strength; the time that each was in solution was 16 hours.

Solution in porous Cell.	Zinc dissolved.			Copper deposited.		
	oz.	dwt.	gr.	oz.	dwt.	gr.
Sal ammoniac.						
Saturated solution	1	5	14	1	2	12
1 part saturated solution 1 part water	1	8	5	1	3	10
1 part saturated solution 3 parts water	0	12	13	0	10	17
Common Salt.						
Saturated solution	0	16	3	0	14	12
1 part saturated solution 1 part water	0	18	9	0	17	8
1 part saturated solution 3 parts water	1	0	5	0	19	16
Sulphate of Zinc.						
Saturated solution	1	3	18	0	19	0
1 part saturated solution 1 part water	1	0	8	0	19	18
1 part saturated solution 3 parts water	0	14	16	0	14	8
Sulphuric Acid.						
1 part to 8 of water	3	1	6	1	4	8
1 part to 16 of water	2	11	8	2	1	8
1 part to 24 of water	2	7	3	2	5	6

How often Solutions should be Changed and Zinc Amalgamated.—Students have often put this question to us: How often should the solution in the cell be renewed, and the zinc plate be amalgamated? The following are the results of many trials made to ascertain the facts necessary to answer this inquiry. The zinc plates used were nearly one foot square, and the copper plate upon which the deposit was made was of the same size as the zinc plates.

In the first series the zinc plates were not taken out either to brush or re-amalgamate, neither were the solutions renewed during the time specified.

		Copper deposited.		Zinc dissolved.	
		oz.	dwt.	oz.	dwt.
2 lb. common salt in one gallon of water	24 hours	12	9	12	17
	48 hours	17	13	20	17
	60 hours	24	15	34	3
2 lb. sulphate of zinc in one gallon of water	24 hours	9	13	9	18
	48 hours	16	4	17	10
	60 hours	23	10	24	8
1 lb. sulphuric acid to 24 of water	24 hours	15	17	17	15
	48 hours	27	16	32	3

From these results it is evident that the best and most economical manner of treating the solution and the zinc would be to renew the solution every 24 hours, as the second 24 hours do not give, without renewal, above half the deposit of the first 24 hours, while the waste of zinc is very little less than in the first.

The next series of experiments was with the same zinc and the same kind of solutions, but the zinc was taken out every 24 hours, and brushed, but not re-amalgamated, and put back again with new solution in the porous cell.

		Copper deposited.		Zinc dissolved.	
		oz.	dwt.	oz.	dwt.
Salt and water .	4 days of 24 hours .	49	16	51	8
Sulphate of zinc .	4 days of 24 hours .	47	14	48	9
Acid and water .	3 days of 24 hours .	48	13	53	7

These results give the most ample reply to the question so often put, and will guide the manufacturer as well as the student in his operations, whether time or material be of the greatest consequence to him.

We may remark that the sulphate of zinc solution does not require renewal, but simply that we half empty the cell and refill it with water. The sulphate of zinc poured out being nearly saturated, may be crystallized, and will serve for other electro-metallurgical operations.

MAKING OF MOULDS.—The directions giving for obtaining a mould from a penny-piece, by deposition, are applicable to taking moulds from any metallic medal, engraving, or figure that is not undercut; and for depositing within the moulds so produced. On the first discovery of this art, the electrotypist was confined to metallic moulds, as the deposition would not take place except upon metallic surfaces; but the discovery that plumbago, or black lead polished, had a conducting power similar to that of metal, and that the deposit would take place upon its surface with nearly the same facility as upon metal, freed the art at once from many of its trammels, and enabled the operator to deposit upon any substance —wood, plaster of Paris, wax, etc.—by brushing over the surface with black lead. It obliged the electro-metallurgist, however, to render himself expert in the art of moulding, since no good electrotype can be obtained without a perfect mould. We shall, for this reason, endeavor now to give such instructions as will enable the student to make good moulds after a very short practice; but we need hardly add, that in this as well as in every operation, however plain may be the instructions and easy the manipulations, practice is necessary to ensure success; so that the student ought not to lose patience should his first attempt not succeed to his wishes. The substances used for taking moulds from objects to be copied by electrotype are beeswax, stearine, plaster of Paris, and fusible metal; recently, gutta percha has been very successfully used. The articles to be copied are generally composed either of plaster of Paris or metal. Suppose, in the first place, the article to be copied is of metal, and a mould is to be taken from it in wax or stearine. The latter we have not found to answer well alone; when used it should be mixed with wax, about half-and-half.

PREPARATION OF WAX.—Whether the beeswax have stearine in it or not, it is best to prepare it in the following manner:—Put some common virgin wax into an earthenware pot or pipkin, and place it over a slow fire; and when it is all melted, stir into it a little white lead (flake white)—say about one ounce of white lead to the pound of wax; this mixture tends to prevent the mould from cracking in the cooling, and from floating in the solution: the mixture should be re-melted two or three times before using it for the first time.

TO TAKE MOULDS IN WAX.—The medal to be copied must be brushed over with a little sweet oil: a soft brush, called a painter's sash tool, suits this purpose well: care must be taken to brush the oil well into all parts of the medal, after which the superfluous oil must be wiped off with a piece of cotton or cotton wool. If the medal has a bright polished surface, very little oil is required, but if the surface be *matted* or *dead*, it requires more care with the oil. A slip of card-board or tin is now bound round the edge of the medal, the edge of which slip should rise about one-fourth of an inch higher than the highest part on the face of the medal: this done, hold the medal with its rim a little sloping, then pour the wax in the lowest portion, and gently bring it level, so that the melted wax may gradually flow over; this will prevent the formation of air bubbles. Care must be taken not to pour the wax on too hot, as that is one great cause of failure in getting good moulds; it should be poured on just as it is beginning to set in the dish. As soon as the composition poured on the medal is *set* (becomes solid), undo the rim, for if it was allowed to remain on till the wax became perfectly cool, the wax would adhere to it, and being thus prevented from shrinking, which it always does a little, would be liable to crack. Put the medal and wax in a cool place, and in about an hour the two will separate easily. When they adhere, the cause is either that too little oil has been used, or that the wax was poured on too hot.

ROSIN WITH WAX.—Rosin has been recommended as a mixture with wax; mixtures of which, in various proportions, we have used with success; but when often used, decomposition, or some change takes place, which makes the mixture granular and flexible, rendering it less useful for taking moulds. When rosin is used, the mixture, when first melted, should be boiled, or nearly so, and kept at that heat until effervescence ceases; it is then to be poured out upon a flat plate to cool, after which it may be used as described.

MOULDS IN PLASTER.—If a plaster of Paris mould is to be taken from the metallic medal, the preparation of the medal is the same as described above; and when so prepared with the rim of card-board or tin, get a basin with as much water in it as will be sufficient to make a proper sized mould (a very little experience will enable the operator to know this), then take the finest plaster of Paris and sprinkle it into the water, stirring it till the mixture becomes of the consistence of thick cream; then pour a small portion upon the face of the medal, and, with a brush similar to that used for oiling it, gently brush the plaster into every part of the surface, which will prevent the formation of air-bubbles; then pour on the remainder of the plaster till it rises to the edge of the rim: if the plaster is good, it will be ready for taking off in an hour. The mould is then to be placed before a fire, or in an oven, until quite dry, after which it is to be placed, back downwards, in a shallow vessel containing melted wax, not of sufficient depth to flow over the face of the mould, allowing the whole to remain over a slow fire until the wax has penetrated the plaster, and appears upon the face. Having removed it to a cool place to harden, it will soon be ready for electrotyping. If the mould is large and the plaster thick, the wax may be put upon the surface, and only as much as will penetrate a small way into the plaster. In both these instances the wax used is generally lost, and there is always liability of the copper solution passing through, and causing what is termed *surface deposit*, making the face of the medal rough. We may remark that, although occasionally there may be a very good electrotype obtained from a plaster mould, still they are in general very inferior; as the saturating of the plaster has a tendency to blunt the impression, and the wax used for the purpose of saturation becomes expensive. It may be partially recovered by boiling the plaster in water: the wax melts out, and is obtained when the water cools. Plaster should not be used for moulds where wax can be employed, being neither so good nor so economical; but there are cases in which the moulds being very large, the use of plaster is unavoidable.

MOULDS IN FUSIBLE ALLOY.—The next means of taking moulds is by fusible metal. This name is given to alloys of two or more metals which melt at a very low temperature; it suits the purpose of taking moulds of small objects very well. The following are examples of such compositions:

Tin.	Lead.	Bismuth.	Zinc.
1	1	2	0
1	2	3	0
1	0	1	1

These all melt at a temperature below that of boiling water. The ingredients are melted together in an iron ladle, poured out upon a flat stone, broken up, and re-melted in the same way two or three times, in order that they may be thoroughly mixed. The medal from which the mould is to be taken is prepared in the same manner as described for wax.

The fusible alloy is melted and poured into a saucer, or, what does better, a small wooden tray. The operator now watches till it cools down into a semifluid state, or to the point of setting, when he brings the medal suddenly upon it, face downwards, and holds it there until the alloy has fairly set; he then allows it to cool, and undoes the slip around the medal, from which the mould will easily separate. The height of the slip of paper above the surface of the medal determines, of course, the thickness of the mould. The beginner very seldom succeeds in his first attempts at making moulds in fusible alloy; but as a little experience teaches more than the reading of an essay upon the subject, he will soon find both his patience and labor rewarded with gratifying success. Some of the finest moulds are taken by this process, but, from the constant loss of the materials by oxidation, etc., it is expensive, so that its use amongst electro-metallurgists is very limited.

MOULDS IN GUTTA PERCHA.—Gutta percha, as a material for moulding, serves the purpose most admirably. We have seen moulds of this substance equal if not superior to any that we ever saw taken in wax, and of a depth of cutting which it would have been very difficult to have taken in wax. The method adopted for taking moulds is to heat the gutta percha in boiling water, or in a chamber heated to the temperature of boiling water, which makes it soft and pliable. The medal is fitted with a metallic rim, or placed in the bottom of a metal saucer with a cylindrical rim a little larger than the medal; the medal being placed back down, a quantity of gutta percha is pressed into the saucer, and as much added as will cause it to stand above the edge of the rim. It is now placed in a common copying-press and kept under pressure until it is quite cold and hard. The impressions taken in this way are generally very fine. When the medal is not deep cut a less pressure may suffice, but when the pressure is too little the impression will be blunt.

Gutta percha takes a coating of black lead readily, and the deposit goes over it easily.

A mixture of gutta percha and marine glue has been recommended for moulds as superior to gutta percha alone. We have not had an opportunity of using this mixture, but have every confidence in the recommendations given of it.

MOULDS FROM FERNS, SEA-WEED, ETC.—A method of taking impressions of fern-leaves and sea-weeds has recently been proposed by Dr. F. Branson, in the *Athenæum*. It is thus described:

"A piece of gutta percha, free from blemish, and the size of the plate required, is placed in boiling water. When thoroughly softened it is taken out and laid flat upon a smooth metal plate and immediately dusted over with the finest bronze powder used for printing gold letters. The object of this is threefold—to dry the surface, to render the surface more smooth, and to prevent adhesion. The plant is then to be neatly laid out upon the bronze surface and covered with a polished metal plate either of copper or of German silver. The whole is then to be subjected to an amount of pressure sufficient to imbed the upper plate in the gutta percha. When the gutta percha is cold, the metal plate may be removed and the fern gently withdrawn from its bed. A beautiful impression of the fern will remain." An electrotype may be deposited upon the bronzed or black leaded gutta percha.

We have seen many electrotype leaves done by this method, which were certainly very pretty as electrotypes, and the process is well adapted for flat leaves; but the pressure required renders it unsuitable for some kinds of leaves—indeed, it destroys the natural forms of the greater number both of leaves and sea-weeds. The products of the process cannot, indeed, be compared with those electrotype leaves the moulds of which are taken by wax. The great merit of the process is its ease and simplicity. The method given for taking the mould of the leaf is suitable for any kind of flat mould in gutta percha. The mould of a leaf may be taken in plaster by placing the leaf upon dry sand and pressing the sand under and on each side to fill up the spaces under the leaf so as to bear the pressure of the plaster, putting a collar of paper round the sand to prevent its yielding, and then pouring the plaster over the whole. When the plaster is set, the leaf is removed and the plaster trimmed round with a knife. This also has its difficulties; for when leaves have hairs upon them they stick into the plaster. The method of taking moulds of leaves in wax is by holding the leaf in the hand and brushing a thin layer of melted wax over the surface to be moulded; allowing this to harden, and then brushing on another layer—and so on until the wax is sufficiently thick to suffer handling. The leaf is then gently drawn off the wax, which is to be black-leaded, and put into the electrotype apparatus to receive the coating of copper. A type of the leaf is by this means obtained with all its natural convolutions.

Nature Printing.—A further improvement upon making moulds of leaves and other vegetable objects, has been practised by an eminent firm in London. The leaf is carefully dried and laid upon a smooth piece of milled lead, which is placed between two steel plates, and passed between rollers, these press the leaf into the lead, and produce a complete mould. Copies from this may be taken with gutta percha or electrotype. Printed impressions of leaves, sea weed, and such like objects, prepared in this way, may be seen in an excellent work published by Bradbury and Evans, and a full detail of the process, with specimens, will be found in the proceedings of the Royal Institution for 1854.

Casting of Reptiles, etc.—Imbed the subject in a mould made of four parts of plaster of Paris, one of unburnt lime powder, and one of Flanders brick-dust. Dry the mould carefully, then make it red hot, and burn the subject out of it, taking care to free the mould from the ashes. Fusible metal may be cast in this mould, and then be covered with copper, from which the alloy may be afterwards melted, or a wax model may be taken of the object, pouring the wax in just before setting. In neither case must the mould be melted until after the model, whether of alloy or wax, is taken, when the whole is placed in water, the lime causes the mould to dissolve or break up, and the figure modelled within it may be taken and covered with copper. Flowers, insects, lizards, and other little animals may be typed in this way. In all these processes, perseverance and care are the best cures for little difficulties.

WAX MOULDS FROM PLASTER.—If the object, which we assume to be a medal, from which the mould is to be taken, be composed of plaster of Paris, and the mould to be taken is in wax, the first operation is to prepare the plaster medal. Some boiled linseed-oil, such as is used by house painters, is to be laid over the surface of the medal with a camel's hair pencil, and continued until it is perfectly saturated, which is known by the plaster ceasing to absorb any more of the oil. This operation succeeds best when the medal is heated a little. The medal should now be laid aside till the oil completely dries, when the plaster will be found to be quite hard, and having the appearance of polished marble; it is, consequently, fit to be used for taking the wax mould, which is done in the same manner as we have described for taking a wax mould from a metallic medal.

Many prefer saturating the medal with water: this is best done by placing the medal back down in the water, but not allowing it to flow over the face; the water rises, by capillary attraction, to the surface of the medal, rendering the face damp without being wet. The rim being now tied on the plaster medal, the melted wax is poured upon it. This method is equally good, but liability to failures is much greater, caused generally by the wax being too hot.

The plaster medal may also be saturated with skimmed milk and then dried; by repeating this twice, the plaster assumes on the surface an appearance like marble, and may be used for taking wax moulds.

MOULD OF PLASTER FROM PLASTER MODELS.—When a plaster mould is to be taken, the face of the model is prepared differently to that described, in order to prevent the adhesion of the two plasters. The best substance we have tried for this purpose is a mixture of soft soap and tallow, universally used by potters for preparing their moulds, and called by them *lacquer*. It is prepared in the following manner:—half-a-pound of soft soap is put into three pints of clean water, which are set on a clear fire, and kept in agitation by stirring; when the mixture begins to boil, add from one ounce to an ounce and a-half of tallow, and keep boiling till it is reduced in bulk to about two pints, when it is ready for use. The surface of the medal must be washed over with this lacquer, allowing it to absorb as much as it can, when it assumes the appearance of polished marble; it is now prepared with a rim of paper, and the mould taken as directed for taking plaster moulds from metallic medals. When hardened, they will separate easily.—Wetting the plaster model with a solution of soap before taking the cast will do, or, if the plaster model has been saturated with oil or milk, it has only to be moistened with sweet oil the same as a metal model.

FUSIBLE ALLOY FROM PLASTER.—If a mould of fusible metal be required from a plaster medal, the plaster may be saturated either with boiling oil or the soap and tallow lacquer, and the mould taken in the same manner as from a metallic medal.

COPPER MOULDS FROM PLASTER.—Many electro-metallurgists prefer taking a mould in copper when the medal is of plaster of Paris. This is done by the electrotype process; the plaster model is saturated with wax over a slow fire, as already detailed, and then prepared for taking an electrotype in the usual manner (see page 534). We need hardly mention that the model in this case is destroyed; but, notwithstanding, in the case of plaster models, to take a copper mould is the most preferable, as it may be repaired in case of slight defect, and it may be used over and over again without deterioration.

When an electrotype is required of a model that is undercut, or of a bust or figure, the process which we have described will not answer, as the mould cannot separate from the model. In such circumstances the general method of proceeding is to part the mould in separate pieces, and then join these together. The material used for this purpose is plaster of Paris. The operation, however, to be well done, requires a person of considerable experience.

ELASTIC MOULDING.—The process patented by Mr. Parks for taking a mould of any kind of model in one piece, is excellently adapted for the electrotypist. The material is composed of glue and treacle. Twelve pounds of glue is steeped for several hours in as much water as will moisten it thoroughly; this is put into a metallic vessel, which is placed in boiling water as a hot bath. When the glue falls into a fluid state, three pounds of treacle are added, and the whole is well mixed by stirring. Suppose, now, that the mould of a small bust is wanted, a cylindrical vessel is chosen so deep that the bust may stand in it an inch or so under the edge. The inside of this vessel is oiled, a piece of stout paper is pasted on the bottom of the bust to prevent the fluid mixture from going inside, and if it is composed of plaster, sand is put inside to prevent it from swimming. It is next completely drenched in oil and placed upright in the vessel. This done, the melted mixture of glue and treacle is poured in till the bust is covered to the depth of an inch. The whole must stand for at least twenty-four hours, till it is perfectly cool throughout—after which it is taken out by inverting the vessel upon a table, when, of course, the bottom of the bust is presented bare. The mould is now cut by means of a sharp knife, from the bottom up the back of the bust to the front of the head. It is next held open by the operator, when an assistant lifts out the bust and the mould is allowed to reclose. A piece of brown paper is tied round it to keep it firm. The operator has now a complete mould of the bust in one piece; but he cannot treat it like wax moulds, as its substance is soluble in water, and would be destroyed if put into the solution. A mixture of wax and rosin, with occasionally a little suet, is melted and allowed to stand till it is on the point of setting, when it is poured carefully into the mould and left to cool. The mould is then untied and opened up as before; the wax bust is taken out; and the mould may be tied up for other casts. Besides wax and rosin there are several other mixtures used—deer's fat is preferable to common suet, stearine, etc. The object is to get a mixture that takes a good cast, and becomes solid at a heat less than that which would melt the mould.

MOULDING OF FIGURES.—If the model or figure be composed of plaster of Paris, a mould is often taken in copper by deposition. The figure is saturated with wax, as described for a medal, and copper deposited upon it sufficiently thick to bear handling without damage when taken from the model. The figure with the copper deposit is carefully sawn in two, and then boiled in water, by which the plaster is softened and easily separated from the copper, which now serves as the mould in which the deposit is to be made. It is prepared in the same way as we have described for depositing in copper moulds. When the deposit is made sufficiently thick, the copper mould is peeled off and the two halves of the figure soldered together. The copper moulds which are deposited upon the wax models taken in the elastic moulding are often treated in the same manner; but more generally these moulds are used for depositing silver or gold into them, to obtain *facsimiles* of the object in these metals, in which case the copper moulds are dissolved off by acids, as will be described in a subsequent section.

FIGURES COVERED WITH COPPER.—When plaster busts or figures are wanted in copper, the most usual way is to prepare the figure with wax as described, and to coat it over with a thin deposit of copper, letting the copper remain. Some operators, when it can be done, remove the plaster and wash over the inside with an alloy of tin and lead melted. In this case the copper must previously be cleaned by washing first in a solution of potash, and then with chloride of zinc. The latter mode will cause the alloy to adhere to the copper and give it strength. In either of these cases the deposit must not be very thick, or it will throw the figures out of proportion, such as the features of a bust, etc. Any slight roughness of deposit may be easily smoothed down by means of fine emery.

THE PREPARATION OF NON-METALLIC MOULDS TO RECEIVE DEPOSIT.—Having detailed what we have found best for obtaining moulds of objects for the purpose of electrotyping, we proceed to the manner of obtaining a deposit upon these moulds. Were any of the plaster or wax moulds attached to the zinc and immersed in the copper solution in the same manner as described with the penny-piece (page 534), no deposit would be obtained, because neither the plaster nor the wax is a conductor of electricity. Some substance must now be applied to the surface in order to give it conducting power. There are several ways of communicating this property, but the best and most simple for the articles under consideration is to apply common black lead (already referred to) in the following manner:—A copper wire is put round the edge of the medal, or, if wax moulds are used, a thin slip of copper may be inserted into the edge of the mould—or, being slightly heated and laid upon the back, the two will adhere. A fine brush is now taken (we have found a small hat-brush very suitable) and dipped into fine black lead, and brushed over the surface of the medal. The brushing is to be continued until all the face round to the wire upon the edge, or slip of copper forming connection, has a complete metallic lustre. A bright polish is necessary to the obtaining a quick and good deposit.

In brushing on the black lead, care should be taken not to allow any to go upon the back or beyond the copper connection, or the deposit will follow it, and so cause a loss of copper, and make the mould more difficult to separate from the deposit; being, as it were, incased. If the electrotypist takes the labor himself of filing off all the superfluous copper from the edge of his deposited medal, it will do more than any written precautions to teach the necessity of preventing as much as possible the deposit going further than is necessary. When the face of the mould is properly black-leaded, the copper wire connected with it is attached to the zinc plate in the porous cell, and the mould immersed in the copper solution; the deposit will immediately begin upon the copper connection, and will soon spread over every part, covering the black-lead polish with less or more facility according to the state of the solutions and other circumstances to be afterwards noticed. When the deposit is considered sufficiently thick for removing—which, in ordinary circumstances, will require from two to three days—the medal is taken out of the solution, and washed in cold water, and the connection is taken off. If the deposit has not gone far over the edge of the mould, the two may be separated by a gentle pull; if otherwise, the superfluous deposit must be eased off, and if care be taken the wax may be fit to use over again: but when the mould is plaster of Paris, however well it may be saturated with wax, it is seldom in a condition to use again. If the plaster mould be large and thick, it is advisable to coat the back with wax or tallow, which is done by brushing it over with either substance in a melted state: the mould being cold will not absorb the wax or tallow: hence it may be recovered again. The sulphate of copper possesses so penetrating a quality that if the slightest imperfection occurs in the saturation of the mould by wax, the solution will penetrate through it, and the copper will be deposited upon the face of the object adhering to the plaster, giving to the metal a rough, matted appearance, and seriously injuring it.

USING METAL MOULDS.—The mould in fusible alloy does not require to be black-leaded, but the back and edge must be protected by a coating of wax or other non-conducting material; it may be connected in the same way as the penny-piece (page 534) by putting a wire round its edge previous to laying on the non-conducting substance, such as tallow or wax, which should also cover the wire. Or a slip of copper, or wire, may be laid upon the back and fastened by a drop or two of sealing-wax; the back is then coated: but care must be taken that the wax do not get between the connection and the medal which will prevent deposit. The deposit on this mould goes on instantaneously, the same as over the penny-piece. When sufficiently thick, it may be taken off in the same manner as from the wax mould, the surface having been prepared by turpentine (page 534) to prevent adherence. These moulds may be used several times, if care be taken not to heat them, as they easily melt.

The medals obtained from metallic moulds prepared with the turpentine solution have a bright surface, which is not liable to change easily, but if the mould has been prepared with oil or composed of wax or plaster, the metal will either be dark, or will very easily tarnish. The means of preserving them, either by bronzing or plating with other metals, will be detailed in a subsequent section.

PRECAUTIONS ON PUTTING THE MOULDS INTO A SOLUTION.—In putting moulds into the copper solution, the operator is often annoyed by small globules of air adhering to the surface, which either prevent the deposit taking place upon these parts, or, when they are very minute, permit the deposit to grow over them—causing small hollows in the mould, which give a very ugly appearance to the face of the medal. To obviate this, give the mould, when newly put into the solution, two or three shakes, or give the wire attached to it, while the mould is in the solution, a smart tap with a key or knife, or any thing convenient; but the most certain means we have tried, is to moisten the surface with alcohol just previous to putting it into the copper solution. A little practice in these manipulations will soon enable the student to avoid these annoyances.

DEPOSITION ON LARGE OBJECTS.—When busts or figures, whether of wax or plaster of Paris, are to be coated with copper, with no other conducting surface than black lead, it is attended with considerable difficulty to the inexperienced electrotypist. The deposit grows over all the prominent parts, leaving hollow places, such as armpits, neck, etc., without any deposit; and when once missed, it requires considerable management to get these parts coated, as the coated parts give a sufficient passage for the current of electricity. It is recommended by some electrotypists to take out the bust, and coat the parts deposited upon with wax, to prevent any further deposit on them; but this practice is not good, especially with plaster of Paris, for an electrotype ought never to be taken out till finished. Sometimes the resistance of the hollow parts is occasioned by the solution becoming exhausted from its position in regard to the positive pole. In this case a change of position effects a remedy. It may be remarked that when a bust or any large surface having hollow parts upon it, is to be electrotyped, as many copper connections as possible ought to be made between these parts and the zinc of the battery. Let the connections with the hollow parts be made with the finest wire which can be had, and let the zinc plate in the cell have a large surface compared to the surface of the figure, and the battery be of considerable intensity; if attention is paid to these conditions, the most intricate figures and busts may be covered over in a few hours. Care has to be observed in taking off the connections from the deposit, or the operator may tear off a portion of the deposit: if the wires used are fine, they should be cut off close to the deposited surface.

To MAKE BUSTS AND FIGURES.—Busts and figures, and other complicated works of art, which cannot be perfectly coated with black lead, may be covered by a film of silver or gold, which serves as a conducting medium to the copper. This is effected by a solution of phosphorus in sulphuret of carbon. The operation being patented, we will take advantage of the description given of it in the specification. "The solution of phosphorus is prepared by adding to each pound of that substance 15 lbs. of the bisulphuret or other sulphuret of carbon, and then thoroughly agitating the mixture; this solution is applicable to various uses, and amongst others, to obtaining deposits of metal upon non-metallic substances, either by combining it with the substances on which it is to be deposited, as in the case of wax, or by coating the surface thereof. Any of the known preparations of wax, may be treated in this way, but the one preferred is composed of from 6 to 8 ounces of the solution: 5 lbs. of wax, and 5 lbs. of deer's fat, melted together at a low heat, on account of the inflammable nature of the phosphorus. The article formed by this composition is acted upon by a solution of silver or gold in the manner hereinafter described with respect to articles which have been coated with the solution."*

COATING OF FLOWERS, ETC.—"If the solution is to be applied to the surface of the article, an addition is made to it of one pound of wax or tallow, one pint of spirits of turpentine, and two ounces of India rubber, dissolved with one pound of asphalt, in bisulphuret of carbon, for every pound of phosphorus contained in the solution. The wax and tallow being first melted, the solution of India rubber and asphalt is stirred in; then the turpentine, and after that the solution of phosphorus is added. The solution prepared in this manner is applied to the surfaces of non-metallic substances, such as wood, flowers, etc., by immersion or brushing;

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* Repertory of Patent Inventions, 1844.

the article is then immersed in a dilute solution of nitrate of silver, or chloride of gold; in a few minutes the surface is covered with a fine film of metal, sufficient to insure a deposit of any required thickness on the article being connected with any of the electrical apparatus at present employed for coating articles with metal. The solution intended to be used is prepared by dissolving four ounces of silver in nitric acid, and afterwards diluting the same with twelve gallons of water; the gold solution is formed by dissolving one ounce of gold in nitro-muriatic acid, and then diluting it with ten gallons of water."

We have frequently repeated the operations described by this patentee with entire satisfaction, and were enabled to cover every variety of surface with great facility.

The solutions of silver and gold, prepared as above, will last for a long time, and do a great many articles. When it is convenient it is best to use both solutions. The connecting wire should first be attached to the article to be coated, before being dipped into the phosphorus solution, but connected at such parts as will not hurt the appearance of the object by leaving a mark when it is taken off. Care should be taken not to touch the article with the hands after it is dipped into the solution. The object supported by the connections is immersed in the phosphorus solution, where it remains for two or three minutes. When taken out it is dipped into the silver solution, and as soon as the surface becomes black, having the appearance of a piece of black china, it is to be dipped several times in distilled water, and then immersed in the solution of protochloride of gold about three minutes: the surface takes a bronze tinge by the reduction of the gold. It is next washed in distilled water by merely dipping, not by throwing water upon it. The wire connection is now attached to the zinc of the battery, and then the article put into the copper solution, and in a few minutes the article is coated over with a deposit of copper. A thin copper surface may thus be given to small busts or figures without sensibly distorting the features by want of proportion.

FIGURES FROM ELASTIC MOULDS.—When taking a wax cast from the elastic mould, described in page 544, we prefer the phosphorized mixture. After taking out the mould it is only necessary to make the connections, and pass it through the gold and silver solutions, as described, and then to connect it with the battery.

We may also mention that the principal object of making copper moulds by this process, in the manufactory, is not to make *facsimiles* in copper, but to make articles of solid silver or gold. Copies of highly wrought work, either chased or engraved, or of articles, duplicates of which cannot be obtained, or of which the workmanship is costly, may by this means be made in solid silver or gold, at little more expense than the cost of the metal. Having obtained the copper mould, silver is deposited in it to any thickness, and the copper dissolved off. However, an extensive trade is now being carried on in figures and other works of art deposited in copper and then bronzed, which gives them an appearance often not much inferior to that of antique works of the highest art.

ELECTROTYPES FROM DAGUERREOTYPES.—What may be justly termed the perfection of electrotyping, is the production of electrotypes from daguerreotypes. The daguerreotype picture being taken, a small portion of the back is cleaned with sand-paper, taking care not to allow any thing to touch the face; a little fine solder is placed on this part; a piece of flattened wire, also cleaned, is placed upon the solder, the whole moistened with dilute muriatic acid, or chloride of zinc. The wire is now held over the gas or a lamp about half an inch from the plate; the heat is transmitted through the wire to the solder, which melts, and the wire is soldered to the type; the back is then protected by wax, and the daguerreotype is now put into the copper solution in the same manner as a medal; the deposit proceeds rapidly, and when sufficiently thick the two easily separate, and an impression of the picture is obtained from the daguerreotype with an expression softer and finer than the original; several electrotypes may, with care, be taken from one picture. The electrotype may now be passed through a weak solution of cyanide of gold and potassium, in connection with a small battery, and thus a beautiful golden tint be given to the picture, which serves to protect it from the action of the atmosphere; but they should also be protected by a glass, which may be fixed on in the manner pointed out in another section. The most successful operators that we have known in this and every other department of electrotyping are Dr. Thomas Paterson, of Glasgow, and Mr. Bawtree, of London.

DEPOSITING BY SEPARATE BATTERY.—Having described, so far as we know them, the best and most simple means of obtaining moulds, and their preparation for receiving the deposit of the metal, we return again to the management of solutions and batteries, and the application to other metals besides copper.

Although in our account of the porous or single cell system (page 533) we have recommended it as the best and most economical for electrotyping, still many eminent electro-metallurgists prefer using the battery system; and indeed there are solutions of copper and of other metals to which the porous cell system cannot be applied, from the nature of the solution and the necessity of intensity to decompose them.

While depositing upon a mould by the single cell, let the wire which connects them be cut in the middle, and a mould be attached to the end of the portion remaining upon the zinc plate, and a small plate of copper to the end of the wire remaining upon the mould in the copper solution, and let these two be put into a second vessel containing a solution of sulphate of copper. The action between the zinc and medal in the double or first cell will go on as before—namely, the electricity passing through the porous cell and the solution to the medal; but on returning to the zinc it must pass through the copper solution, which is in the second vessel, between the mould and copper plate, where it produces the same effects as in the first cell. The sulphuric acid is liberated at the copper plate and dissolves it, and the copper is deposited upon the mould, so that the solution in this cell is maintained at one strength; hence there is no necessity for hanging crystals of sulphate of copper in this solution.

It will be observed that the electricity having to pass through a second solution, is made to perform double duty, and must consequently be much more economical. We found the results to be these: A single cell, with a mould, was placed two inches from the porous cell, and of the same size as the zinc plate; and another, similarly arranged, but connected with a metal mould and copper plate of similar size to the zinc and copper, was placed one inch apart in the copper solution of second cell. The mould in the single cell had gained 100 grains, and the zinc plate lost 108 grains. The mould in the battery cell of the other arrangement had only deposited upon it 30 grains—the zinc plate had lost 35 grains; but the mould in the second or decomposition cell had also deposited upon it 30 grains, making in all 60 grains deposited for 35 zinc dissolved, but taking nearly double the time. These arrangements, as we have before observed, are simply a modification of a single pair of Daniell's battery connected with a decomposition cell, the advantages of which are not applicable to any other battery, as in no other battery does deposition take place within the battery cells: indeed this method of using a compound depositing apparatus is very seldom employed. Batteries of a different form, as Smee's are generally adopted. Figure 573 represents a Smee's battery, connected with a medal and copper plate in a separate or decomposition cell; and Fig. 574 is a large decomposition trough for doing several medals at one time. Of course any battery may be attached to these medals and plate by the brass connections seen on the end of the trough. Bear in remembrance

Fig. 573.

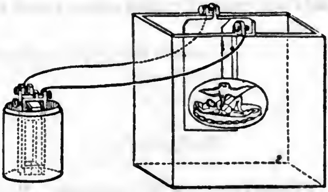
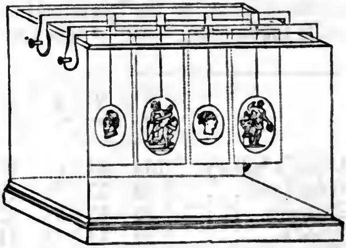


Fig. 574.



that the zinc of the battery is connected with the medals, and the copper or platinized silver with the copper in the decomposition cell.

SIZE OF THE ELECTRODES.—When a separate battery is used for the purpose of depositing in a decomposition cell, there are several conditions which are well to be observed, as they influence the amount and character of the deposit. The first is the size of the electrodes or medals, in relation to the zinc in the battery. The results we have obtained may be expressed in general terms. When the deposit upon electrodes of the same size as the zinc plates in a Wollaston's battery equals 100, that upon electrodes one half the size of the zinc plates in the battery will be equal to 57, and upon electrodes double the size of the zincs of the battery 190; but this last condition is affected by the intensity of the arrangement.

RELATIVE POWER OF BATTERIES.—The following experiments, made with electrodes double the size of the zinc plates of the batteries, all at equal distances (1 inch apart), will show the relative power of the batteries. The time in action was one hour each: only one pair of plates constituted the battery.

Grove's battery deposited . .	104	grains.
Single cell	62	"
Daniell's	33	"
Smee's	22	"
Wollaston's	18	"

CONSTANCY OF BATTERIES.—But the first hour of the action of most batteries differs from an hour afterwards, so that one kind of battery may be most useful for a short time, and another sort if the action is to be continued for a length of time. The following table will illustrate this remark, the condition being the same as in last experiment, or the last experiments being continued, and the results taken every hour for seven successive hours:

	1 hour.	2 hours.	3 hours.	4 hours.	5 hours.	6 hours.	7 hours.	Total.
Grove's battery .	104	86	66	60	54	49	45	464 grs.
Single cell . . .	62	57	54	46	39	29	24	311 "
Daniell's . . .	33	35	34	32	32	30	31	227 "
Smee's	22	16	14	11	12	11	10	96 "
Wollaston's . .	18	14	15	12	11	10	10	90 "

To make this comparision more practical, larger plates were used for the battery, and proportionately larger electrodes, and the battery kept in operation until one pound of copper was deposited, renewing the acid, and brushing the zincs every 24 hours. The time taken to effect this was:

Grove's Battery	19½ hours.
Single cell	45 "
Daniell's*	49 "
Smee's	147 "
Wollaston's	151 "

COMPARATIVE PRODUCE OF BATTERIES.—The expense of the materials used in these experiments was as follows (of course the materials will differ in cost both at different times and in different localities, and more common materials may be used):

By the process with Grove's battery, one pound of deposited copper costs

1 lb. Copper, from positive electrodes	25 cts.
1¼ lb. Amalgamated zinc	21 "
1½ lb. Nitric acid	19 "
Sulphuric acid	02 "
	67 cts.
Add time, say one cent per hour, for comparison	20 "
	87 cts.

By single cell apparatus, one pound of deposited copper costs

1 lb. Sulphuric acid	04 cts.
$1\frac{1}{16}$ lb. Amalgamated zinc	17 "
4 lb. Sulphate of copper	37 "
	58 cts.
Time, at one cent per hour	45 "
	$1.03

By Daniell's battery, one pound of deposited copper costs

$1\frac{2}{16}$ lb. Amalgamated zinc	19 cts.
4 lb. Sulphate of copper	37 "
1 lb. Copper from electrode	25 "
Sulphuric acid	02 "
	83 cts.
Time, at one cent per hour	49 "
	$1.32

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* The Daniell's battery used in this experiment had flat plates, not circular, as described at page 523.

By Smee's battery, one pound of deposited copper costs

$1\frac{1}{2}$ lb. Amalgamated zinc	21 cts.
3 lb. Sulphuric acid	12 "
1 lb. Copper from electrode	25 "
	58 cts.
Time, at one cent per hour	$1.47
	$2.05

By Wollaston's battery, one pound of deposited copper costs

1 lb. Copper from electrode	25 cts.
$1\frac{2}{16}$ lb. Amalgamated zinc	19 "
3 lb. Sulphuric acid	12 "
	55 cts.
Time, at one cent per hour	$1.51
	$2.06

By thus adding the time, at a given rate, it serves to illustrate what we have before stated respecting the necessity of placing the value of time against the cost of materials. In manufactories, where time has to be paid for, it may be cheapest to use the battery with the most costly materials; but where time is of no consideration, or, as is often the case, if, while the operations are going on, the workmen are employed in other necessary labor, a cheaper apparatus will answer: but the student or manufacturer will, by the above general results, be enabled to choose the process most suitable for his purposes. It must be borne in mind that an allowance has to be made on the first, second, and third, for wear and tear of the porous vessels, not included in the above estimate. Although the results of these experiments give, exclusive of time, the cost of one pound of electrotyped copper—thus

Grove's battery	67 cts.
Single cell	58 "
Daniell's	83 "
Smee's	58 "
Wollaston's	55 "

still we know from long experience in the use of single cell, Smee's, and Wollaston's batteries, for manufacturing purposes, that the price of the pound of copper deposited may be more correctly stated at 62 cents—there being always loss in making the purest article (the copper) from impure materials, as the sulphate of copper, or the ordinary copper of commerce which is used as electrodes.

Mr. Smee, in his "Advice to capitalists who propose entering upon the business of electro-metallurgy," gives a table of expenses incurred by the use of different batteries. But his rules are based too exclusively upon theoretical considerations, and without that regard for practical conditions which are so important to the manufacturer. Mr. Smee recommends for use what he calls "an odds-and-ends battery," composed of odd scraps of zinc put into acid, having in the same vessel a piece of copper or platinized silver and a wire placed in contact with them which forms the electrode. This battery may be convenient for the amateur electrotypist, as it enables him to use up all his waste zinc. Raw zinc, or spelter, Mr. Smee says, may also be used in this way, constituting the cheapest of all batteries for manufacturing purposes. The data of his calculations are as follows:—The copper sheet forming the positive electrode is quoted at 25 cents per lb.; wrought zinc, 14 cents per lb.; raw zinc at a little more than half the price of wrought zinc, which we will call 8 cents per lb., although he rates it at 10 cents. Iron is given at from 2 to 4 cents per lb. The equivalent weight of copper is given at 32, of zinc at 32, and of iron at 28; that is to say, 32 parts (say ounces) of zinc dissolved in a battery will, or should deposit 32 ounces of copper; and if iron be used, 28 ounces of iron should deposit 32 ounces of copper. Hence, in the plain language of a manufacturer, we should say that, with an odds-and-ends battery and raw zinc, there would be, for every pound of copper deposited,

16 oz. of zinc used	08 cts.
16 oz. of copper dissolved . .	25 "
	33 cts.

And when iron is used, the expense of depositing 1 lb of copper would be,

16 oz. of iron, *say*	04 cts.
16 oz. of copper	25 "
	29 cts.

Notwithstanding these results, Mr. Smee proves, by several fractional formulæ and an algebraic equation, that the cost of depositing a pound of copper is

By iron	37 cts.
By odds-and-ends battery . .	25 " *
	62 cts.

To this it may be replied by the manufacturer, that, in the first place, raw zinc or spelter used in the way described for an odds-and-ends battery would lose two or three times the quantity that is stated for every equivalent of copper; and secondly, that this form

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* **Smee's Elements of Electro-metallurgy, 3d edition, p. 112.**

of battery is altogether unsuitable for manufacturing purposes, even when amalgamated scrap zincs are used; and, as regards the calculation, it is not easy to see that, while a pound of copper, dissolved from the positive electrode, originally costs 25 cents, it could, notwithstanding, be deposited by the destruction of 1 lb. of zinc, not including acid, etc., at the expense of only 25 cents. It ought always to be remembered, that, for manufacturing purposes, the surface upon which the metal is to be deposited in general amounts to several square feet. The article may be, for example, a large ornamental vase, having four square feet of surface. An odds-and-ends battery, or an iron single pair battery would be too weak. To deposit, with a separate battery, upon a surface such as that of the vase, it requires two or three pairs of plates to give what we may call economical power.

RECOVERY OF MERCURY FROM WASTE ZINC.—The general practice of manufacturers, when the scraps of zinc become small, is either to treat them as referred to at page 512, to distil the mercury from the zinc, or to sell the scraps to parties who do distil them. This is done by putting the scraps into an iron retort, subjecting it to a red heat, and allowing the beak of the retort to pass into a condenser, which has a tube dipping into water. The mercury distils over, and condenses in the water. The zinc left in the retort is found to be so impure as not to be fit to melt and roll again, but it may be used in the composition of common brass. Mr. De la Rue, in a communication to the Chemical Society,* gives the results of several analytical experiments upon scrap zinc. Before distillation the scraps usually give the following results in 100 parts:

Zinc	67·3
Mercury	4·3
Dross and loss . .	28·4
	100·0

The composition of the zinc left after distillation is given as—

Zinc	90·
Iron	2·56
Lead	6·
Copper	1·44
	100·00

COMPOUND CELL PROCESS.—Another method of economizing power was proposed in what is termed the *compound cell system*, by which it was said that the electricity passing through a series of cells would be able to produce the same quantity of work in every cell with no more cost. This plan may be stated thus:

A is a Smee's battery; the wire Z is conducting the electricity to

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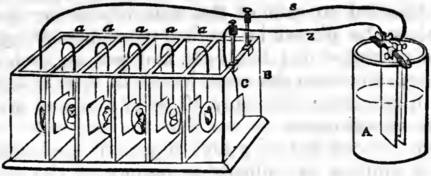
* Memoirs and Proceedings of the Chemical Society, vol. ii. page 393.

the compound trough which is composed of a series of water-tight cells, as *a a*, and is connected with a piece of copper C, forming a positive electrode; in the same cell, and facing this electrode, is a medal, connected by a copper wire to a piece of copper placed in the second cell, opposite which is another medal connected in the same manner with another piece of copper, and so on through the series, which terminates with a medal attached to the wire of the battery. The electricity from the battery passes through all these cells, and reduces its equivalent in each cell. Thus the reduction of 32 grains of zinc in the battery would deposit 32 grains of copper multiplied by 6 times, or as many times as there are cells.

Fig. 575.



This is correct in principle, and at first sight seems to be exceedingly economical; but it is not so, for every cell adds so much to the resistance of the current, that intensity batteries must be used; so that, supposing we have a compound cell of six divisions, in which are placed six separate medals, it would require a battery of six pairs of plates to give intensity sufficient to overcome the resistance, and the same number of medals could be made of the same weight by six separate zincs, and in less than half the time they could be made by this arrangement, and with a less destruction of zinc. For large operations, where the articles receiving the deposits and the electrode are necessarily a good way apart, the process is altogether impracticable in a commercial point of view. This is one of the remarkable instances where theoretical possibility and commercial economy are at variance.

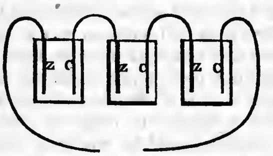
Effects of Resistance.—At page 551 we mentioned, that if a single cell deposits 100 grains in a given time, and it be converted into a battery having the two electrodes in a solution of sulphate of copper, there will only be deposited in the same time 30 grains. This is caused by the extra resistance which the solution between the two electrodes, in the decomposition cell, offers to the passage of the electricity, the amount of which corresponds to the amount deposited—the latter depending upon the former.

If we take two small plates of copper and zinc amalgamated, and place them in dilute sulphuric acid, in contact, but not so close as to prevent the gas evolved from the copper plate to escape, and allow them to remain until there have been dissolved from the zinc

100 grains, and we call this the measure of the maximum amount of electricity which that surface of zinc and copper can give out in the time taken to dissolve the 100 grains: then, if the two metals in the acid be separated one inch, being connected by a wire or slip of copper above the liquid, and kept in action the same length of time as the former, there will be dissolved from the zinc only about 56 grains. If the wire in connection with the zinc and copper be extended and cut in the middle, and have a piece of copper attached to each of the same size as the zinc plate in acid, and these be placed in another vessel containing a solution of sulphate of copper (as Fig. 544), and put an inch apart, and the whole kept in action the same length of time as before, it will be found in this case that only 10 grains of zinc are dissolved. From these experiments we see that the resistance of the one inch of acid between the zinc and copper in the battery, and the one inch of solution of sulphate of copper in the second or decomposition cell, is 90 or nine-tenths—only yielding one-tenth of the electricity which the zinc and copper are capable of giving.

INTENSITY.—If we now take another zinc and copper plate of the same size as the former, and arrange them in the acid solution, and connect them with the copper plates in the decomposition cell, as shown in Fig. 544, and keep them in action the same length of time as in the former experiments, there will be dissolved from the zinc about 19 grains, and deposited upon the copper plate attached to the zinc in the decomposition cell 18 grains of copper.

Fig. 576.



If three zincs and coppers be arranged as described and placed in the acid, there will be dissolved from the zinc plate 26 grains, and deposited upon the copper 25 grains. If six pairs zinc and copper be arranged as above and placed in acid, there will be deposited 36 grains of copper, which we will also take as the measure of what is dissolved from the zinc; and if nine pairs of zinc and copper be used, there will be deposited 43 grains, and so on until the quantity dissolved from each zinc, or deposited on the copper plate be 100, equal to that obtained by the close contact of the zinc and copper in acid, which will require upwards of 30 pairs of zinc and copper. It must be borne in mind that the same quantity of zinc will be dissolved from every plate in the arrangement. Thus, in nine pairs where 43 grains were deposited, there would be dissolved from every zinc in the battery 43 grains.

It will now be apparent that the use of several pairs in the battery is to overcome resistance, by which quantity is gained at the same time up to a given point; but quantity gained by this means is expensive. The 10 grains deposited by the single pair of zinc and copper only required 10 grains of zinc, but the 43 grains by the nine pairs would require 405 grains of zinc to be dissolved.

RELATIVE INTENSITY OF BATTERIES.—Different batteries have different degrees of power to overcome resistance—greater intensity. The following experiments will illustrate this: A single pair of a Wollaston's, Smee's, and Grove's batteries were fitted up as nearly equal in circumstances as the different arrangements would allow—each exposing the same surface of zinc, and connected with electrodes placed in a solution of sulphate of copper, first 1 inch, then 2 inches, 3 inches, and 4 inches apart—half an hour in each. They were then reversed, beginning with the electrodes at 4 inches and coming to 1 inch. These experiments were repeated several times, and a mean of the whole taken. The results were:

Deposited—	**Wollaston.**	**Smee.**	**Grove.**
Electrodes 1 inch . . .	8·8 grains	12·0	31·0
2 inches . .	6·6 "	6·8	26·0
3 inches . .	4·7 "	6·0	17·0
4 inches . .	3·0 "	4·6	14·0

From this it will be seen that Wollaston's stands lowest in intensity, which is more apparent as the distance of the electrodes is increased. Smee's is one-third more than Wollaston's at 1 inch, and one-half more at 4 inches; while Grove's is three and a-half more than Wollaston's, and two and a-half more than Smee's at 1 inch, but four and a-half more than Wollaston's and three more than Smee's at 4 inches. If we take the mean of these results as a comparison of batteries, their value will stand as under:

One of Grove's equal to three of Smee's,
and to three and three-fourths of Wollaston's.

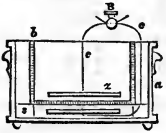
The following table gives the results of different batteries, arranged in series, kept in action the same length of time, namely, one hour. The battery plates were very small, the electrodes twice the size of the battery plates:

	One Pair.	Two Pairs.	Four Pairs.	Six Pairs.	Nine Pairs.
Grove's	55	72	93	97	98
Daniell's	15	35	60	77	86
Smee's	11	19	29	41	58
Wollaston's	8	15	24	33	48

This table gives results approaching to and in principle the same as the others: it will be observed that one pair of Grove's is equal to nine pairs of either Wollaston's or Smee's. It is also worthy of remark, that Grove's increases slowly in quantity above four pairs, the intensity being sufficient at four pairs to overcome the resistance offered to the current of electricity. For ordinary electrotyping, intensity arrangements are unnecessary, except where the article upon which the deposit is being made is of such a character as will not allow the positive electrode to be brought close to it, or when there are deep cut objects, or any circumstance that increases distance and necessitates power to overcome resistance.

Mode of Suspending Objects for Coating.—In beginning to operate in the art of electrotyping, the student often pauses, and asks the question, What is the best position in which a medal should be hung in the solution? Convenience has brought into general practice the suspending of it perpendicularly in the solution, having the positive electrode or pole facing it in a parallel direction; but to this method there are some objections. If, for instance, the porous diaphragm, or single-cell system be used, for obtaining the medals, it is found that upon the lower portion of the medal the deposition is much thicker than upon the upper portion. Indeed, when even ordinary attention is not paid, the lower part becomes not only thicker, but studded over with round nodules of copper, or with lines composed of these nodules, while the upper part remains thin, and is covered over with what is termed the sandy deposit copper, in dark brown grains, capable of being rubbed off with the slightest friction. No doubt this is in a great measure prevented by agitating the solution; but it is inconvenient, and requires constant attention.

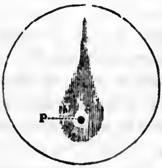
Fig. 577.



If a separate battery is used, and the deposition of the medal is effected in a separate vessel, by having a copper positive electrode, the same inconvenience takes place to a greater or less extent, according to the distance at which the two poles are placed. These inconveniences are known to all electrotypists, and the cause is ascribed to the different densities of the solution. The reason why the solution becomes of different densities is easily understood in the single cell process, there being no copper pole to maintain the strength of the solution; as it becomes exhausted of copper by the deposition, the lighter portion floats on the top, and the heavier portion remains below; and although crystals of sulphate of copper be suspended in the solution, as they dissolve they sink by their gravity, and cause a flow upon the lower portion of the medal, and consequently a much more powerful deposit. But why the same should take place with a separate battery, where there is a positive electrode of copper being dissolved, just in proportion to the copper extracted from the solution by the medals, was for a long time not known.

NON-TRANSFER OF ELEMENTS.—In a paper read upon this subject before the Royal Society by the late Professor Daniell and Professor Miller, they gave, as the results of their investigations, that certain metals are transferred by the electric current in small proportion, differing in different metals.* About the same time the author had observed, when operating upon the large scale, results which led him to the conclusion, that no metal is transferred in any quantity by the electric current, nor any element taking the position of the metal in an electrotype, but that the acid element was always transferred equivalent to the electricity passing. It was thus shown that during the deposition of metal, say copper, in electrotyping, the acid, when exhausted of the copper at the surface of the medal, is transferred to the positive pole, and dissolves a portion of copper; but this portion is not transferred by the electric current to the medal: hence it will be observed, that the solution next the medal will become exhausted of copper, and will consequently rise to the surface from its greater lightness. There is no doubt a flow of stronger solution in a horizontal direction from the positive pole to the medal, caused by the lighter portion ascending; but this does not mend the evil: the light portion is increasing on the surface, and the whole solution soon becomes of different densities from the surface to the bottom of the medal; and this constant current of the solution flowing up the surface upon which the electrotypist is depositing, causes the lines that are observed in deposits under certain circumstances, and which are sometimes very annoying. If a small hollow be in the mould, or even if a small portion of a plain surface resist, the metal will accumulate round the edge of the resisting portion, giving the deposit an appearance as if made in a flowing stream, like a stone standing up in a current of water. The black point in the centre represents the resisting spot around which the deposit will thicken, causing a ridge of metal to radiate to a point immediately above the resisting portion. These disappointments are much more annoying in solutions of gold and silver than in sulphate of copper, as will be noticed when we come to treat of plating and gilding. A point of grease or dirt, or small hole not cleaned out, hardly visible to the naked eye, will give a very prominent effect upon the plain polished surface of a piece of metal.

Fig. 578.



From these observations, the reader will now be able to answer the question—what is the best position to place a medal in the solution? To make it still more apparent, take a glass jar, filled with a solution of sulphate of copper; place a piece of copper upon the bottom of the jar, and suspend the medal at the top,

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* Philosophical Transactions, Part 1, for 1844; and Memoirs and Proceedings of the Chemical Society, Vol. iii. page 53.

having their two faces parallel; connect them with a battery; in a short time the solution round the medal becomes exhausted, and even colorless, the medal covered with a dirty brown powder, and no further deposit will take place. But reverse the case; place the medal at the bottom, and the copper positive electrode at the top; the deposition goes on constant and smooth; the solution is maintained in the same condition as it was at the first, there being a constant transfer; the acid is transferred by the current from the medal to the copper pole: the sulphate of copper formed descends by its gravity to the medal. There are, no doubt, a few slight objections to placing the medal under the positive electrode—such as the impurities in the copper getting disintegrated, and falling upon the surface, but a piece of cloth wrapped round the pole prevents this. However, when a fine surface is wanted, care ought always to be taken to have clean solutions filtered, and kept covered from dust; and when the single cell is used, the crystals of sulphate of copper should be suspended in a fine linen bag, or the shelf holding them be lined with linen.

EFFECTS OF DIFFERENCE IN THE DENSITY OF SOLUTION.—Although in principle this is the best method, we believe that very few practice it, because of the trouble attending the arrangement of the electrodes in this position. When the medals are small the annoyances from unequal density are not so material, but if the surface of the article which is being deposited be large—say eight inches or upwards—the difference in the thickness of the lower and upper portion of the medal is very great. When suspended perpendicularly, they should be shifted several times, making the upper portion the lower, besides occasionally stirring the solution, or shaking the article. Indeed when convenient, the article receiving the deposit should be kept as much in motion as possible, as it regulates the deposit, making it smoother and less brittle.

CRYSTALS OF COPPER ON ELECTRODES.—It will be found, when working with a battery, that the sulphate of copper solution will become stronger round the positive electrode, which is gradually dissolved by the transferred acid. A frequent effect is, that the electrode often gets coated over with crystals of sulphate of copper, which adhere with great tenacity, and stop the electric action. Under such circumstances, it is only necessary to clean the electrode from the crystals and to add a little water to the solution, which will prevent a recurrence of the crystals for a time. But the stirring of the solution occasionally will do much to prevent this crystallization.

CHAPTER XXVII.

MISCELLANEOUS APPLICATIONS OF THE PROCESS OF COATING WITH COPPER.

BESIDES the applications and processes which we have described under the general term of electrotyping, there are various applications of the process of depositing metals upon other substances, which have been, and may be still more usefully applied. We may, at a trifling cost, impart a coating of copper to cornices for decorating buildings, to terra cotta, engravings on wood, etc., etc. Cloth may also be easily covered, and made to assume the appearance of a sheet of copper, having the lightness and pliability of cloth. Lace has been covered with copper, and used for battery plates, and has also been gilt and made into beautiful ornaments. Table-covers with metallic ornaments richly gilt, and book-covers, have all been tried with more or less success, although they have not yet been profitably produced.

COPPERED CLOTH.—Ordinary cloth, covered with copper, was prepared a few years ago in considerable quantities for the covering of roofs, wagons, etc.; but the necessary price precluded its use when competing with the ordinary materials for these purposes, although it possesses many eminent qualities for some of these uses—such as forming fire-proof covers to shelter wagons from the sparks discharged by a locomotive. The choice of the kind of cloth was another difficulty; linen was too expensive, and required a good coating of copper to make it water-tight; the best substance was a felted cotton with India-rubber, but after a few months exposure the India-rubber in the cloth decomposed. The operations of coating cloth with copper were the same as described for the wax medals: the cloth was brushed over with a polish of black lead, and then stretched upon a frame of wood having a copper band round it, in which were placed small hooks or pins, and the cloth attached to these. A vat, four feet deep and twelve yards long, was made of brick and cement; this was divided lengthwise by a wooden frame with panes the same as a window, which were filled in with unglazed earthenware plates, cemented by marine glue, and the whole made water-tight. Into one division of the vat were placed the dilute acid and sheets of zinc; in the other the solution of copper, in which was placed the cloth upon the frame. The arrangement was so perfect that we have often seen pieces of cloth, twelve yards long by one yard wide, completely covered with copper in one hour. The result of many trials was, that one pound weight of copper gave a perfect solid covering to twenty superficial square feet of cloth.

A similar thickness is quite sufficient for other surfaces for mere exposure to the atmosphere, such as wood-work, cornices, etc.. and may be produced at the same rate, about 2s. 6d. per pound of copper.

Besides these applications, many others have been suggested and tried with variable success. Some have probably been abandoned too soon, others have had both capital and talent applied, and success is yet to come. We shall only name a few of these applications.

CALICO PRINTERS' ROLLERS.—So early as 1841 active means were tried to apply the electro-deposition of copper to the preparation of rollers for printing calicoes, both by depositing the copper upon wax or other moulds, to make an entire roller of copper, or to deposit a surface of copper on other metals, such as iron or brass; but none of them have yet succeeded. To make an entire roller is much more expensive, without an equivalent advantage over the ordinary method of casting, rolling and boring. To deposit a layer of copper on iron is attended with many practical difficulties, both in protecting the iron from the acid solution for so long a time as is required to deposit the proper thickness, and in securing the adhesion of the two metals during the subsequent operations. It requires a deposit of about a quarter of an inch in thickness to allow for turning before engraving. There is then the annealing to soften the copper, etc., which interferes with the adhesion of the two metals, probably from their different rates of expansion, and other causes. Similar objections may be made to the coating of brass rollers with copper. Numerous and varied have been the experiments made, but all without success; nevertheless we have every confidence that means will be obtained for producing rollers by the electro process.

ETCHING OF ROLLERS.—Another application of the process to printers' rollers was to plate the surface of the roller with silver for the purpose of etching. The engraving is then made through the silver coating; the roller is next passed through nitric acid, which acts upon the exposed copper, the silver taking the place of varnish in ordinary etching: but practical difficulties have caused the abandonment of this application also.

PRINTING.—The electro-metallurgical process has been applied to many operations in ordinary printing. Mr. Warren de la Rue has been eminently successful in many of these applications. It has also been applied to plates for printing music, and for embossing soft materials, such as leather. By depositing a sheet of copper upon a skin of morocco leather, it may be used for imparting an impression to other skins of leather, giving them the appearance of fine morocco.

The printing of music has also been successfully done by electrotyping the plate from a stereotype cast. The same may be done from ordinary stereotype plates.

GLYPOGRAPHY.—A process which Mr. Palmer, the inventor, named Glyphography, has been one of the most successful attempts to apply the electrotype to the art of engraving. The principle of the invention consists in depositing copper in the grooves or engravings made in a layer of some soft substance spread on a sheet of copper, and covering the whole with a sheet of electrotype copper. The counterpart of the engraving thus produced is used for printing from in the same manner as letter-press printers' types or woodcuts. It may therefore be called a mode of stereotyping, with this difference, that it is made directly from the drawing by the artist. The drawing, however, must be made in a particular way, which, with the other necessary manipulations, is thus given by Mr. Palmer:*

"A piece of ordinary copper plate, such as is used for engraving, is stained *black* on one side, over which is spread a very thin layer of *white* opaque composition, resembling white wax both in its nature and appearance. This done, the plate is ready for use.

"In order to draw properly on these plates various sorts of points are used (according to the directions here given), which remove, wherever they are passed, a portion of the white composition, whereby the blackened surface of the plate is exposed, forming a striking contrast with the surrounding white ground, so that the artist sees his effect at once.

"The drawing, being thus completed, is put into the hands of one who inspects it very carefully and minutely, to see that no part of the work has been damaged or filled-in with dirt or dust; from thence it passes into a third person's hands, by whom it is brought in contact with a substance having a chemical attraction or affinity for the remaining portions of the composition thereon, whereby they are heighted *ad libitum.* Thus, by a careful manipulation, the *lights* of the drawing become thickened all over the plate equally, and the main difficulty is at once overcome. A little more however remains to be done. The depth of these non-printing parts of the block must be in some degree proportionate to their width, consequently the larger breadths of *lights* require to be thickened on the plate to a much greater extent in order to produce this depth. This part of the process is purely mechanical and easily accomplished.

"It is indispensably necessary that the printing surfaces of a block prepared for the press should project in such relief from the block itself as shall prevent the probability of the inking-roller touching the interstices of the same whilst passing over them. This is accomplished in wood engraving by cutting out these intervening parts, which form the lights of the print, to a sufficient depth; but in glyphography the depth of these parts is formed by the remaining portions of the white composition on the plate, analogous to the thickness or height of which must be the depth on the block, seeing that the latter is, in fact (to simplify the matter), a *cast or reverse* of the former. But if this composition were

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* **Glyphography, or engraved drawing, for printing at the typo press after the manner of woodcuts, 1844.**

spread on the plate as thickly as required for this purpose, it would be impossible for the artist to put either close, fine, or free work thereon; consequently the thinnest possible coating is put on the plate previously to the drawing being made, and the required thickness obtained ultimately as described.

"The plate thus prepared is again carefully inspected through a powerful lens, and closely scrutinized to see that it is ready for the next stage of the process, which is to place it in a trough and submit it to the action of a galvanic battery, by means of which copper is deposited into the indentations thereof, and, continuing to fill them up, it gradually spreads itself all over the surface of the composition until a sufficiently thick plate of copper is obtained, which on being separated will be found to be a perfect cast of the drawing which formed the *clichée.*

"Lastly, the metallic plate thus produced is soldered to another piece of metal to strengthen it, and then mounted on a piece of wood to bring it to the height of the printer's type. This completes the process, and the glyphographic block is now ready for the press.

"It should however have been stated previously, that if any parts of the block require to be *lowered,* it is done with the greatest facility in the process of mounting."

This process has however not come into much use as a substitute for wood engraving, in consequence of the impossibility of finding a suitable varnish for the use of the artist or engraver. It has, in fact, given way to another process, also embraced in Mr. Palmer's patent, which is worked thus: A copper plate is etched by the process commonly employed by engravers, the lines being cut into the copper with a bold stroke. The lines are then bitten deeper by nitric acid. The etching is made *direct,* not *reversed,* as it is upon a plate that is to be worked at the copperplate press. When the engraving is ready, the etching varnish through which the drawing is cut is covered with a conducting substance, and an electrotype plate is deposited upon the etching. When this is removed from the mould it requires to be trimmed, for it is impossible to etch a plate, or to bite the etching, so that all the lines shall be exactly of the same depth. To remedy this the face of the electrotype is levelled by grinding and burnishing. The following instructions for artists are published by the patentee:

INSTRUCTIONS ON GLYPHOGRAPHY FOR THE AMATEUR.—"The amateur must remember that he is producing a work of art for the surface press, and not for copperplate printing.

"The drawing or etching should not be made with lines of equal thickness in all the tints. If it is so treated with a *thick* line, and if the cross hatching be kept of the same strength as the principal line, it will appear like a coarse pen-and-ink drawing. If it is treated in the above manner with a *fine* line, and the work laid very close, it will have the appearance of one of the old etchings. The amateur, therefore, will do well to remark, that it is only by a judicious mixture of bold and delicate work that beauty of style can be obtained; and as the darkest shades are generally foremost, and become gradually lighter to the distance, so that the darkest or nearest tones should generally be formed by the boldest work, and gradually increase in delicacy to the offscape.

"Etching is a process nearly resembling drawing with a very fine pen or pencil, and should be proceeded with as follows:

"Having obtained a polished copper-plate with an etching ground properly laid, proceed to put your design upon the plate.

"If it is a print or miniature that is being copied, you must make a sketch or tracing of the same with a black lead-pencil: it must then be traced on to the plate, remembering always, that the proof from the block will be in the same position as the etching; and that nothing must be etched or written backwards, as for the ordinary copperplate printing.

"In order to trace the object on to the plate, take a piece of transfer paper,* place it face downwards upon the plate, secure the corners with a piece of wall wax or paste, or hold it steadily down, if there is not much to trace; then place on your sketch or tracing, go over the outline with your etching-needle or a very hard black lead-pencil, removing a corner at a time to see that all is correctly transferred, and nothing omitted, or that the outline be not too heavy and thick, in which case you must trace lighter.

"Having thus got your subject, as it were, sketched upon the plate, proceed in all respects with your etching-needle as if making a drawing with a black lead-pencil, only working more firmly, taking care always slightly to cut the copper.

"Be careful not to try to form the dark touches and the *black* parts of the subject with a number of lines crossing and recrossing each other, but scrape them away entirely with the point of your penknife, or any other convenient instrument.

"In commencing the etching of a view, it is usual to begin with the offscape, etching the same as neatly and as close *as the nature of the printing will admit*, working more firmly and boldly in every progressive tone, until you reach the foreground. In portraits it is usual to commence with the eye; and in draperies at the top, working downwards.

"Owing to the great difference between surface and copperplate printing, depth of tone should be sought as much from the breadth or thickness of the lines, as from laying them close together; and on the contrary, lightness of tint must be obtained by the distance of the lines from each other, as well as from their delicacy.

"If you make a false line, or wish to efface any portion of the work, a little Brunswick black (which can be procured at most oil and color shops), spread thinly, may be used to stop it out; or rub

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* To prepare the transfer paper, take some thin post or tissue paper, rub the surface well with black lead, vermilion, red chalk, or any coloring matter: wipe this preparation well off with a piece of clean rag, and it will be ready for use.

a little of the superfluous ground from the side of the plate with a camel's hair pencil and turpentine: when this is dry the work can be re-etched and finished at pleasure."

This last process has afforded some excellent work in the shape of maps, among which we may cite the *Penny Atlas*, published by Messrs. Chapman and Hall. Among subjects of a more picturesque nature executed by glyphography, we may instance Mr. George Cruikshank's etchings of *The Bottle*. These are sufficient to show that the art of electrotyping engravings, though yet in its infancy, promises to be hereafter of importance in the fine arts.

COPYING OF COPPERPLATE ENGRAVINGS.—Copperplate engravings, of all sizes, and of every degree of excellence, have been copied by electrotype. The process is exactly the same as that of making a copy of a penny-piece, as described at page 533; namely, an electrotype mould is first made in copper, on which, of course, the engraving appears in relief; upon which mould any number of electrotype copies of the copperplate engraving may be deposited successively. The duplicates thus made are accurate copies of the original engraving; but they are rapidly worn away by the friction they undergo in the ordinary process of copperplate printing. The process has therefore not displaced the use of engravings on steel.

COATING OF GLASS AND PORCELAIN.—This is done by putting a fine coating of copal varnish over the glass, then black-leading it, and depositing the copper. Another method has been proposed, namely, to make a varnish of two parts asphaltum and one part mastic, by fusing these together, and, when cool, dissolving the mixture in spirits of turpentine to a syrup consistence. To prevent the deposit coming off the glass, the vessel is first corroded by the fumes of hydrofluoric acid. A solution of gutta percha or benzole has also been proposed as a varnish for fixing on the black-lead and deposit.*

Retorts, basins, and other chemical vessels, are sometimes covered with copper for their protection during boiling and evaporation. China saucepans have also been made and covered with copper to take the place of tinned copper vessels, but the adhesion of the metal upon these substances, even when we attempt to secure it by the means above referred to, is never so perfect but that after a short use the deposit of copper loosens from the vessels. There is then great liability for liquids to get between the coating and the vessel, and when heat is afterwards applied these liquids saturated with verdigris boil out. Consequently such coverings are not well adapted either for culinary purposes or delicate chemical operations. They have, notwithstanding, been highly recommended, and the practice of covering the bulbs of large plain retorts, etc., may be useful in a few large manufacturing operations, but our experience is certainly not favorable to their general use.

Mr. John Ridgway, of Cauldon-place, Staffordshire, china manu-

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* Progress of General Science, vol. ii.; and Pharm. Journal, vol. viii.

facturer, has recently patented certain improvements in the method or process of ornamenting or decorating articles of glass, china, earthenware, or other ceramic manufactures. In the specification of his patent, just enrolled, Mr. Ridgway states that his first object is to apply a new glaze, which shall enable the metallic coating to adhere firmly, by capillary attraction, and give affinity for copper as a first coating. In pursuance of this, he first submits the article to an alcoholic solution, or a gelatinous solution. He then brushes over it an impalpable powder, composed of half carburet of iron, and half sulphate of copper. The article thus treated is then to be corroded by the fumes of hydrofluoric acid. The article is then to be smoothed, by brushing it over with silver sand, or by the scratch-brush; but when the shape and nature of the article will not admit of this, it is to be plunged into a liquor, consisting of 6 quarts sulphuric acid, 4 quarts aquafortis, ¾ oz. muriatic acid, and 6 quarts water. Grease is to be carefully removed from the article, and a thin film of mercury is to be applied. The solution of copper consists of 1 sulphate of copper, and 4 filtered water. Suitable solutions for silvering or gilding are to be applied, in accordance with the practice of electrotyping. The claim is not to the solutions the coating as such, but to the application of "electrotyping," or electro-metallurgy, to the objects stated in the title, provided the articles be so prepared as to allow them to combine from an alloy with them.

ON GALVANIC SOLDERING.—Among the many applications of the deposition of metals, there is one we have been often asked about, namely, if it would not be possible to solder different metals together by that process. The following article, which is taken from the Technologist, will give a full reply to all who may be still inquiring for this application:

"Under the name of galvanic soldering, a process is known by means of which two pieces of metal may be united by means of another metal, which is precipitated thereon through the agency of a galvanic current. This mode of soldering by the 'wet method' has been often recommended in various periodicals relating to the industrial arts; but it has been objected that, practically speaking, the union between two pieces of metal could not be effected by means of a metal precipitated by galvanic agency. In order, however, to arrive at a definite conclusion upon this question, M. Elsner undertook the following experiments, the results of which are in favor of the practical use of the operation of soldering by galvanic agency. In conducting these experiments, the kind of battery known as Daniell's 'constant battery' was employed; and upon the end of the copper wire, which formed the negative electrode, a strong ring of sheet-copper was placed. This ring was cut asunder at one point, and the distance left between the several parts was about the sixtieth of an inch. At the end of a few days (during which time the exciting liquors were several times renewed) the space in the severed portion of the ring was completely filled up with copper regulus, which had been precipitated; and on partially cutting with a file through the part thus filled up, and examining it with a lens, it was observed to be very equally filled with solid and coherent copper.

"Another copper ring was then cut into two parts, and the two semi-angular segments thus obtained were placed with the faces of the sections opposite each other, and submitted to the action of a galvanic current. At the end of a few days, the segments were united by the copper precipitated, thus forming again a complete ring. It was also found in this case, on removing with a file a portion of the thickness of the ring at the points of contact, that the spaces had been completely filled up by copper galvanically precipitated, which had united the whole. On observing these points carefully with a lens, the regular deposition of the copper could be readily traced between the formerly separated portions of the ring.

"A third experiment was made in the following manner: Two strong rings of sheet-copper were laid with their freshly-cut faces one upon another, so that the two rings constituted a cylinder. These rings were surrounded by a band of sheet-tin which was coated with a solution of wax, so that the two rings were equally surrounded by a conducting material. Thus disposed, these rings were attached to the negative wire of the battery and immersed in the bath of sulphate of copper. At the end of a few days the interior surface of the rings was covered with precipitated copper, and between the contact surfaces of the two rings copper was also precipitated. These rings had only been submitted to the galvanic current to such an extent as to cover their interior surface with a thin coating of precipitated copper, and yet they were already completely re-united, and formed a cylinder consisting of a single piece. The exterior conducting covering, consisting of a sheet of tin, was of course removed before testing the cohesion or persistence of the galvanic precipitate. It may be remarked that these rings, after being for a certain time in contact (during the galvanic action), together with the plate of copper upon which they rested, became so encrusted with precipitated metallic copper that some force was found necessary to effect their detachment from the copper wire.

"There would appear to be no doubt, then, according to the results obtained in the preceding experiments, that two pieces of metal may be firmly united by means of galvanically-precipitated copper: in a word, that soldering by galvanic agency is perfectly practicable. It will therefore be possible to firmly unite the different parts of a large piece of metal, and to make a perfect figure of them by galvanic precipitation of a metal (copper, in ordinary cases). If solutions of salts of gold or silver were employed in as concentrated a form as those of copper above mentioned, there is reason to believe that galvanic soldering would also result. In fact, M. de Hackewitz states that in some experiments on a larger scale which he undertook, to obtain hollow figures by galvanoplastic means, he had remarked that galvanic union often took place between the pieces operated upon. M. Elsner states that while conducting the experiments above-mentioned, he remarked that by employing too powerful a current, the negative electrodes of copper, and even the plate of copper, and ring of the same metal resting thereon, became covered with a deep brown substance, in the same manner as this occurs under similar circumstances in galvanic gilding, as is well known. After several unsuccessful attempts to prevent the formation of this brown coating, M. Elsner found that it was possible to remove it entirely on immersing the articles covered therewith during a few seconds in a mixture of sulphuric and nitric acids. By this means the precipitated copper was made to assume its natural red color. The possibility of practically effecting the operation of soldering by galvanic agency may be explained in a few words, in a theoretical point of view. The article is in fact in an electro-negative state of excitation, whilst the zinc operates positively. The result is, that the faces which are placed opposite each other, when the ring has been cut, are negative; that is to say, in an electric condition of the same denomination. During the progress of the electrolytic decomposition of the metallic salt in solution (sulphate of copper in the above case), the electro-positive molecules of copper which are detached simultaneously arrange themselves upon the two opposite faces, and in the direction of the break. Now, from the moment that these molecules are deposited, they constitute with the piece a homogeneous mass, and from that time act negatively upon the copper which is contained in the solution, and again precipitate copper in the form of regulus. This method of operation continues until the space which existed between the two separate pieces of metal is filled up with metallic copper—in fact the layers of copper which become deposited in an equal manner upon the contiguous faces of the metal gradually diminish the distance which separated the latter, until at length the metallic layers which cross in the opposite direction meet each other; the result being, that the whole of the break which originally existed between the faces will have disappeared and become filled up with copper.

"With respect to the solidity (the degree of cohesion) of the galvanic soldering, it is the same as that of copper or other metal precipitated by galvanic agency. It will moreover be well understood that too energetic galvanic excitation must have an injurious influence upon the cohesion of the metal precipitated; and in this case precisely the same phenomena will be observed as those which have long manifested themselves in ordinary galvano-plastic operations."—L. ELSNER, *Technologist.*

We mention another application of the electro deposition, which might be extended.

GALVANO-PLASTIC NIELLO.—Niello, a peculiar style of enamelling, consists in engraving or stamping figures on a plate of silver or gold, and then filling the incised lines or impressed pattern with a sort of enamel—differing, however, from true enamel—which is a kind of glass, by being formed of a mixture of the sulphurets of lead, silver, and copper. This mixture is of a black color—hence the name niello, from nigellum, derived from niger, black—and when melted into the intaglio parts of a plate gives it somewhat the appearance of an inked engraved copperplate. A new kind of niello work has lately been introduced on the Continent, in which, however, the figures are not produced by an enamel of sulphuret of silver, as in the true niello, but by a different-colored metal; thus on a plate of gold may be produced fine engravings, the lines of which are in silver, and so on. This can be effected in two ways: first, by covering the plate to be ornamented with a varnish exactly as is used in etching; the pattern or ornament is then to be engraved on this varnish, and the metallic surface etched out to the proper depth. The engraved plate is to be placed in a solution of the metal intended to form the pattern, and a deposit allowed to form in the usual way adopted in all galvanoplastic works. When the intaglio lines have been completely filled up by the deposited metal, the plate is removed from the solution and ground, when the pattern will be fully developed. The second method consists in sketching the ornament on a sheet of paper with lithographic ink, placing this, with the side upon which the drawing was made, upon a plate of silver or other metal to be ornamented, and pressing them together; the paper is now removed with water, slightly acidified, leaving the ink adhering to the plate, which is to be sprinkled with sand. When the ink has fully dried, the sand is blown away; the plate is placed in a solution of the metal which it is intended should form the ground, and put in connection with the battery. By this means a deposit will be formed over the whole surface, except the parts protected by the ink. On the removal of the latter with alcohol or spirits of turpentine, etc., the original metal will be exposed, forming a pattern. Many highly ornamental and useful applications might be made of these processes, especially in the manufacture of church furniture. Instead of simply engraving the name and legend upon pieces of plate presented to persons, it might be put in in letters of gold at very little more expense.

CHAPTER XXVIII.

BRONZING.

We have already mentioned that when a medal has been made from a metallic mould, protected by a little wax dissolved in turpentine, it retains its bright copper lustre for a long time, even when exposed to the air; but generally the copper medals and other objects are very liable to tarnish, for which reason it is usual to give them a coating of bronze, that they may acquire a permanently agreeable appearance.

BROWN BRONZES.—Bronzing is effected by several very simple methods, the most common of which is the following:

Take a wine-glass of water, and add to it four or five drops of nitric acid; with this solution wet the medal (which ought to have been previously well cleaned from oil or grease) and then allow it to dry; when dry impart to it a gradual and equable heat, by which the surface will be darkened in proportion to the heat applied.

ANOTHER METHOD.—Make a thin paste of crocus and water: lay this paste on the face of the medal, which must then be put into an oven, or laid on an iron plate over a slow fire; when the paste is perfectly reduced to powder, brush it off and lay on another coating; at the same time quicken the fire, taking care that the additional heat is uniform; as soon as the second application of paste is thoroughly dried, brush it off. The medal being now effectually secured from grease, which often occasions failures in bronzing, coat it a third time, but add to the strength of the fire, and sustain the heat for a considerable time: a little experience will soon enable the amateur to decide when the medal may be withdrawn; the third coating being removed, the surface will present a beautiful brown bronze. If the bronze is deemed too light the process can be repeated.

Another very simple method is this: after the medal is well cleaned from wax or grease, by washing it in a little caustic alkali, brush some black lead over the face of it, and then heat it in the same way as described for crocus; or a thin paste of black lead may be used, and the processes already referred to be repeated until the desired brown tint is obtained. In this kind of bronze a little Hematitic iron ore, which has an unctuous feel, may be brushed over the face of the bronze, by which a beautiful lustre is imparted to it, and a considerable variety in the shade may be obtained. In the brown bronzes the copper is slightly oxidized on the surface.

BLACK BRONZES.—A very dark colored bronze may be obtained by using a little sulphuretted alkali (sulphuret of ammonia is best). The face of the medal is washed over with the solution, which should be dilute, and the medal is to be dried at a gentle heat. It should afterwards be polished by a hard hair brush. Sulphuretted hydrogen gas is sometimes employed to give this black bronze, but the effect of it is not so good, and the gas is very deleterious when breathed. In these bronzes the surface of the copper is converted into a sulphuret.

Many metallic solutions, such as weak acid solutions of platinum, gold, palladium, antimony, etc., will impart a dark color to the surface of medals when they are dipped into them. The medal after being dipped into the metallic solution is to be well washed and brushed. In such bronzes the metals contained in the solution are precipitated upon the face of the copper medal, which effect is accompanied by a partial solution of the copper.

GREEN BRONZES.—Green bronzes require a little more time than those already described. They depend upon the formation of an acetate, carbonate, or other green salt of copper upon the surface of the medal. Steeping for some days in a strong solution of common salt will give a partial bronzing which is very beautiful, and if washed in water, and allowed to dry slowly, is very permanent. Sal ammoniac may be substituted for common salt. Even a strong solution of sugar, alone, or with a little acetic or oxalic acid, will produce a green bronze; so also will exposure to the fumes of dilute acetic acid, to weak fumes of hydrochloric acid, and to several other vapors. A dilute solution of ammonia allowed to dry upon the copper surface will leave a green tint, but not very permanent.

Electrotypes may also be bronzed green, having the appearance of ancient bronze, by a very simple process: take a small portion of bleaching powder, place it in the bottom of a dry vessel, and suspend the medal over it, and cover the vessel: in a short time the medal will take on a green coating, the depth of which may be regulated by the quantity of bleaching powder used, or the time that the medal is suspended in its fumes: of course any sort of vessel, or any means by which the electrotype may be exposed to the fumes of the powder, will answer the purpose: a few grains of the powder is all that is required. According as the medal is clean or tarnished, dry or wet, when suspended, different dints with different degrees of adhesion will be obtained.

The green bronzes are generally applied to figures and busts.

These directions and hints will enable the student to vary his bronzes. Practice will give him perfection, and enable him to fix upon that which best pleases his taste. Scarcely two electrotypists agree upon the same method of bronzing, but differ in some little details of practice, or on some point of taste. Each prefers the plan that has given to him his best results, and which he can hardly impart by description to another.

Should the electrotypist wish to coat the copper medal with another metal, as silver and gold, directions will be given under plating and gilding how to proceed to effect his purpose.

CHAPTER XXIX.

DEPOSITION OF METALS UPON ONE ANOTHER.

COATING OF IRON WITH COPPER.—Besides making articles of solid copper, we may at a small cost give a coating of copper to another metal, such as iron, which if kept in a dry place, will retain the appearance of copper for any length of time. But in covering iron with copper, or any one metal with another, great care must be taken that a proper kind of solution be used.

It is a familiar fact, that if a piece of iron, such as the blade of a knife, be dipped into a solution of sulphate of copper, it receives a coating of that metal. This is often described as the result of galvanic action, but there is no more galvanic action in this than in any ordinary chemical combination; it is simply a case of chemical substitution; the acid that is in union with the copper having a stronger attraction for iron, leaves the copper, and combines with the iron: the copper is left on the surface of the iron, but the two metals not having sufficient polar attraction to cause them to adhere so firmly as to exclude the action of the acid, the copper is undermined, and falls to the bottom of the solution as a powder. After some copper has fallen upon the surface of the iron, local galvanic action is induced between it and the iron; but this secondary action is altogether distinct from that which first takes place.

Any solution that has the power to give a metallic coating to a metal when dipped into it, should not be used to coat that metal by electricity.

The attraction of the common mineral acids for the ordinary metals is as follows: Zinc, iron, copper, nickel, silver, gold, platinum.

If the metal to be deposited be copper held in solution by an acid, say sulphuric acid, then iron or zinc cannot be coated with copper from this solution; the acid having a greater attraction for these metals, will leave the copper and combine with them as described above: but if the metal to be coated be any of those under copper, in the above table, then no chemical action will take place, and no deposit will be made, except as the effect of the electric current introduced by the battery. This we believe is the cause why De la Rive, Spencer, and others, failed, at an early stage of the art, in their experiments in plating and gilding, as they employed acid solutions, which are quite impracticable when used for depositing upon inferior metals. Under these circumstances, other solvents for the metals must be used, which have a different relative attraction for the metals than the acids have. The substance first applied for this purpose is, after sixteen years experience, still found to be the best—namely, cyanide of potassium.

CYANIDE OF POTASSIUM.—This substance may be prepared by exposing ferrocyanide of potassium (yellow prussiate of potash) to a red heat in an iron crucible; then pounding the mass, and boiling it in alcohol of about spec. grav. 0·900: cyanide of potassium crystallizes on cooling the resulting solution. It is now, however, almost universally prepared for electro-metallurgical purposes, by a process which was first suggested by Messrs. F. and E. Rodgers, but afterwards more fully explained by Professor Liebig, and hence called "Liebig's Process:" it is at once both simple and easy of performance.

Ferrocyanide of potassium, pounded fine, is dried over a slow fire (we have found an iron plate, or clean shovel, to serve the purpose very well): it must be constantly stirred to prevent its forming a cake upon the hot iron; when perfectly free from moisture, 8 parts must be thoroughly well mixed with three parts of carbonate of potash, also well dried: put a cast-iron crucible into the fire, and, when it is red hot, nearly fill it with the mixture, and keep up the heat by occasional augmentations of fuel: the crucible should be kept covered as much as possible. In a short time the whole fuses into a beautiful liquid with the evolution of gas. It should be kept in this state for 10 or 15 minutes, being occasionally stirred with an iron rod: the portion adhering to the red should be examined from time to time, and when the liquid on it cools white, it is an indication that it is ready to be removed from the fire; but the first time a cast-iron crucible is used, this test will not be so accurate, the salt having then a light gray color. When the crucible is removed from the fire, it should be placed upon a stone, the mass stirred, and then allowed to settle for a short time, after which the clear, or liquid part, is to be poured off into a clean iron vessel. The sediment should be scraped clean out of the crucible while it is hot, as the crucible will do to use again several times; but if the mass at bottom be allowed to cool it will be difficult to remove it from the crucible afterwards. The clear liquid poured off is cyanide of potassium, having from 25 to 30 per cent. of cyanate of potash, and other impurities generally contained in commercial yellow prussiate of potash: 80 per cent. of cyanide of potassium is the greatest proportion that this process can give. We have occasionally obtained it at 78 per cent. from commercial materials, but more generally at 70 and 72 per cent; and we have found cyanide of potassium in the market containing as little as 49 per cent. of pure cyanide.

The results of the manufacture of this salt on a large scale, from the ordinary materials of commerce, show that 55 lbs. of yellow prussiate, dried as directed above, yield 48 lbs.; and 19 lbs. of carbonate of potash give 18 lbs. of dry salts; in all 66 lbs. of the proper mixture. The crucible used was of this shape, Fig. 579, capable of holding from two to three pints; in general two of them were used up in making the above quantity of cyanide, even when great care was taken. One great cause of the crucible giving way is the depth of the fire, and openness of the bars of the grate. The bottom of the crucible, between each pair of bars, fuses from the great heat concentrated near the opening. To remedy this evil, a square tile of fire-clay should be laid upon the bars upon which the crucible is to rest. The tile must not cover all the bars, else the draught will be stopped—an equal space must be left at each side of the tile, which will preserve a regular heat around the crucible.

Fig. 579.

The quantity of clean cyanide of potassium obtained from the above quantity of materials was about 38 lbs.; the sediment scraped out of the crucible, being put into water, yielded about 6 lbs. more in solution, but of inferior quality—good enough, however, for precipitations, the cleaning of silver, and other general purposes in the factory.

It may be mentioned that in these operations the crucible is never allowed to cool, but as soon as the sediment is scraped out, it is again put into the furnace. If the iron sediment is not well cleaned out, it imbibes oxygen rapidly, and the charge next taken from the crucible will have an excess of cyanate of potash, besides lessening the capacity of the crucible. Generally speaking, however, even when the utmost care is taken, the last charge has more cyanate of potash than the first.

CYANIDE OF COPPER.—To prepare copper solutions by means of cyanide of potassium, for covering iron and other positive metals, there are several methods.

First Method.—To a solution of sulphate of copper, add by degrees a solution of cyanide of potassium, which will give a yellowish green precipitate, with slight effervescence. There will be evolved a gas, having a most pungent odor, to prevent the inhalation of which the most watchful carefulness has to be exercised, as it is very deleterious. It will be found that the copper is not all precipitated by the cyanide of potassium, for according to this mode, when a precipitate ceases to be formed, the solution remains greenish blue, probably owing to the decomposition of the cyanate of potash, and the formation of ammonia, which holds copper in solution, and forms also some complicated compounds with the cyanides of copper. If cyanide of potassium is added until the blue solution disappears, still copper is held in the solution, and may be detected by taking out a little, and adding to it a few drops of sulphuric acid, which will give a white precipitate of subcyanide of copper. The loss of copper sustained is the only objection to this mode of preparing a copper solution. The cyanide of potassium is added until a precipitate is no longer formed; it is then allowed to settle, the clear liquid is poured off, and the vessel is to be filled with water: when the precipitate has again settled, the liquor is poured off, and this washing is repeated four or five times, in order to wash out the sulphate of potash which is formed during the precipitation. After being thus washed, a solution of cyanide of potassium is added to the precipitate until it dissolves. The coppering solution is now complete: it is of a light yellow color, and is well adapted for ordinary purposes. The loss of copper is, however, considerable, being about one-fifth of the whole.

Second Method.—A coppering solution may also be prepared by adding cyanide of potassium, to oxide of copper, or to carbonate of copper, until it is dissolved. But these solutions are objectionable, the latter especially so, as it contains a great quantity of carbonate of potash, formed from the mutual decomposition of the carbonate of copper and cyanide of potassium, and the carbonate of potash deteriorates the solution; the former leaves potash in the solution, but this is not so bad as the carbonate of potash.

Third Method.—The method we have adopted in manufacturing purposes is as follows:—To a solution of sulphate of copper, we add a solution of ferrocyanide of potassium, so long as a precipitate continues to be formed: this is allowed to settle, and the clear liquor being decanted, the vessel is filled with water, and when the precipitate settles, the liquor is again decanted, and we continue to repeat these washings until the sulphate of potash is washed quite out. This is known by adding a little chloride of barium to a small quantity of the washings, and when there is no white precipitate formed by this test, the precipitate is sufficiently washed. A solution of cyanide of potassium is now added to this precipitate until it is dissolved, during which process the solution becomes warm by the chemical reaction that takes place. The solution is filtered, and allowed to repose all night. If the solution of cyanide of potassium that is used is strong, the greater portion of the ferrocyanide of potassium crystallizes in the solution, and may be collected and preserved for use again. If the solution of cyanide of potassium used to dissolve the precipitate is dilute, it will be necessary to condense the liquor by evaporation, to obtain the yellow prussiate in crystals; the remaining solution is the coppering solution. Should it not be convenient to separate the yellow prussiate by crystallization, the presence of that salt in the solution does not deteriorate it, nor interfere with its power of depositing copper.

PECULIARITIES IN WORKING CYANIDE OF COPPER SOLUTION.—The true composition of the salts thus formed by copper and cyanide of potassium has not yet been determined, being both various and complicated, but their relations to the battery and electrolyzation are peculiar. The solution must be worked at a heat of not less than from 150° to 200° Fahrenheit. All other solutions we have tried follow the laws laid down by Spencer and Smee, namely, that if the electricity is so strong as to cause gas to be evolved at the electrode, the metal will be deposited in a sandy or powdered state; but the solution of cyanide of copper and potassium is an exception to these laws, and there is no reguline deposit obtained unless gas is freely evolved from the surface of the article upon which the deposit is taking place. This necessitates the use of batteries of several pairs intensity, varying from five to nine pairs of Wollaston's battery, according to the heat and the state of the solution.

As this solution is used hot, a considerable evaporation takes place, which requires that additions be made to the solution from time to time. If water alone is used for this purpose, it will precipitate a great quantity of copper as a white powder, but this is prevented by dissolving a little cyanide of potassium in the water at the rate of about four ounces to the gallon. The vessels used in factories for this solution are generally of copper, which are heated over a flue, or on a sand-bath—the vessel itself serving as the positive electrode of the battery; but any vessel will suit if a copper electrode is employed, when the vessel is not of copper.

PREPARATION OF IRON FOR COATING WITH COPPER.—When it is required to cover an iron article with copper, it is first steeped in hot caustic potash or soda, to remove any grease or oil. Being washed from that, it is placed for a short time in dilute sulphuric acid, consisting of about one part of acid to sixteen parts of water, which removes any oxide that may exist. It is then washed in water, and scoured with sand till the surface is perfectly clean, and finally attached to the battery, and immersed in the cyanide solution. All this must be done with despatch, so as to prevent the iron from combining with oxygen. An immersion of five minutes duration in the cyanide solution is sufficient to deposit upon the iron a film of copper. But it is necessary to the complete protection of the iron, that it should have a considerable thick coating: and, as the cyanide process is expensive, it is preferable, when the iron has received a film of copper by the cyanide solution, to take it out, wash it in water, and attach it to a single cell or weak battery, and put it into a solution of sulphate of copper. If there is any part not sufficiently covered with copper by the cyanide solution, the sulphate will make these parts of a dark color, which a touch of the finger will remove. When such is the case, the article must be taken out, scoured, and put again into the cyanide solution till perfectly covered. A little practice will render this very easy. The sulphate solution for covering iron should be prepared by adding to it by degrees a little caustic soda, so long as the precipitate formed is re-dissolved. This neutralizes a great portion of the sulphuric acid, and thus the iron is not so readily acted upon.

EFFECTS OF CONDUCTING POWER IN SOLUTIONS AND METALS.—In covering iron, platinum, or such comparatively bad-conducting metals, with other metals that are good conductors, or the solutions of which are good conductors, the property of conduction in relation to the solution is beautifully illustrated. If we take a copper wire, say 8 or 10 feet long, one end of which is attached to the zinc of a battery, and laid parallel with the positive electrode into a solution for the purpose of receiving a deposit, it will be found that the greatest amount of deposit has taken place at the end furthest from the battery: but if an iron or platinum wire be substituted for the copper one, the contrary result will take place; for the end furthest from the battery will be the last to receive the coating, and will have the least quantity of metal deposited upon it. If the copper wire was 30 feet long, little alteration would be seen in the deposit; but upon an iron or platinum wire of that length the deposit proceeds only a certain distance, and no deposit will take place on the end furthest from the battery until the current has passed a considerable time, after which the deposit is observed to advance gradually. The copper as it becomes deposited on the iron acts as a conductor, transmitting the deposit further onwards to its final point, as well as adding to the deposition already effected upon the iron. The length of deposit that would be formed on the first immersion of the wire depends upon the conducting power of the solution; for, as already stated, solutions vary in this property as well as metals. We have found that a few feet of iron wire offer a greater resistance to the passage of the current than the solution between the iron wire and the positive electrode, which is only about 2 or 3 inches; but their exact relations to each other we have not yet had an opportunity of investigating.

Under these circumstances, it may be asked, why not increase the intensity of the battery, and so force it along the wire? But this, as will be apparent, can only be done within certain limits; for by increasing the intensity of the battery it may be rendered too strong for the solution near the battery, and thus a sandy deposit will be given at the one end and none at the other. The electro-metallurgist, when coating long rods of iron wire with any metal, has to make connections with the battery every few feet. The wire is generally coiled up in the form of a cork-screw, and suspended by copper wires. We have found it very convenient to coil it upon a reel, having its armatures tipped with copper, and connected with the battery. This plan insures a regular coating, but the position of the wire requires to be changed during the operation, otherwise the parts which press upon the arms of the reel will be left without deposit.

ILLUSTRATION OF CONDUCTION.—As an illustration of the property of conduction, we mention the following circumstance:—Having a large iron shaft, or rod, about 12 feet long and 3 inches average diameter, to cover with copper, we had it properly cleaned, placed in a hot solution of cyanide of copper and potassium, and surrounded by sheets of copper as a positive electrode. Two batteries of 7 pairs intensity were attached, one at each end of the shaft; but, by an oversight, one of the batteries was not properly connected, the copper terminal of the battery having been attached to the shaft. Had the shaft been of copper, the one battery would have neutralized the other, so that there would not have been any deposit; or, had the one battery been stronger than the other, there would have been a current and deposit equal to the excess of power of the one over the other. But, under the stated circumstances, a different result was obtained. After the batteries had been in action two hours, we found that a beautiful copper coating was imparted to that half of the shaft which extended from the point properly connected, while the other half was quite bare—no deposit having taken place upon it: but a deposit had been made upon the copper electrode opposite this non-affected half. The batteries did not (as we could perceive) affect one another, except that the one improperly connected prevented the deposit effected by the other proceeding further than the half length of the shaft; but it made the deposit obtained more perfect than would have been the case had there been only one battery at one end.

In this instance, the distance of the shaft from the electrode was 6 inches, so that the resistance of 6 feet of the iron was more than 6 inches of the solution; hence the influence of the contra-acting battery could not reach further: or if any power passed further it was neutralized by the other battery—which we are inclined to think did not take place—as the amount or thickness of deposit upon the one half was fully more than we would have anticipated upon the whole, had the batteries been properly connected.

NON-ADHERENCE OF DEPOSIT.—Objections have been made to covering iron with copper for its protection, from an impression that the copper will not adhere to the iron; but if the operation is carefully performed the copper will adhere; when it does not, it will generally be found that it is the copper deposited from the sulphate which loosens from the copper deposited from the cyanide—occasioned no doubt, by the article not having been sufficiently washed from the cyanide solution, and thus having a thin film of cyanide of copper precipitated upon the surface, which prevents the adhesion of the after deposit. Or, as it happens sometimes, that the cyanide of copper solution has not much free cyanide of potassium, and, consequently on putting the article into water, the cyanide of copper is decomposed by the water, and precipitated upon the surface. If a little cyanide of potassium is dissolved in the first water used for washing out the depositing solution, this will be prevented.

We have repeatedly deposited copper upon iron wire, and afterwards had it drawn out to twice its original length without the copper striping off; but, as the copper becomes hard and brittle, it is liable to break if the wire is much bent, and if it be made red hot, to anneal or soften it, the copper will oxidize, and if the coating is thin, the iron will be left bare in some places. We have seen iron bolts, covered with copper, driven through 17 inch wood, and nails of all sizes subjected to rough work, without the deposit being injured. Some iron work coated in 1842, and exposed to the atmosphere, remains in good condition still. These remarks are also applicable to iron covered with zinc. The coating of iron with copper has been tried in a great variety of ways for large operations, but in general these trials have, commercially, ended unsuccessfully; the labor and cost is greater than the advantages sought will warrant for ordinary purposes. Many years ago trials were made to cover cast-iron with copper, and then gild or plate for ornamental use, but only with partial success. More recently, however, a patent has been taken out for the same purpose, and which, being one of these applications that would be useful in beautifying and improving the taste of the community, we give an abstract of the specification as follows:

COATING CAST-IRON WITH OTHER METALS.—"Mr. W. Newton (for a correspondent) has patented the coating cast-iron permanently with copper, by depositing the copper by galvanic action, from a solution prepared by first taking a saturated solution of sulphate of copper in water and precipitating with carbonate of potash, and then re-dissolving in cyanide of potassium, whether the copper be deposited directly on the surface of the cast iron, or on zinc previously deposited thereon. The second part of this invention consists of coating cast-iron with the alloy of copper called brass, by first coating the cast-iron with copper, or zinc, or both, and then depositing the brass thereon, by galvanic action, from a solution formed by mixing with the solution of copper employed in the first part of the invention, a solution of zinc prepared in substantially the same manner. The iron articles thus coated, may be subsequently coated with gold or silver, so as to give them the appearance of these latter metals. The articles of cast-iron to be coated or plated are first to be cleansed by what is known as the 'pickling' process, with dilute sulphuric acid, and then 'scratch-brushed,' as it is termed, to free the surface from scale, sand, and other foreign substances which may not have been removed by the acid; and after this the castings are to be immersed in dilute nitro-muriatic acid. Any other mode of thoroughly cleansing the surface may be substituted for that above indicated. A solution of zinc is then prepared in the following manner:—Dissolve the sulphate of zinc in water until the water is saturated, and precipitate by means of prussiate of potash. The precipitate is then collected in a filter, and re-dissolved in cyanide of potassium. This constitutes solution number one. A solution of copper is then prepared in the same manner, by dissolving sulphate of copper in water, and precipitating with carbonate of potash: this precipitate is dissolved in cyanide of potassium, and is called the second or copper solution. The third, or what may be termed the brass solution, is then prepared by mixing together the first or zinc solution with the second or copper solution, in such proportions as to produce the shade of color required—increasing the proportional quantity of the one or the other at the discretion of the operator. The iron castings having been thoroughly cleansed, are first immersed in the first or zinc solution, and the galvanic battery applied in the usual manner of electrotyping and continued until the required thickness of zinc is deposited on the surface of and caused to unite with the surface of the cast-iron, which is a carbonate of iron. The castings thus coated or plated with zinc, are then to be immersed in the second or copper solution, and the galvanic battery applied, as with the first or zinc solution, and continued until the required thickness of copper shall have been deposited. In this way it will be found that the copper coating has become thoroughly attached to the zinc, and the zinc to the iron, so that they cannot be removed except by filing or cutting, as in the case of a solid mass of copper; so that articles, of whatever form desired, which can be made of cast-iron—that is, of carbonate of iron—can be coated with copper, so as to answer nearly if not all the purposes to which they could be applied if made of solid copper; thus greatly economizing the cost. After the surface of cast-iron has been coated with zinc, or with copper, or with zinc and then with copper, which latter is much the best, if it be desired to coat it with brass, it is to be immersed in the third or brass solution, and the galvanic battery applied, until the required thickness shall have been deposited. In doing this it is important that the positive pole of the battery should be made of brass, and as nearly as practicable of the shade of the brass to be deposited; for if a copper pole be applied, it will deposit in excess the copper portion of the solution. If desired, the brass can be deposited on the coating of zinc instead of the coating of copper; but it will be found decidedly better to deposit the brass on the coating of copper, whether the copper be deposited directly on the cast-iron or on a coating of zinc, although the latter is the best. In this way articles are produced, having all the appearance, and answering nearly if not all the same purposes as if made entirely of brass, and at much less cost. The cast-iron being thus coated with brass, the surface may be bronzed in the usual and well-known manner of bronzing brass; and as the process of bronzing on brass and copper is well known, it will be unnecessary to give a detailed description of it. The surface of the cast-iron being thus coated with brass, or with copper, can then be coated effectually with silver or gold in any of the well known modes of coating brass or copper with those fine metals; it will not, however, be necessary to give the details of such mode or modes, as they are well known in the arts. The patentee remarks that it will be found better to deposit the silver or gold on the brass coating than on the copper coating, on account of the color—particularly when, from reasons of economy, it is desired to make the coating of fine metal very thin. The patentee claims the process herein described, or any mere modification thereof, for coating cast-iron (carbonate of iron) with copper, by causing the copper, from a solution such as above described, to deposit, by galvanic action, directly on the surface of the cast-iron, or on the zinc previously deposited thereon, as set forth. And also the process herein described, or any mere modification thereof, for coating cast-iron with the alloy of copper, known as brass, by causing the brass, from a solution such as above described, to deposit, by galvanic action, on to the surface of the cast-iron, previously coated with zinc, or copper, or both, as specified."

COATING OF IRON WITH ZINC.—In covering iron with zinc, the precautions necessary for copper are not required: zinc being the positive metal, acids have a stronger affinity for it than for iron, and therefore an acid solution may be used. The one generally used is the sulphate.

SULPHATE OF ZINC.—Zinc dissolves easily in sulphuric acid, and the solution by evaporation yields crystals of sulphate of zinc; but as the salt is very cheap and abundant in the market, it is more convenient and economical to buy than to make it. The solution for depositing is made by dissolving 2 lbs of the crystallized salt in one gallon of water. The single cell process cannot be used advantageously with this solution. A separate battery is necessary, and a zinc positive electrode. The metal is very easily deposited —one or two pairs of Wollaston's battery being sufficient for coating small articles.

Zinc may be deposited upon black-leaded surfaces in the same manner as copper; but, unless more than ordinary precautions are observed, an article formed in this manner is so brittle that it can hardly be handled without breaking, from its crystalline character. When the deposition upon black-lead is attempted, the best method is to have the solution saturated with salt, employing a battery of six or seven pairs of plates, and keeping the articles on which the deposit is taking place constantly in motion.

The use of cyanide of zinc has been recommended, but for what good reason it is hard to know. It is unnecessary, and its use presents great practical difficulties. The positive electrode becomes coated, after a few minutes working, with a white pasty matter which prevents further action and stops the current. Some of this white coating collected, washed, and dried in the air, gave by analysis,

Oxide of zinc	51·3
Cyanogen	1·7
Iron	trace
Potash	2·3
Carbonic acid	27·8
Matter insoluble in HCl.	2·5
Water	14·8
	100·4

The zinc is converted into carbonate of zinc: the potash is combined with the cyanogen as cyanide of potassium.

USE OF ZINC COATING.—The principal application of zinc is upon iron, to protect it from corrosion, which it does, not only as a coating, but, from its more electro-positive character, it protects it by a galvanic influence. The voltaic influence of zinc for protecting iron is a subject that has occupied the attention of practical men for a long time; it is one of high importance: nevertheless there seems yet a great deficiency in our knowledge of the extent of this influence, and how and when it is effective.

Upon this subject, Professor Faraday, in the Report of the Harbors of Refuge Commissioners, states, "Zinced iron would no doubt resist the action of sea-water so long as the surface was covered with zinc, or even when partially denuded of that metal: but zinc dissolves rapidly in sea-water, and after it is gone, the iron would follow.

"As to voltaic protection, it has often struck me that the cast-iron piles proposed for lighthouses, or beacons, might be protected by zinc in the same manner as Davy proposed to protect copper by iron; but there is no doubt the corrosion of the zinc would be rapid. If not found too expensive, the object would be to apply the zinc protectors in a place where they could be examined often, and replaced when rendered ineffective. In this manner I have little doubt that iron would be protected in sea-water."

INFLUENCE OF GALVANISM IN PROTECTING METALS FROM DESTRUCTION BY OXIDATION AND SOLUTION.—The galvanic influence of one metal in protecting another is in relation to their negative and positive qualities together with their conducting powers (p. 515). Their relations in sea-water are—silver, copper, bismuth, antimony, iron, tin, lead, cadmium, zinc; the first the most negative, the last the most positive in the series. So that, according to this scale, the further apart the metals may be which are selected for experiment, the more decided will be the power of the positive to protect the negative. Copper and zinc operate more strongly together than iron and zinc.

A metal that is insoluble when placed singly in a fluid, may be made soluble by connection with a relatively negative metal placed in the same fluid. For example, pure zinc put into muriatic acid is unaffected, but when connected with copper in the same fluid it is rapidly operated upon. Or a metal may be soluble in a fluid alone, but may be rendered insoluble by connection with a relatively positive metal which undergoes decomposition instead. Thus: copper is dissolved in sea-water when alone, but when a piece of zinc is connected with it, the copper is unaffected. This last effect is the substance of Davy's method of protection alluded to by Dr. Faraday, in applying the principle of which it is necessary to take into consideration,

1st, The amount and power of electricity generated by the connected metals in the same fluid; and

2d, The conducting power of the metal which is being protected.

1st. The amount and power of the electricity evolved is in proportion to the difference of the relative negative and positive condition of the metals employed. The more negative the coated metal is, the less it requires protection, although its powers of protection are the greatest. And the more positive the coated metal, the more liable it is to be destroyed, and the greater the amount of electricity required to protect it; but unfortunately it is less able to generate this electricity when in contact with another metal. Thus these two conditions are opposed to the application of galvanic influence for protecting iron.

Suppose, for example, that 4 square inches of zinc, in connection with 4 square feet of copper, give out sufficient electricity to protect the copper from sea-water, it will be found that to obtain the same amount of electricity by iron and zinc, 2 square feet of the latter to 4 square feet of the former are required.* Besides which, the same quantity of electricity that protects copper will not pro-

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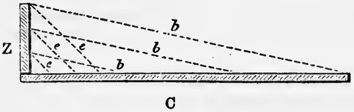
* These proportions, given in round numbers, are nearly accurate ; but they vary according to the kind of iron, the state of the water, the distance of the metals, etc.

tect iron; nor will any quantity of zinc protect iron from corrosion in sea-water—even a bar of iron placed in a zinc vessel filled with sea-water is not completely protected.

2d. The conducting power of the negative or protected metal subjected to submarine immersion is a subject of very great importance. Suppose a piece of copper and a piece of zinc be connected under a solution—say a copper bar (C) 4 feet long, with a piece of zinc (Z) 4 inches in length, erected on one end, as in the annexed sketch:

Fig. 580.



The conducting power of the copper is so much superior to that of the solution that the whole length of the bar will become instantly negative, and the current of electricity will pass to and from all parts of the bar at the same time in the lines *b*, *b*, *b*; but the current will be more active towards the point of contact than towards the distant extremity—the resistance of the solution being less in proportion to the proximity of the metals. But if a bar of iron, and a piece of zinc as a protector, be placed in the same circumstances, the phenomena assume quite a different aspect: the conducting power of iron being much less than that of copper, the distant extremity will not be affected by the electric current, which will find a more easy passage, as indicated by the dotted lines *e*, *e*, *e*, beyond which the electric effort ceases; and even in that portion of the bar which is under the influence of the current, the part nearest the zinc is better defended than those parts which are farther distant. This partial protection, while it induces a negative state at the near end, renders the other end more positive. Such a diversity of condition gives rise to voltaic action between the two extremities of the bar, and the result is the destruction of the far end. In all cases of voltaic protection the more equal the influence over the whole surface protected, the more perfect is the protection. An inequality of protection, such as we have described, is productive of numerous evils. It is, we believe, the source of many of the injuries occurring in our day to copper sheathing. One part of a sheet becoming, by some local cause, negative, the other parts are thus rendered positive; the result is, that upon the borders of an individual sheet either overlapping or underlying its neighboring sheet, an electric current is excited, passing through the stratum of moisture which may intervene, and the ultimate effect is that the positive edge is dissolved as effectually as if cut by a knife. The evil arising in one place may be so contagious as to affect a whole neighborhood—sometimes the whole side of a ship's bottom.

In fresh water iron cannot be protected any length of time, for the zinc coating speedily passes into a blackish substance, which peels off and exposes the iron to rust. When iron is simply exposed to the air, a good coating of zinc is a sure protection. We have seen iron of various qualities coated by the electro-processes and exposed to the atmosphere, in all weathers, for several years, without being more affected than a piece of zinc would be. In spots where abrasion has taken place by accident, the protecting power of the zinc is lost, and the iron rusts as if there were no zinc present. No other result, however, could be anticipated, as there can be no electric excitation without a liquid to connect the two metals.

The iron to be coated by zinc is to be cleaned and prepared in the same manner as we have described for the purpose of covering it with copper (page 579).

CHAPTER XXX.

ELECTRO-PLATING.

The next applications of the electro-deposition we have to notice are those relating to silver and gold, embracing the arts of electro-plating and gilding—arts which are gradually revolutionizing some extensive branches of manufacture, having the same object but acting by a different means.

To Make Silver Solution.—The solution of silver used for plating consists of cyanide of silver dissolved in cyanide of potassium which may be prepared in various ways. We shall first describe some of the preparations most in use, and also point out practical objections which, in special cases, have occurred under our own observation, not omitting to specify and recommend those methods which have approved themselves to us as being most simple and effective.

The method generally adopted is as follows:—Metallic silver is dissolved in four parts of nitric acid, diluted with one part of water: the diluted acid is heated in a vessel, and the silver is added by degrees. The operator must avoid breathing the fumes which ascend, as they are highly deleterious. The metal being dissolved, the solution is transferred to a large vessel, and diluted with water. To this is added a solution of cyanide of potassium so long as a white precipitate is formed. This precipitate is cyanide of silver, and the action which ensues may be thus represented:

Substances used:	*Substances produced:*
Nitrate of silver $= AgO, NO^5$	Nitrate of potash $= KO, NO^5$
Cyanide of potassium $= KCy$	Cyanide of silver $= AgCy$

$$AgO, NO^5 + KCy = KO, NO^5 + AgCy$$

The propriety of diluting the nitrate of silver before precipitating by the cyanide of potassium arises from the fact, that the salts of potash and soda (such as the nitrates, chlorides and sulphates), when in strong solution, dissolve small quantities of the silver salt, and thus cause a loss, which is prevented by previous dilution with water.

When the precipitate of cyanide of silver has settled, the clear solution is carefully decanted, and the vessel filled up with water, which is again decanted as soon as the precipitate has settled. This process is to be repeated three or four times, so as effectually to wash out the soluble salts. When properly washed, a solution of cyanide of potassium is added to the precipitate, until it is all dissolved. The resulting solution constitutes the cyanide of potassium and silver, and forms the plating solution. It ought to be filtered previous to using, as there is always formed a black sediment, composed of iron, silver, and cyanogen, which, if left in the solution, would fall upon the surface of the article receiving the deposit, and make it rough. The sediment, however, must not be thrown away, as it contains silver. The cyanide of potassium, used to dissolve the cyanide of silver, may be so diluted that the plating solution, when formed, shall contain one ounce of silver in the gallon: of course the proportion of silver may be larger or smaller, but that given is what we consider best for plating.

In dissolving 100 ounces of silver, the following proportions of each ingredient are those which we have found in practice to be the best. Take 7 pounds of the best nitric acid* and 61 ounces of cyanide of potassium, of the average quality described at page 576; this quantity will precipitate the 100 ounces of silver dissolved in the acid solution. After this is washed, take 62 ounces more of cyanide of potassium, the solution of which will dissolve the precipitate: this being done, the plating solution is then formed. Of course, these proportions will vary according to the difference in the quality of the materials; but they will serve to give an idea of the cost of the silver solution prepared in this manner.

CYANIDE OF SILVER DISSOLVED IN YELLOW PRUSSIATE OF POTASH.—We have occasionally dissolved the cyanide of silver by yellow prussiate of potash, three pounds of which are required to dissolve one ounce of silver. This forms an excellent plating solution, and yields a beautiful surface of silver. It must have a weak battery power, and consequently the silver is very soft. The positive electrode does not dissolve in this solution: there is formed upon its surface a white scaly crust, which drops off and falls to the bottom; and the solution soon becomes exhausted of silver.

SOLUTION MADE WITH OXIDE OF SILVER.—It has been recommended to dissolve the oxide of silver in cyanide of potassium, which forms a solution of cyanide of potassium and silver; but this preparation is less economical, because the materials used in converting the silver into an oxide are lost: it requires the same amount

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* The nitric acid must be free from hydrochloric (muriatic) acid: to a small quantity of the acid add a few drops of solution of nitrate of silver; if it gives a milky white precipitate, it contains muriatic acid, and should be rejected.

of cyanide of potassium as the process just described, and brings, moreover, an equivalent of potash into the solution, which is a disadvantage. The following diagram shows the reactions that occur:

Substances used:	*Substances produced:*
Oxide of silver = AgO	Potash = KO
Cyanide of potassium = KCy	Cyanide of silver and potassium = $KCy, AgCy$
Cyanide of potassium = KCy	

$$AgO+2\,KCy=KO+KC, AgCy.$$

SOLUTION MADE WITH CHLORIDE OF SILVER.—The nitrate of silver may also be precipitated by adding a solution of common salt to it, and treating it in the same way as described for precipitation by cyanide of potassium: this would form chloride of silver, which may be dissolved in cyanide of potassium, thus forming the silver solution. But the objection urged against the use of oxide of silver is equally applicable in the case of chloride; and much greater care is required in precipitating large quantities and strong solutions of silver by common salt, than by cyanide of potassium, the chloride of silver being more soluble in the salts of the alkalies—as the nitrates, chlorides, and sulphates—than cyanide of silver is; and there is therefore great liability to loss by this process, in which we have not the redeeming quality of a saving of materials, as the following diagram will show:

Substances used:	*Substances produced:*
Chloride of silver = $AgCl$	Chloride of potassium = KCl
Cyanide of potassium = KCy	Cyanide of silver and potassium = $KCyAgCy$
Cyanide of potassium = KCy	

$$AgCl+2\,KCy=KCl+KCy, AgCy.$$

Thus, we observe, that the action taking place is not mere solution, but decomposition; which upon one hundred ounces of silver in this preparation produces an impurity of seventy ounces of chloride of potassium, which, although not very injurious to the solution, would be much better away.

THE BEST METHOD OF MAKING SILVER SOLUTION.—The best and cheapest method of making up the silver solution is by the battery, which saves all expense of acids and the labor of precipitation. This is effected by taking advantage of the principle of non-transfer of metal in electrolytes (see page 561). To prepare a silver solution which is intended to have an ounce of silver to the gallon (see p. 588), observe the following directions: Dissolve 123 ounces of cyanide of potassium in 100 gallons of water; get one or two flat porous vessels, and place them in this solution to within half an inch of the mouth, and fill them to the same height with the solution; in these porous vessels place small plates or sheets of iron or copper, and connect them with the zinc terminal of a battery: in the large solution place a sheet or sheets of silver connected with the copper terminal of the battery. This arrangement being made at night, and the power employed being two of Wollaston's batteries, of five pairs of plates, the zincs 7 inches square, it will be found in the morning that there will be dissolved from 60 to 80 ounces of silver from the sheets. The solution is now ready for use: and by observing that the articles to be plated have less surface than the silver plate forming the positive electrode, for the first two days, the solution will then have the proper quantity of silver in it. We have occasionally found a little silver in the porous cell: it is therefore not advisable to throw away the solution in them without first testing it for silver, which is done by adding a little muriatic acid to it.

The amateur electrotypist may, from this description, make up a small quantity of solution for silvering his medals or figures. For example, a half-ounce of silver to the gallon of solution will do very well; a small quantity may be prepared in little more than an hour.

As the cyanide of potassium dissolves silver without the aid of a battery, by merely allowing a piece of silver to steep in this solution for a few days, a plating liquor may be formed; but this is tedious and uncertain, although for small operations, and where porous vessels are not convenient, it will serve the purpose.

Other solutions of silver may be employed if the law stated at page 575 is strictly observed. Indeed, every salt of silver has not only been tried, but is either the subject of a patent, or prominently included in it. None of them, however, with the exception of two, have we found of any practical value, besides that already described: these are the chloride of silver dissolved in hyposulphite of soda, and the sulphite of silver dissolved in sulphite of potash or sulphite of soda.

HYPOSULPHITE OF SILVER SOLUTION.—The simplest method known to us for forming the hyposulphite of silver solution is this: Take one pound of pure carbonate of soda, well dried, as described at page 576; mix it intimately with five ounces of flour of sulphur; place the mixture over a slow fire without flame in a porcelain or stoneware basin, which must be supported by an iron trelis, or any convenient support, to prevent it touching the red coal or flame; keep the mixture constantly stirring, and maintain the heat till the sulphur melts, and the mass inclines to get pasty and rough. While in this state keep stirring for about fifteen minutes, in order to bring every part in contact with the air. Set the mixture to cool—after which dissolve in water. Boil the solution for some time, adding sulphur; then filter it, and allow it to evaporate at a slow heat. The crystals formed are hyposulphite of soda.

To prepare the silver solution, the silver is first dissolved in nitric acid, and then precipitated by a solution of common salt, and washed, with the precautions stated at page 587. When the precipitated chloride of silver is well washed, some of the crystals of hyposulphite of soda are dissolved, and the solution is added to the chloride of silver, which it dissolves, forming the plating solution. It is not necessary to crystallize the hyposulphite of soda, if used as soon as made.

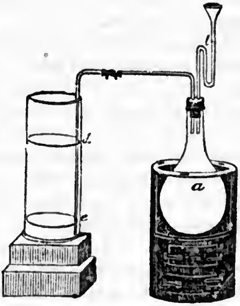
The hyposulphite of silver solution is very easily decomposed by the electric current, so that a weak battery will suffice to plate by it: but its great objection is its liability to decompose in the light, and to deposit the silver as sulphuret: unless great care is exercised, the silver deposited from it will be in a granular condition, which is a great objection in plating.

SULPHITE OF SILVER PLATING SOLUTION.—The sulphite of silver solution is prepared in the following manner, as described by the patentee of the process:

"The solution which I use is made in the following manner: I take of the best pearl-ash of commerce 28 lbs (avoirdupois) and add to it 30 lbs (avoirdupois) of water, and boil them in an iron vessel until the pearl-ash is dissolved; the solution should then be poured into an earthenware or other suitable vessel, and suffered to stand until the liquor becomes cold. It should then be filtered, and 14 lbs (avoirdupois) of distilled water added thereto; sulphurous acid gas (obtained by any of the known processes) should then be passed into the filtered liquor until it is saturated, taking care not to add sulphurous acid gas in excess. The liquor should be again filtered, and the liquor so filtered is what I term the solvent, or sulphite of potash.

"To make the silvering liquor which I use in coating with silver the surface of articles formed of metal or metallic alloys, I dissolve 12 oz. (avoirdupois) of crystallized nitrate of silver in 3 lbs. of distilled water (in a clean earthenware vessel), and add to the solution, by a little at a time, the before-mentioned solvent, so long as a whitish colored precipitate is produced (care being taken not to add more of the solvent than is necessary). After the precipitate has subsided, I pour off the supernatant liquor, and wash the precipitate with distilled water. To the precipitate I add as much of the before-mentioned solvent as will dissolve it, and afterwards add about $\frac{1}{8}$th part more of the solvent, so that the solvent may be in excess; I then stir them well together and let them remain about 24 hours, and then filter the solution, when it will be ready for use. This is what I designate silvering liquor."*

Fig. 581.



Sulphurous acid gas for making the above liquor may be pre-

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* Repertory of Patent Inventions, 5th series, p. 210, 1843.

pared by heating sulphuric acid, undiluted, in a flask or any convenient vessel, to which should be added small pieces of copper or charcoal: the gas escaping is made to pass into the solution to be saturated with it.

Fig. 581 is a very convenient apparatus for the preparation of this gas for saturating solutions.

This solution is also very easily decomposed by the electric current, and serves the purposes of plating very well; but it is also liable to decomposition by light, and is not so good in practice as the solution of cyanide of potassium and silver. The latter solution is, however, liable to a kind of decomposition not yet fully investigated, but it is wholly confined to its impurities, and it never deposits its silver; whereas the decomposition that takes place in the sulphite or hyposulphite affects the silver compound, and precipitates the silver from solution.

TO RECOVER SILVER FROM SOLUTION.—When a silver solution gets out of order, and cannot be rendered fit for use again, the silver may be recovered by adding to the solution any acid that will neutralize the alkali; if nitric or sulphuric acid be used, the silver precipitates as cyanide, but if hydrochloric acid be used, the silver will be precipitated as a chloride: in either case the solution should be diluted, or a portion of the precipitate will be re-dissolved. The precipitate is allowed to deposit, the clear liquor decanted, and the vessel filled with water to wash the precipitate, which is afterwards collected upon a filter and dried, and then mixed with twice its weight of carbonate of potash, and fused in a Hessian crucible for 15 minutes, or until the fused fluid ceases to effervesce. On removing the crucible, and pouring the whole into an iron ladle, when cool the silver will be found in the metallic state at the bottom of the ladle.

In these operations when pouring the acid into the cyanide solution, great care must be taken not to inhale the fumes given off, which are very abundant, sickening, and poisonous. The operation should be done in the open air, and even then it is bad. Instead of throwing down the silver by an acid it is better to evaporate the solution to dryness, and to fuse the product as described; in which case the cyanide is an excellent reducing flux, requiring no addition of carbonate of potash, and saves the necessity of evolving poisonous fumes.

When the solution has contained yellow prussiate of potash, it is found that during this fusion portions of the metal sometimes form a scoriaceous nodule at the bottom of the crucible, and all the heat that can be applied by an ordinary assay furnace will not fuse it. This refractory piece, when cooled, has generally a rough scoriaceous surface, and is exceedingly hard. When filed it has more the color of German silver than of real silver; it has considerable malleability, and retains its bright appearance for a long time without tarnish. An analysis of this alloy gave—

Silver	82·15
Copper	9·12
Iron	7·50
Carbonaceous matter	·46
	99·23

If we suppose the carbonaceous matter to be an accidental impurity, this alloy will nearly agree with the formula Ag^3 Cu Fe.

Preparation of Articles for Plating.—Articles that are to be plated are first boiled in an alkaline ley, to free them from grease, then washed from the ley, and dipped into dilute nitric acid, which removes any oxide that may be formed upon the surface; they are afterwards brushed over with a hard brush and sand, of which a kind obtained from the Isle of Wight, and known as silver-sand is best. The alkaline ley should be in a caustic state, which is easily effected by boiling the carbonated alkali with slaked lime, until, on the addition of a little acid to a small drop of the solution, no effervescence occurs. The lime is then allowed to settle, and the clear liquor is fit for use. The ley should have about half-a-pound of soda-ash, or pearl ash, to the gallon of water. The nitric acid, into which the article is dipped, may be diluted to such an extent that it will merely act upon the metal. Any old acid will do for this purpose. In large factories the acid used for dipping before plating is generally afterwards employed for the above purpose of cleaning.

The article being thoroughly cleaned and dried, has a copper wire attached to it, either by twisting it round the article or putting it through any open part of it, to maintain it in suspension. It is then dipped into nitric acid as quickly as possible, and washed through water, and then immersed in the silver solution, suspending it by the wire which crosses the mouth of the vessel from the zinc of the battery. The nitric acid generally used and found best for dipping has a specific gravity 1·518, contains 10 per cent. sulphuric acid, and is got at about 6 cts. per lb. The article is instantaneously coated with silver, and ought to be taken out after a few seconds and well brushed. On a large scale, brushes of brass wire attached to a lath are used for this purpose; but a hard hair brush with a little fine sand will do for small work. This brushing is used in case any particle of foreign matter may be still on the surface. It is then replaced in the solution, and in the course of a few hours a coating of the thickness of tissue-paper is deposited on it, having the beautiful matted appearance of dead silver. If it is desired to preserve the surface in this condition, the article must be taken out, care being taken not to touch it by the hand, and immersed in boiling distilled water for a few minutes. On being withdrawn, sufficient heat has been imparted to the metal to dry it instantly. If it is a medal, it ought to be put in an air-tight frame immediately, or if a figure, it may be at once placed under a glass shade, as a very few days exposure to the air tarnishes it, by the formation of sulphuret of silver, and that more especially in a room where there is fire or gas. If the article is not wanted to have a *dead* surface, it is brushed with a wire brush, and old ale, beer, or water containing in solution a little gum, glue, or sugar, but the amateur may use a hard hair brush. It may be afterwards burnished according to the usual method of burnishing, by rubbing the surface with considerable pressure with polished steel or the mineral termed *bloodstone.*

We may remark, that in depositing silver from the solution, a weak battery may be used; though when the battery is weak the silver deposited is soft, but if used as strong as the solution will allow, say 8 or 9 pairs, the silver will be equal in hardness to rolled or hammered silver. If the battery is stronger than the solution will stand, or the article very small compared to the size of the plate of silver forming the positive electrode, the silver will be deposited as a powder. The average cost of depositing silver in this way is 4 cts. per ounce. Gas should never be seen escaping from either pole: and the surface of the article should always correspond as nearly as possible with that of the positive electrode, otherwise the deposit runs the risk of not being good; it requires more care, and the solution is apt to be altered in strength, because if the positive electrode be large compared with the negative, the solution will become stronger in silver, while if smaller in proportion the solution will become exhausted of silver.

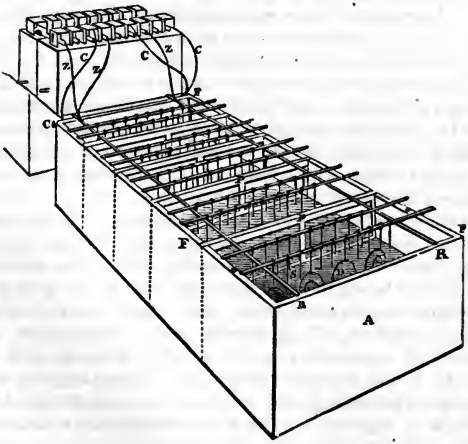
In plating large articles (such as those plated in factories), it is not always sufficient to dip them in nitric acid; wash and immerse them in the solution, in order to effect a perfect adhesion of the two metals. To secure this, a small portion of quicksilver is dissolved in nitric acid, and a little of this solution is added to water, in sufficient quantity to enable it to give a white silvery tint to a piece of copper when dipped into it: the article then, whether made of copper, brass, or German silver, is, after being dipped in the nitric acid and washed, dipped into the nitrate of mercury solution till the surface is white: it is then well washed by plunging it into two separate vessels containing clean water, and finally put into the plating solution. This secures perfect adhesion of the metals. One ounce of quicksilver thus dissolved will do for a long time, though the liquor is used every day. When the mercury in this solution is exhausted, it is liable to turn the article black upon being dipped into it: this must be avoided, as in that case it also causes the deposited metal to strip off.

PRACTICAL INSTRUCTIONS IN PLATING.—We need hardly add that it is necessary that the battery should be so arranged, that the *quantity* of electricity generated should correspond with the surface of the articles to be coated, and that the *intensity* should bear reference to the state of the solutions; that is to say, that the *quantity* should be sufficient to give the required coating of metal in a given time, and the *intensity* such as to cause the electricity to pass through the solution to the articles. It is also essential for regular working, as stated above, that the plates of metal forming the positive pole in the solution should be of corresponding surface to the articles to be coated, and face them on both sides.

The following is the arrangement adopted in some of the large plating manufactories:—The *vat*, or plating vessel measures about 6½ feet in length, by 33 inches in breadth, and 33 inches in depth, and generally contains from 200 to 250 gallons of solution; the silver plates serving as electrodes, which were formerly nailed upon frames of wood, are now generally fixed upon light iron frames, these not being affected by the solution: two battery troughs are arranged as seen in Fig. 582, consisting of 6 batteries of three pairs intensity. The zinc plates immersed in the acid measure 6 inches by 7 inches, the exposed surfaces of which measure 84 square inches: these multiplied by 6 give 504 square inches, from which electricity is disengaged. The surface of the silver electrodes exposed to the articles receiving the deposit vary from 3000 to 4000 square inches of surface.

The following figure, with explanation, will illustrate these observations:

Fig. 582.



A, Vat or vessel containing the solution; B, Battery with zinc pole Z, connected with rods R R; and copper pole C, connected with the metallic sheets P P, in the solution, by means of the copper slip F; D D, are articles suspended in the solution by wires from the rods R R; S, the solution. So soon as the articles, which are connected with the negative pole of the battery, and the metallic sheets, connected with the positive pole, are both immersed in the solution, the galvanic circuit is completed.

In most plating establishments the batteries are now placed outside the house, and the connecting rods are brought from them into the vats, so as to preserve the workmen from the injury arising from inhaling the hydrogen gas which is given off by the zincs, as it often contains arsenic, and hence is highly injurious to health; the gas of the battery has a strong effect upon the nostril, exciting dryness with pain. Wherever the batteries are placed, they should not be exposed to cold, as their operation is much affected by the temperature.

In the early days of electro-plating the batteries used were round. They consisted of a copper cylindrical vessel, about 20 inches deep, and 5 inches diameter, filled with dilute sulphuric acid. A piece of wood was placed at the bottom of this vessel, and a cylinder of zinc, the same depth as the copper vessel, and about 3 inches diameter, was placed inside the copper vessel. A wooden ring, floating on the surface of the acid, prevented the zinc and copper touching—a binding screw was attached to each, and formed a battery of a single pair. Six batteries of this size were connected with such a vat as is described above. The test of strength employed to determine whether the working power was sufficient, was that, when connected with an electro-magnet, it should support a 7 lb. weight. We believe that many platers and gilders still use such batteries, and that, when the solutions and apparatus are all in good condition, they do well. They are, however, far from being so economical as the battery with square plates shown above. Some electro-metallurgists use large and deep stoneware vessels in which are placed the zinc and copper—the plates having several square feet of surface. We have already shown, when treating of batteries, that very large plates are not consistent with economy.

To ascertain the amount of metal deposited, it is only necessary to weigh the articles carefully before and after plating. But between the first weighing and the immersion of the articles in the plating solution there is the dipping into nitric acid to be accounted for: this, on an average, will cause a loss of about one pennyweight upon an article of the size of a foot square; thus, if a waiter of a foot square, made of copper or German silver, shows, when coated, a difference in weight of 19 pennyweights, the silver laid on must be estimated at an ounce, or 20 pennyweights. When the article is a "replate," *i. e.*, an old plated article that has become bare of silver in parts, the allowance or reduction for the dipping in the acid is only to include the portions left bare, for the silvered parts are not acted upon by it. One of the practical difficulties which the inexperienced will occasionally meet with when a "replate" is dipped in the nitric acid, is, that a galvanic action is produced between the silver and the copper portions, which causes a black line round the edge of the silver: this ought immediately to be rubbed off, but even with rapid and careful rubbing there is great danger that the coating will loosen and blister at those parts; and beside this, it happens that the parts of the "replate" which are sound, the silver not being acted upon by the acid, but rather protected by the galvanic action, are not in a fit state to receive and maintain a perfect adhesion of the deposit, and therefore the risk is great that the new coating will separate from the old, or, in technical language, that the part will *strip*. Under these circumstances experience has taught that the best way to proceed is to take all the old silver off the article, and deposit an entirely new coating.

There are two methods of taking off the silver:

TAKING SILVER FROM COPPER, ETC.—First, stripping or dissolving it off; this is done by putting into a stoneware or copper pan some strong sulphuric acid (vitriol), to which a little nitrate of potash is added: the article is laid into this solution, which will dissolve the silver without materially affecting the copper; saltpetre is added by degrees, as occasion requires; and if the action is slow a little heat is applied to the vessel. The silver being removed, the article is washed well and then passed through the potash solution, and finished for plating. When the sulphuric acid becomes saturated with silver it is diluted, and the silver is precipitated by a solution of common salt: the chloride of silver formed is collected and fused in a crucible with carbonate of potash, when the silver is obtained in a metallic state, as a knob or button. The crucible should not be over two-thirds full and should be kept in fusion till effervescence ceases. The crucible is then removed from the fire, and, when cool, it is broken.

The article thus stripped by acids often shows a little roughness, not from the effects of the acid, but because the copper under the silver has not been polished; it is therefore a necessary practice in the electro-plating factories to polish the articles before plating. This is done by means of a circular brush, more or less hard as required, fixed upon a lath, and a thin paste made of oil and pumice-stone ground as fine as flour. By this process the surface of any article can be smoothened and polished; but a little experience is required to ensure success, and enable the operator to polish the surface equally without leaving brush marks. We need scarcely say, that after this process the article must be cleaned in potash before it is plated.

Second Method.—Instead of stripping off the silver by means of acid, it is a more common and preferable mode to brush off the silver by the operation just described. In this case the brushings must be collected, dried, and burned; this may be done in an iron pan, keeping it at a red heat until all carbonaceous matters are consumed, the remainder is fused with carbonate of soda or potash, when the silver is obtained, in combination with a little copper.

CYANIDE OF SILVER AND POTASSIUM, ITS DECOMPOSITION DURING THE PLATING PROCESS.—The silver salt in the plating solution is a true double salt, being, as already described, a compound of one equivalent of cyanide of silver, and one of cyanide of potassium

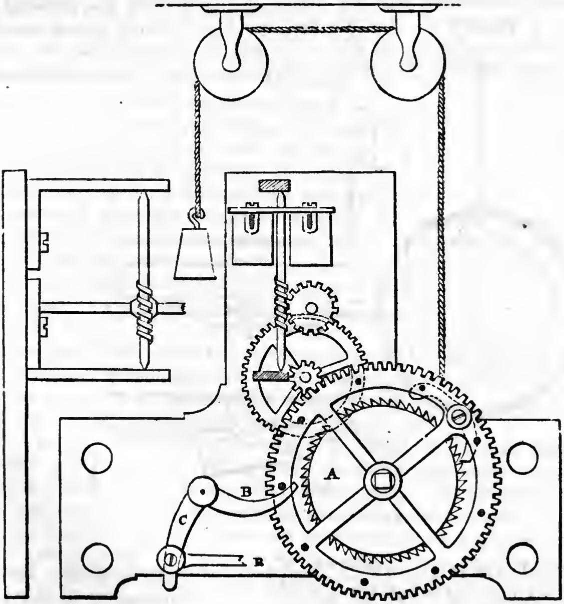
—two distinct salts. In the decomposition of the silver solution by the electric current, the former, cyanide of silver, is alone affected: the silver is deposited, and the cyanogen passes to the positive plate or electrode. The cyanide of potassium is therefore set at liberty upon the surface of the article receiving the silver deposition, and its solution being specifically lighter than the general mass of the plating solution, rises to the top: this causes a current to take place along the face of the article being plated. If the article has a flat surface, suppose that of a waiter or tray, upon which a prominence exists, as a mounting round the edge, such as a gadroon, see Fig. 583, it will cause lines and ridges from the bottom to the top, as already described at page 561. Newly-formed solutions are most subject to produce this annoyance.

Fig. 583.

OTHER EFFECTS PRODUCED IN WORKING.—As the cyanogen combines with the silver plate forming the positive electrode, it is dissolved by the free cyanide of potassium, which the solution must have; and, being specifically heavier, sinks to the bottom, by which a current downwards is excited: this is of no greater annoyance than that it renders the solution of unequal density, which in its turn yields an unequal deposit, more being laid upon the lower parts of the article than on the upper: the silver plate also is destroyed more rapidly at the bottom than at the top, except at the surface of the solution, if the silver be above it, where the plate gets cut through. In a new solution, which contained 1½ ounces of silver to the gallon, we have found, just before taking out the articles, that the top part of the solution contained 200 grains of silver less, and the bottom part 200 grains more per gallon, than when the articles were put into it. These difficulties and annoyances may, however, be nearly surmounted by keeping the articles in motion: agitating or stirring the solution occasionally would also obviate these annoyances; but this is not advisable, for if the sediment (which always forms) were stirred up it would settle upon the face of the articles and make them rough. Where there is engine power it is an easy matter to keep the articles in motion; but where this power is not available, a very simple apparatus, invented by Mr. Alexander Mitchell, of Glasgow, may be fitted up at a trifling cost, to give the necessary motion by clockwork. The annexed sketch exhibits this apparatus.

MACHINE FOR MOVING GOODS WHILE SUBJECTING TO THE ELECTRO-PLATING PROCESS.—Fig. 584, side elevation, with front frame off; Fig. 585, end elevation of that part of front frame where the fly is held; Figs. 586 and 587, the plating vat, with frame moving on inclined plane.

The large wheel A, Fig. 585, is propelled by a weight suspended from the roof by a cord which winds round its barrel, the same as common clockwork. The circumference is studded with small pins which catch the arm B, moving it in a downward direction, and consequently moving the arm C in a forward direction. The latter, being attached to the frame by a small rod R, Figs. 585 and 587, moves it up the inclined plane E, Fig. 587, until the pin fixed in the wheel A passes the end of the arm B. The frame then moving down the incline E, brings B in gear with the next pin, and the same motion again takes place, and so on successively. The speed is regulated by the train moving in an endless screw fitted on the last wheel of the arbor of a fan. The four holes in Fig. 585, are for bolts or pillows for screwing the two frames together. The frame has four pulleys and inclines, the latter adjustable to a greater or less degree by the screw and grove at E.



Figs. 584 585.

DEPOSIT DISSOLVING OFF IN SOLUTION.—In depositing any metal, but more particularly such as require solutions having an excess of the solvent, such as of cyanide of potassium in the depositing of gold and silver, care should be taken that nothing stops the current of electricity suddenly, while the article being deposited upon remains in the solution, otherwise the metal deposited will speedily dissolve off. This we have often experienced, and many others have no doubt done the same. Indeed, we have seen a beautiful deposit going on, and left the operation with great hope of excellent results, but on returning shortly after have found the whole dissolved off. And often, when the process was apparently going on well, and the articles had been in the solution the usual time to receive a fair coating of metal, upon taking them out and weighing them there was hardly any perceptible difference from the original weight—in short, there had been no material deposit. These phenomena will be found to occur with the greatest frequency when the solutions and the batteries are in the best condition for working, and when the article upon which the deposit is going on, and the pole or plate of metal forming the positive electrode are at a considerable distance from each other. But before explaining what we consider to be the cause of these annoyances we will refer to another phenomenon connected with them.

Fig. 586.

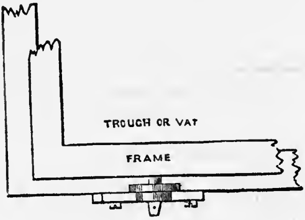
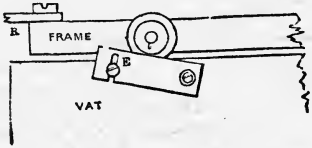


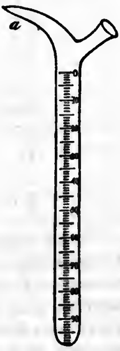
Fig. 587.



Opposite Currents of Electricity from Vats.—If, under the circumstances referred to, and when the deposit has gone on for some time, the wires connecting the battery with the electrodes in the depositing solution be disconnected from the battery, and their two ends be joined together, a current of electricity nearly as strong as that from the battery will pass through the wires, but in the opposite direction from that which was obtained by the battery; and if two pieces of metal were attached to these wires and put into a solution of copper, or any metal, a deposition would occur, the original electrodes now constituting a battery in relation to this second decomposition cell: the current, however, would gradually weaken until it ceased. The cause of all these actions and reactions is this: The article being plated with silver in connection with the battery, exhausts the solution of silver around it, leaving free cyanide of potassium in solution, while around the sheet of silver which is serving as the positive electrode, the solution is on the contrary becoming saturated with silver, so that we have all the conditions necessary to constitute a battery, having silver in two kinds of solution—the one capable of dissolving silver, the other not. In these conditions lies the source of the annoyances described above. From the moment the deposition of metal begins, there also arises an opposite current of electricity, tending to neutralize the effects of the battery, which current goes on increasing in quantity until the two currents neutralize each other, or it may be until the current from the trough overpowers that from the battery. In the latter case, as we have said, there may, at the termination of the ordinary period, be little or no silver deposited on the articles intended to be plated. Motion in the silver or depositing solution will prevent all these annoyances; and this being now generally adopted, these phenomena are not now observed, but the effects take place less or more in every solution.

Test for the Quantity of Free Cyanide of Potassium in Solutions.—It has been already mentioned that the cyanide of silver, as it forms upon the surface of the silver plate, is dissolved by the cyanide of potassium. This renders it necessary to have always in the solution free cyanide of potassium. Were we to use the pure crystalline salt of cyanide of potassium and silver, dissolved in water, without any free cyanide of potassium, we should not obtain a deposit beyond a momentary blush; as the silver plate or electrode would get an instantaneous coating of cyanide of silver, and this not being dissolved the current would stop. The quantity of free cyanide of potassium required in the solution varies according to the amount of silver that is present, and the rapidity of the deposition. If there be too little of it, the deposit will go on slowly; if there be too much, the silver plate will be dissolved in greater proportion than the quantity deposited, and the solution will consequently get stronger. The proportion we have found best is about half by weight of free cyanide of potassium to the quantity of silver in solution; thus, if the solution contains two ounces of silver to the gallon, it should have one ounce of free cyanide of potassium per gallon. This is known by taking some nitrate of silver, dissolving it in distilled water,

Fig. 588.



and placing it in a common alkalimeter, graduated into 100 parts, Fig. 588. The proportion of the nitrate of silver in the solution is that every two graduations of the solution should contain 1 grain. A given quantity of the plating solution is now taken—say 1 ounce by measure, and the test solution of nitrate of silver is added to it by degrees, so long as the precipitate formed is redissolved. When this ceases the number of graduations is then noted, and the following equation gives the quantity of free cyanide. Every 175 nitrate of silver are equal to 130 cyanide of potassium in solution. Suppose 20 graduations were taken, equal to 10 grains nitrate of silver, then 175: 130 : : 10 : 7.4 grains free cyanide of potassium. This, multiplied by 160, the number of fluid ounces per gallon, will make about 2½ ounces. We have taken 2 graduations to one grain of nitrate of silver, that the solution may be considerably dilute and less liable to error. The following table is calculated at a half grain nitrate of silver to the graduation, and will be a guide to the student or workman. The quantity of solution tested is one ounce by measure.

Number of graduations used.	Free cyanide per gallon.		
	oz.	dwt.	gr.
1	0	2	13
2	0	5	3
3	0	7	16
4	0	10	6
5	0	12	19
6	0	15	9
7	0	17	22
8	1	0	13
9	1	3	1
10	1	5	12
11	1	8	5
12	1	10	19
13	1	13	8
14	1	15	22
15	1	18	11
16	2	1	2
17	2	3	14
18	2	6	2
19	2	8	11
20	2	11	0

Another method may be adopted. If, for instance, we dissolve a small quantity of sulphate of copper and add to it an excess of ammonia, there is produced a deep blue color. Cyanide of potassium will destroy the blue color, in a fixed chemical proportion. To obtain this proportion, take ten grains of pure cyanide of potassium and dissolve in water; then take a certain quantity, say 100 grains, of sulphate of copper and convert it into ammoniuret, the whole measuring a given quantity, and pour from an alkalimeter this blue liquor into the cyanide of potassium till it ceases to destroy the color, then mark the number of graduations required, and that amount of copper solution will represent 10 grains cyanide of potassium—a quantitative test will thus be got for the full cyanide of potassium in the solution, and should be used as follows: Say that the color of 60 graduations of the blue solution was destroyed by the 10 grains of cyanide of potassium, then to test the quantity of free cyanide of potassium in the plating solution, take 60 graduations of the blue liquor in any convenient vessel, and add to it from an alkalimeter the plating solution till the color of the blue liquor is destroyed, then note the quantity which contains 10 grains free cyanide, from which the quantity in the whole solution may be calculated.

RATE OF DEPOSITING SILVER.—When articles are taken out of the solution they are swilled in water, and then put into boiling water. They are afterwards put into hot sawdust, which dries them perfectly. Their color is chalk-white. They are generally weighed before being scratch-brushed; that is, brushed with the fine wire brushes and stale beer as already described. Although this operation does not displace any of the silver, still, in taking off the chalky appearance, there is a slight loss of weight. The appearance after scratching is that of bright metallic silver. Any thickness of silver may be given to a plate by continuing the operation a proper length of time. One ounce and a quarter to one ounce and a half of silver to the square foot of surface, will give an excellent plate about the thickness of ordinary writing paper.

BRIGHT DEPOSIT.—A little sulphuret of carbon added to the plating solution prevents the chalky appearance, and gives the deposit the appearance of metallic silver; the reaction which takes place in this mixture is not yet understood. The best method of applying the sulphuret of carbon is to put one or two ounces into a large bottle, then fill it with strong silver solution, having an excess of cyanide of potassium, and let it repose for several days, shaking it occasionally. A little of this silver solution is added, as required, to this plating solution, which will give the articles plated the same appearance as if scratched. It is also found that the presence of sulphuret of carbon prevents the solution from going out of order; indeed we have seen a solution that has been constantly working from two to three years, while, generally, they were subject to go out of order for a time, in less than one year—although, after standing a time, they would recover—but these are curious reactions not yet investigated.

DIFFERENT METALS FOR PLATING.—Silver may be deposited upon any metal, but not upon all with equal facility. Copper, brass, and German silver, are the best metals to plate; iron, zinc, tin, pewter, and Britannia metal, are much more difficult; lead is easier, but it is not a good metal, because of the rapidity with which it tarnishes, and, from its softness, easily yields to the pressure of the burnisher: nevertheless all these metals and alloys may be, and are, plated, but cannot give the satisfaction which brass, copper, or German silver afford. In plating upon alloys having tin in them, such as Britannia metal, they must not be dipped into nitric acid previous to plating; but into a hot and strong solution of caustic potash or soda for five minutes, and put directly into the plating solution (which should have an excess of cyanide of potassium, and the battery be as strong as the liquor will admit of without gas being evolved), until covered, when the silver may be thickened by an ordinary solution and battery.

ELECTRICITY GIVEN OFF FROM SANDY DEPOSITS.—We may mention that when depositing silver upon a large surface, and the solution or battery being in the condition to give the sandy deposit, or rather when the deposit has gone on for a long time and the solution not been agitated, so that it has become very much exhausted of silver round the article, the deposit towards the end of the time has been almost impalpable to the touch, like flour: sometimes the grains were a little coarser. The practice, in such cases, is to lift the articles from the solution, and to place them in boiling water, and after steeping there some time, to take them out, when the heat of the metal soon causes it to dry. Under these circumstances, when the deposit was of the sort stated, we have seen on a large waiter or tray, when the hand was rapidly drawn over the surface, after it was dried in the manner described, the same effect produced as when the hand is drawn over an electrified handkerchief, or sheet of paper, accompanied with a crackling noise and pricking sensation. We have repeatedly observed these phenomena, but never having chanced to be in the dark, no light was visible from the surface rubbed. Although these are the conditions under which the observations were made, the phenomena were not produced every time these conditions were found. It is probably caused by the fact that this kind of deposit, which is of a chalky appearance, is a bad conductor of electricity, and as the boiling water was often very impure, holding salts in solution, the rapid evaporation of the water from the surface of this sort of deposit might leave it excited for a short time, and the hand being drawn across at the time of excitation, the electricity was liberated.

THE OLD METHOD OF PLATING.—Many objections have been urged against the application of electro-deposition to the purposes of plating, as a branch of manufacture, either as a competitor or substitute for the old method, technically called *Sheffield plate*—so called because Sheffield is a principal seat of that manufacture. To enable our readers to form a proper estimate of the objections urged, by enabling them to judge of the relative importance and value of the two processes, we shall add a brief description of the old method.

An ingot of copper being cast, was filed square and smooth, and a piece of silver was placed upon it, the two surfaces being perfectly clean: a little borax having been introduced between the two metals, they were bound together with iron wire, and then heated in a furnace nearly to the melting point; the small quantity of borax increased the fusibility of the two metals at their surface, and thus they were fused together. When fusion was effected the metals were subjected to the dilating process of heavy rollers, the dimensions in length and width being regulated according to the articles to be made. This sheet formed the base or foundation of every article, of whatever shape or form, and however it was to be ornamented when finished.

To produce ornaments, leaf silver was stamped in iron dies representing the ornaments required, which, when removed from the dies, were filled with an alloy of lead and tin. These were then soldered upon the flat or shaped plain surface with soft solder, which melts at a very low temperature: thus were produced the silver edges, or mounts.

The quality of the ornament depended entirely upon the price of the article; but whatever the quality, all ornaments in the old mode of plating were thus made, the only difference being the thickness of the silver leaf used:—Ornamental feet, handles, knobs, etc., were made in the same manner, being struck up in *two* parts, filled with lead and tin, soldered together with soft solder, and afterwards soldered to the main body. Articles (such as table candlesticks) which would be too heavy if filled with lead, were filled with rosin, pitch or any other similar substance, for the purpose of preventing the article being flattened by pressure. Hence it is evident that no *solid* article could be made by the old mode of plating, the only way of producing articles being to work them up by the hammer, or to strike them in dies from a flat surface: and being restricted to the use of soft solder, on account of the plated metal and the shells of silver, forming the edges, not supporting the required heat to melt *silver* solder, it is equally evident that the joinings so constructed would be easily removed either by force or heat.

The nearest approach to *solid* articles made by the old method of plating, were forks and spoons: these were generally made of iron, thin silver being soldered upon the surface, which was afterwards dressed smooth, and polished.

The heat used in this operation was merely that of an ordinary soldering iron; because, were a greater heat applied, the silver would form an alloy with the tin and lead of the solder, and melt: the same heat that cemented the metals in the first instance would be sufficient to disunite them; and thus, when these forks were exposed in hot gravy, the solder was liable to become soft, and the silver covering, yielding readily to the knife, to peel up or become abraided, in consequence of the soft intervening metal.

ADVANTAGES OF ELECTRO-PLATING.—The advantages offered to the plater by the electro-process are many, arising from the fact of the articles being plated *after*, instead of *before*, being manufactured. This at once entirely removed all those restrictions on taste and design, under which the plater was forced, by the nature of his process, to labor.

The following may be considered some of the principal differences existing in the two processes of plating—the old method and the electro-process:

1. The electro-plater is not limited in the use of the metal upon which he plates. There is generally used, as the basis of all electro-plated goods, a hard white metal, which possesses the sound, and approaches very nearly to the color, of silver. Inferior goods are sometimes made in brass.

2. The electro-plater is not restricted to the use of soft solder, which melts at a very low temperature, and forms a very insufficient joint, besides preventing any sound or ring in the article so soldered. Where cheap goods are required, this may be used in *this* process as well as in the old, but is always open to the same objection. All goods of superior quality, made for the electro-process, are soldered with what is termed in the trade *hard silver solder*, composed of 2 parts of silver and 1 part of brass melted together, which is not affected by any ordinary degree of heat, and presents a joint as strong as the metal itself.

The common solder of braziers may also be used with advantage: it is very hard and durable and requires a strong heat to melt it.

3. The electro-plater, in producing ornamental articles, is not obliged to incur the expense of cutting iron dies for every minute portion; being under no restriction, he models his pattern, and by casting and chasing in *solid* metal, produces an exact copy, which is *afterwards* plated or gilt.

Thus any pattern which can be executed in silver may be readily made in plate by this method.

4. The junction of the plating with the metal below, by the electro-process, is perfect, without the presence of any intervening substance: the forks and spoons thus made are not open to the objection of the old process, and are found to answer all the purposes of silver, in sound, appearance, and wear: they are generally tested, previously to polishing, by exposure in a furnace to a red heat.

5. From the facility with which *old* goods may be now restored, these goods bear an intrinsic value; whereas before the introduction of the electro-process, a plated article worn through in any part was valueless.

OBJECTIONS TO ELECTRO-PLATING.—Several objections to the electro-process have been keenly urged; but they may all be reduced to the following:

1st objection: Deposited metal is crystalline, and therefore, though it may impart in appearance a silver coating, it must necessarily be full of minute interstices between the crystals: hence when a metal, such as copper, is plated, it is liable to be acted upon by the atmosphere, or injured by whatever is brought into contact with it.

This objection was not without foundation, as all deposited metals are crystalline in texture, but they do not necessarily leave interstices; the objection, however, is almost entirely removed by keeping the articles in motion during the deposition: by motion and proper arrangement of battery we have deposited silver of as high specific gravity as hammered silver, which could not be the case if it were porous.

2d objection: As only pure silver is deposited, it must necessarily be soft, and consequently liable to abrasion, and more rapid wear.

This objection is also partly true. Only pure silver can be deposited; but it is not necessarily soft: the quality of the deposit, in this respect, depends (as already noticed) a great deal upon the nature of the solution and the battery power. Intensity of battery gives hardness to the metal deposited. There is no complaint more common amongst the burnishers of electro-plated articles, than that the metal is hard; and it is far from being an uncommon occurrence, that some goods have to be heated so that they may be more easily burnished or polished. How far this annealing may affect the wear of the goods is not yet ascertained. That the silver is pure we think an advantage—hence the superior color which electro-plated goods possess: besides which, purchasers are not subject to the risk of having a plate much alloyed.

3d objection: The mounts or prominences of articles, which must have the greatest wear, have the least and thinnest deposit.

This objection is entirely without foundation, as the prominences have always the greatest portion of deposit, and the hollow parts the least.

SOLID SILVER ARTICLES MADE BY THE BATTERY.—Silver may be deposited from its cyanide solution upon wax moulds polished with black lead, almost as easily as copper; but for this purpose it is better to have the solution much stronger in silver than for plating. We have found that 8 ounces of silver to the gallon of solution make a very good strength. Nevertheless, no articles are made in silver by depositing upon wax in this manner. Strong solutions of cyanide of potassium and silver act upon wax, and would soon destroy a mould. The method of making articles in solid silver by the electro-process has been already explained (page 544,) namely, a copper mould is made by the electrotype, and the silver is deposited within this mould to the proper thickness; after which it is kept in a hot solution of crocus and muriatic acid, or boiled in dilute hydrochloric acid, which dissolves the copper without injuring the silver.

The method which we esteem as best for dissolving off the copper is this: an iron solution is first made by dissolving a quantity of copperas in water, placing it on a fire till it begins to boil: a little nitric acid is then added—nitrates of potash and soda will do just as well—the iron, which is thus peroxidized, may be precipitated either by ammonia, or carbonate of soda; the precipitate being washed, muriatic acid is added till the oxide of iron is dissolved. This forms the solution for dissolving the copper. When the solution becomes almost colorless, and has ceased to act on the copper, the addition of a little ammonia will precipitate the iron again; after a little exposure, the copper remains in solution, which is decanted off and preserved for recovering the copper; this is done by neutralizing the ammonia by an acid, and putting in pieces of iron, which deposit the copper in the metallic state. The precipitate of iron is again dissolved in muriatic acid, and employed in dissolving the copper. Thus the iron may be used over and over again with little trouble, and the persalt of iron will be found to dissolve the copper more rapidly than an acid; persulphate of iron must not be used, as it dissolves the silver along with the copper. The silver article is then cleaned in the usual way (page 593), and heated to redness over a clear charcoal fire, which gives it the appearance of dead silver, in which state it may be kept, or, if desired, it may be scratched and burnished.

When ammonia is first added to the above solution of copper and iron, both these metals are precipitated together as a brown precipitate. After a little exposure, the copper dissolves, and the iron is at the same time peroxidized, having been previously reduced to the protoxide by the copper dissolving. When the persulphate of iron is used for dissolving copper, and ammonia is then added to the solution, the same results take place:—the precipitation of both copper and iron. But the compound seems not so stable, the copper passing more quickly into an oxide, which dissolves in the ammonia. However, with free ammonia, either with the chloride or sulphate, the oxidation of the metals is slower than with water alone.

Copper moulds intended for receiving a deposit must be protected on the back, but if the solution is very strong, there is every danger that it will decompose the protecting substance, thus rendering the solution very dirty, and causing a sediment. For the purpose of protecting the mould, various suggestions and experiments have been made; amongst other substances, pitch has been tried: it is easily affected alone, but on boiling a little of it in potash, a heavy and dirty sediment is left, destitute of any adhesive property; on putting a quantity of this sediment into a pot nearly filled with melted pitch, a violent effervescence will take place, setting free a volume of white fumes having a creosotic smell. After all effervescence has ceased, which will not be before a considerable time, and when all the mass seems to have been acted upon, the process of making an excellent protecting coating is completed—a coating which will not yield in the solution, and which is at once both good and cheap, its only fault being its brittleness.

In the manufacture of solid silver articles, the electro-process has not yet been of extensive application: and in making duplicates of rare objects of art, and costly chased or engraved articles in silver, one prevailing objection has been felt, namely, they have no "ring," and seem, when laid suddenly upon a table, to be cracked or unsound, or like so much lead; this disadvantage is no doubt partly owed to the crystalline character of the deposit, and partly to the pure character of the silver, in which state it has not a sound like standard or alloyed silver. That this latter cause is the principal one, appears from the fact that a piece of silver thus deposited is not much improved in sound by being heated and hammered, which would destroy all crystallization.

We may mention that the same objections are applicable to articles made in gold by the electro-deposit; nevertheless, for figures and ornaments, these objections are of little weight. When in Marlborough House a few months back, we were shown a plate of antique pattern in deposited silver, which was all but free from these defects.

DEAD SILVERING FOR MEDALS.—The perfect smoothness which a medal generally possesses on the surface, renders it very difficult to obtain a coating of dead silver upon it, having the beautiful silky lustre which characterizes that kind of work, except by giving it a very thick coating of silver, which takes away the sharpness of the impression. This dead appearance can be easily obtained by putting the medal, previous to silvering, in a solution of copper, and depositing upon it, by means of a weak current, a mere blush of copper, which gives the face of the medal that beautiful crystalline richness that deposited copper is known to give. The medal is then to be washed from the copper solution, and immediately to be put into the silver solution. A very slight coating of silver will suffice to give the dead frosty lustre so much admired, and in general so difficult to obtain.

OXIDIZING SILVER.—A very beautiful effect is produced upon the surface of silver articles technically termed oxidizing, which gives the surface an appearance of polished steel. This can be easily effected by taking a little chloride of platinum, prepared as described at page 527, heating the solution and applying it to the silver when an oxidized surface is required, and allowing the solution to dry upon the silver. The darkness of the color produced varies according to the strength of the platinum solution, from a light steel gray to nearly black. The effects of this process, when done along with what is termed dead work, is very pretty, and may be easily applied to medals, giving scope for the exercise of taste. Upon this we quote the following:

"The high appreciation in which ornaments in oxidized silver are now held, render a notice of the process followed interesting. There are two distinct shades in use, one produced by chloride, which has a brownish tint, and the other by sulphur, which has a bluish black tint. To produce the former, it is only necessary to wash the article with a solution of sal-ammoniac; a much more beautiful tint may, however, be obtained by employing a solution composed of equal parts of sulphate of copper and sal-ammoniac in vinegar. The fine black tint may be produced by a slightly warm solution of sulphuret of potassium or sodium."—*Chem. Techn. Mittheilungen von Dr. Ellsner.*

PROTECTION OF SILVER SURFACE.—All silver or plated articles are subject to tarnish by exposure to the air, especially in this climate, and where coals containing so much sulphur are used; the tarnish being generally a sulphuret of silver. Deposited silver is more easily tarnished than standard silver.

Medals or figures silvered for the sake of their appearance ought to be protected from the air, or they very soon lose their silver color; a medal may be put into a frame air-tight, and a figure should be covered with a glass shade: if the silver has been left dead, any attempt to clean it destroys its appearance. Varnishes have been tried to protect the silver from the atmosphere; but all varnishes, however colorless, detract from the silver lustre, and are not good. For ordinary purposes, medals may be very conveniently protected by laying a piece of common glass over the surface, cut to the exact size, and held close by a piece of paper pasted round the edges of both, and then a stout piece on the back. We have had silver medals, preserved by this means, for more than ten years. Little round medals may be conveniently covered by watch-glasses, fastened on in the same manner.

CLEANING OF SILVER.—A weak solution of cyanide of potassium, used as a wash over tarnished silver, will brighten it. This solution was, and we believe is still, sold in small bottles for this purpose, but it is not good, as it dissolves the silver rapidly, and is such a deadly poison that it must be used with great caution on articles that may be required for domestic purposes.

A variety of cleaning pastes and powders are used for silver or plated goods. Those containing mercury and oxide of lead should be avoided, for although they give a dark color when newly put on, it soon blackens. The best paste we have found is a mixture of fine precipitated chalk, carbonate of magnesia, and oxide of iron. These materials are made into a paste, and rubbed upon the plate with soft leather: for wrought or chased surfaces a hard brush is best. The goods should be finished by polishing with leather and a little of this mixture in a dry state, which will give that fine dark mirror-looking color so much admired. Common coarse whiting and flannel cloths should not be used, as thev wear the silver rapidly.

CHAPTER XXXI.

ELECTRO-GILDING.

THE operation of gilding, or covering other metals with a coating of gold, is performed in the same manner as the operation of plating, with the exception of a few practical modifications, which we shall now notice in detail.

PREPARATION OF SOLUTION OF GOLD.—The gold solution for gilding is prepared by dissolving gold in three parts of muriatic acid and one of nitric acid, which forms the chloride of gold. This is digested with calcined magnesia, and the gold is precipitated as an oxide. The oxide is boiled in strong nitric acid, which dissolves any magnesia in union with it: the oxide being well washed is dissolved in cyanide of potassium, which gives cyanide of gold and potassium; thus:—

Substances used:		*Substances produced:*	
Oxide of Gold	$=AuO$	Cyanide of Gold and Potassium	$=KCy+AuCy$
2. Cyanide of Potassium	$=2KCy$	Potash	$=KO$

$$Auo+2\,KCy=KO+(KCy+AuCy.)$$

By this method a proportion of potash is formed in the solution, as an impurity; it is not, however, very detrimental to the process. In preparing the oxide of gold there is always a little of the gold lost, to recover which the washings should be kept, evaporated to dryness, and fused.

Another and very simple method is this:—Add a solution of cyanide of potassium to the chloride of gold until all the precipitate is redissolved; but this gives chloride of potassium in the solution, which is not good. In the preparation of the solution by this means there are some interesting reactions. As the chloride of gold has always an excess of acid, the addition of cyanide of potassium causes violent effervescence, and no precipitate of gold takes place until all the free acid is neutralized, which causes a considerable loss to the cyanide of potassium. There is always formed in this deposition a quantity of ammonia and carbonic acid, from the deposition of the cyanate of potash; and if the chloride of gold be recently prepared and hot, there is often formed some aurate of ammonia (fulminate of gold), which precipitates with the cyanide of gold. Were this precipitate to be collected and dried, it would explode when slightly heated. On previously diluting the chloride of gold, or using it cold, this compound is not formed.

After the free acid is neutralized by the potash, further addition of the cyanide of potassium precipitates the gold as cyanide of gold, having a light yellow color; but as this is slightly soluble in ammonia and some of the alkaline salts, it is not advisable to wash the precipitate lest there be a loss of gold. Cyanide of potassium is generally added until the precipitate is redissolved; consequently much impurity is formed in the solution, namely, nitrate and carbonate of potash with chloride of potassium and ammonia. Notwithstanding, this solution works very well for a short time, and it is very good for operations on a small scale.

Battery Process of Preparing Gold Solution.—The best method of preparing the gold solution is that described for silver (p. 589). Say the operator wishes to prepare a gallon of gold solution, he dissolves four ounces of cyanide of potassium in one gallon of water, and heats the solution to 150° Fah.; he now takes a small porous cell and fills it with this cyanide solution, and places it inside the gallon of solution: into this cell is put a small plate of iron or copper, and attached by a wire to the zinc of a battery. A piece of gold is placed into the large solution, facing the plate in the porous cell, and attached to the copper of the battery. The whole is allowed to remain in action until the gold, which is to be taken out from time to time and weighed, has lost the quantity required in solution. By this means a solution of any strength can be made, according to the time allowed. The solution in the porous cell, except the action has continued long, will have no gold, and may be thrown away. Half an hour will suffice for a small quantity of solution—of course any quantity of solution may be made up by the same means. For all the operations of gilding by the cyanide solution, it must be heated to at least 130° Fah. The articles to be gilt are cleaned in the way described for silver, but are not dipped into nitric acid previously to being put in the gold solution. Three or four minutes is sufficient time to gild any small article. After the articles are cleaned and dried they are weighed—and when gilt they are weighed again; thus the quantity of gold deposited is ascertained. Any convenient means may be adopted for heating the solution. The one generally adopted is to put a stoneware pan containing the solution into an iron or tinplate vessel filled with water, which is kept at the boiling point either by being placed upon a hot plate or over gas. The hotter the solution the less battery power is required. Generally three or four pairs of plates are used for gilding, and the solution is kept at 130° to 150° Fah. But one pair will answer if the solution is heated to 200°.

Process of Gilding.—The process of gilding is generally performed upon silver articles. The method of proceeding is as follows: When the articles are cleaned as described in our chapter on plating, they are weighed, and well scratched with wire brushes, which cleanse away any tarnish from the surface, and prevents the formation of air-bubbles. They are then kept in clean water until it is convenient to immerse them in the gold solution. One immersion is then given, which merely imparts a blush of gold; they are taken out and again brushed; they are then put back into the solution and kept there for three or four minutes, which will be sufficient if the solution and battery are in good condition; but the length of time necessarily depends on these two conditions, which must be studied and regulated by the operator.

Iron, tin, and lead, are very difficult to gild direct; they therefore generally have a thin coating of copper deposited upon them by the cyanide of copper solution and immediately put into the gilding solution.

Conditions required in Gilding.—The gilding solution generally contains from one-half to an ounce of gold in the gallon, but for covering small articles, such as medals, for tinging daguerreotypes, gilding rings, thimbles, etc., a weaker solution will do. The solution should be sufficient in quantity to gild the articles at once, so that it should not have to be done bit by bit; for when there is a part in the solution and a part out, there will generally be a line mark at the point touching the surface of the solution. The rapidity with which metals are acted upon at the surface line of the solution is remarkable. If the positive electrode is not wholly immersed in the solution, it will, in a short time, be cut through at the surface of the water, as if cut by a knife. This is also the case in silver, copper, and other solutions, as before referred to.

MAINTAINING THE GOLD SOLUTION.—As the gold solution evaporates by being hot, distilled water must from time to time be added. The water should always be added when the operation of gilding is over, not when it is about to be commenced, or the solution will not give so satisfactory a result. When the gilding operation is continued successively for several days, the water should be added at night. The average cost of depositing gold is about 4 cts. per pennyweight.

The means of testing the free cyanide of potassium, with nitrate of silver, as described for silver, is not applicable to the gold solution; but it may be tested by the ammoniuret of copper, see p. 603. To obtain a deposit of a good color much depends upon the state of the solution and battery; it is therefore necessary that strict attention be paid to these, and more so as the gold solution is very liable to change if the relative size of the article receiving the deposit is not according to that of the positive plate.

The result of a series of observations and experiments, continued daily throughout a period of nine months, showed that in five instances only the deposit was exactly equal to the quantity dissolved from the positive plate. In many cases the difference did not exceed 3 per cent., though occasionally it rose to 50 per cent. The average difference however was 25 per cent. In some cases double the quantity dissolved was deposited, in others the reverse occurred—both resulting from alterations made in the respective processes; for in these experiments we varied, as far as practicable, the state of the solution and the relative sizes of the negative and positive electrodes.

The most simple method of keeping a constant register of the state of the solution is to weigh the gold electrode before putting it into the solution; and, when taking it out, to compare the loss with the amount deposited: a little allowance, however, must be made for small portions of metal dissolved in the solution, from the articles that are gilt, which, when gilding is performed daily, is considerable in a year. A constant control can thus be exercised over the solution, to which there will have to be added from time to time a little cyanide of potassium, a simple test of requirement being that the gold pole should always come out clean—for if it has a film or crust it is a certain indication that the solution is deficient of cyanide of potassium. Care must be taken to distinguish this crust, which is occasionally dark-green or black, from a black appearance which the gold pole will take when very small in comparison to the article being gilt, and which is caused by the tendency to evolve gas. In this case an addition of cyanide of potassium would increase the evil. The black appearance from the tendency to the escape of gas has a slimy appearance. This generally takes place when the solution is nearly exhausted of gold, of which fact this appearance, taken conjointly with the relative sizes of the electrodes, are a sure guide.

TO REGULATE THE COLOR OF THE GILDING.—The gold upon the gilt article, on coming out of the solution should be of a dark-yellow color, approaching to brown, but this when scratched will yield a beautifully-rich deep gold. If the color is blackish it ought not to be finished, for it will never either brush or burnish a good color. If the battery is too strong, and gas is given off from the article, the color will be black; if the solution is too cold, or the battery rather weak, the gold will be light-colored; so that every variety of shade may be imparted. A very rich dead gild may be made by adding ammoniuret of gold to the solution just as the articles are being put in, or what is better, add some sulphuret of carbon in the same way as for silver solutions, which affects the color and appearance of the gold in the same way as it does the silver.

COLORING OF GILDING.—A defective colored gilding may be improved by the same method as that adopted in the old process to color gilding or gold, namely, by the help of the following mixture:

3 parts Nitrate of Potash
1½ Alum
1½ Sulphate of Zinc
1½ Common Salt.

These ingredients are put into a small quantity of water, to form a sort of paste, which is put upon the articles to be colored: they are then placed upon an iron plate over a clear fire, so that they will attain nearly to a black heat, when they are suddenly plunged into cold water: this gives them a beautiful high color. Different hues may be had by a variation in the mixture.

TO DISSOLVE GOLD FROM GILT ARTICLES.—Before regilding articles which are partly covered with gold, or when the gilding is imperfect, and the articles require regilding, the gold should be removed from them by putting them into strong nitric acid; and when the articles have been placed in the acid, by adding some common salt, not in solution, but in crystals. By this method gold may be dissolved from any metal, even from iron, without injuring it in the least. After coming out of the acid, the articles must be polished. The best method, however, is to brush off the gold as described for silver (page 597), which gives the polish at the same time.

To Recover the Gold.—When the gold is dissolved off by the acid after it is saturated, or when it ceases to dissolve the gold rapidly, the acid is diluted with several times its bulk of water, and then soda or potash added till the greater portion of the acid is neutralized. A solution of sulphate of iron (copperas) is then added, so long as a precipitate is formed; when this settles down it is carefully collected upon a paper filter, washed and dried, and then fused in a crucible with a little borax and common salt, when the gold is found as a button at the bottom of the crucible.

When the gold is brushed off, the brushings are burned at a red heat, and the residue fused with carbonate of soda and a little borax: in this case, the gold will not be pure and will have to be refined.

Objections to Electro-gilding.—Objections have also been made to the application of electro-gilding to the arts, of the same kind as those urged against electro-plating; but the now almost universal adoption of this process by gilders, because of the perfection to which the articles are brought, forms the best answer we can give to such objections. However, let us take a hasty glance at the old process and its consequences, that we may be enabled to judge of the comparative merits of both methods.

Before the introduction of electro-deposition, the only method of gilding was by forming an amalgam of gold and mercury, which, at the consistence of a thin paste, was brushed upon the articles over a strong heat; the mercury being gradually dissipated, the gold remained fixed upon the articles. This process is most pernicious, and destructive to human life; the mercury, volatilized by the heat, insinuates itself into the bodies of the workmen, notwithstanding the greatest care; and those who are so fortunate as to escape for a time absolute disease, are constantly liable to salivation from its effects. Paralysis is common among them, and the average of their lives is very short; it has been estimated as not exceeding 35 years. It is difficult to believe that men could be found to engage in such a business, reckless of the consequences so fearfully exhibited before them; and it would naturally be thought they would hail with pleasure the introduction of any process which would be put a stop to such a dreadful sacrifice of human life. But it is very difficult to overcome interest and prejudice, even when the object to be gained is of such vast importance.

Effects of Cyanogen on Health.—The effects produced upon the health of those who work constantly over cyanide solutions are not yet fully tested, by which we could form a comparison with the old process; for every new trade, or operation, gives rise to a new disease, or some new forms of an old disease. Having ourselves inhaled much of the fumes of that *"ominous"* gas given off from the cyanide of potassium solution, we are not prepared to stand its advocate, but would rather warn all employed at the business, or who may in any degree have to do with these solutions, to be very careful not to use too much freedom. The hands of those engaged in gilding or plating are subjected to ulceration, particularly if they have been immersed in the solution. The ulcers are not only annoying but painful; and, on their first appearance, if care is not properly taken to wash them in strong cyanide of potassium, and then in acid water, the operator will, in a short time, have to take a few days rest. We have repeatedly seen, by the aid of a magnifying glass, gold and silver reduced in these ulcerations. We have also known of eruptions breaking out over the bodies of workmen after inhaling those deleterious fumes when they were very bad, as when solutions were precipitated by acids or being evaporated to dryness in a close apartment for the recovery of the metal. Repeatedly have we seen the legs of workmen thus afflicted, and always after they have been exposed to extra fumes.

The following statement of the general effects of electro-plating and gilding on the health of those engaged in them, as experienced by ourselves and others, may not be uninteresting to our readers: but it is necessary to premise that the apartments in which we were employed were improperly ventilated.

The gas has a heavy sickening smell, and gives to the mouth a saline taste, and scarcity of saliva; the saliva secreted is frothy. The nose becomes dry and itchy, and small pimples are found within the nostrils, which are very painful (we have felt these effects in the nose from the hydrogen of the batteries, where there were no cyanide solutions). Then follows a general languor of body; disinclination to take food, and a want of relish. After being in this state for some time, there follows a benumbing sensation in the head, with pains, *not* acute, shooting along the brow; the head feels as a heavy mass, without any individuality in its operations. Then there is bleeding at the nose in the mornings when newly out of bed; after that comes giddiness; objects are seen flitting before the eyes, and momentary feelings as of the earth lifting up, and then leaving the feet, so as to cause a stagger. This is accompanied with feelings of terror, gloomy apprehension, and irritability of temper. Then follows a rushing of blood to the head; the rush is felt behind the ears with a kind of hissing noise, causing severe pain and blindness: this passes off in a few seconds, leaving a giddiness which lasts for several minutes. In our own case the rushing of blood was without pain, but attended with instant blindness, and then followed with giddiness. For months afterwards a dimness remained as if a mist intervened between us and the objects looked at: it was always worse towards evening, when we grew very languid and inclined to sleep. We rose comparatively well in the morning: yet were restless, our stomach was acid, visage pale, features sharp, eyes sunk in the head, and round them dark in color: these effects were slowly developed. Our experience was nearly three years.

We have been thus particular in detailing these effects, as a warning to all employed in the process; but we have no doubt that in lofty rooms, airy and well ventilated, these effects would not be felt. Employers would do well to look to this matter; and amateurs, who only use a small solution in a tumbler, should not, as the custom sometimes is, keep it in their bed-rooms; the practice is decidedly dangerous.

PRACTICAL SUGGESTIONS IN GILDING.—According to the amount of gold deposited, so will be its durability: a few grains will serve to give a gold *color* to a very large surface, but it will not last: this proves, however, that the process may be used for the most inferior quality of gilding. Gold thinly laid upon silver will be of a light color, because of the property of gold to transmit light. The solution for gilding silver should be made very hot, but for copper it should be at its minimum heat. A mere blush may be sufficient for articles not subjected to wear; but on watch-cases, pencil-cases, chains, and the like, a good coating should be given. An ordinary sized watch-case should have from 20 grains to a pennyweight; a mere coloring will be sufficient for the inside, but the outside should have as much as possible. A watch-case thus gilt, for ordinary wear, will last five or six years without becoming bare. We have known some to be in use full six years without losing their covering. Small silver chains, such as those sold at eight shillings, should have 12 grains; pencil-cases, of ordinary size should have from 3 to 5 grains; a thimble from 1 to 2 grains. These suggestions will serve as a guide to amateur gilders, many of whom, having imparted only a color to their pencil-cases, feel chagrin and disappointment upon seeing them speedily become bare; hence arises much of the obloquy thrown upon the process.

CHAPTER XXXII.

RESULTS OF EXPERIMENTS ON THE DEPOSITION ON OTHER METALS AS COATINGS.

COATING WITH PLATINUM.—This metal has never yet been successfully deposited as a protecting coating to other metals. A solution may be made by dissolving it in a mixture of nitric and muriatic acids, the same as is employed in dissolving gold; but heat must be applied. The solution is then evaporated to dryness, and to the remaining mass is added a solution of cyanide of potassium; next, it must be slightly heated for a short time, and then filtered. This solution, evaporated, yields beautiful crystals of cyanide of platinum and potassium; but it is unnecessary to crystallize the salt. A very weak battery power is required to deposit the metal: the solution should be heated to 100°. Great care must be taken to obtain a fine metallic deposit: indeed the operator may not succeed once in twenty times in getting more than a mere coloring of metal over the surface, and that not very adhesive. The causes of the difficulty are probably these: the platinum used as an electrode is not acted upon; the quantity of salt in solution is very little; it requires a particular battery strength to gives a good deposit, and the slightest strength beyond this gives a black deposit; so that, were the proper relations obtained, whenever there is any deposit, the relations of battery and solution are changed, and the black pulverulent deposit follows.

We have occasionally succeeded in obtaining a bright metallic deposit of platinum, possessing the qualities of adhesion and durability: some of the articles thus covered presented no signs of change after many years: but we have never been so fortunate as to get a platinum deposit that could protect any metal from the action of acids, or other fluids by which the metal could be affected. We have covered iron, such as the end of a glass-blower's blowpipe, so that it could be made red-hot without the iron rusting, but rather taking the characteristic appearance of platinum: but even that did not protect the iron from rusting when it was put a short time into water, or kept exposed to moist air. We have seen again and again recommendations of certain solutions of platinum for the purpose of obtaining a reguline metal, and no doubt it has been obtained, but, as stated above, we believe more incidentally than at will. The protoxalate of platinum has been strongly recommended for covering copper and brass with platinum.*

COATING WITH PALLADIUM.—Palladium is a metal very easily deposited. The solution is prepared by dissolving the metal in nitro-muriatic acid, and evaporating the solution nearly to dryness; then adding cyanide of potassium till the whole is dissolved: the solution is then filtered and ready for use. The cyanide of potassium holds a large quantity of this metal in solution, and the electrode is acted upon while the deposit is proceeding. Articles covered with this metal assume the appearance of the metal; but so far as we are aware, it has not yet been applied to any practical purpose. It requires rather a thick deposit to protect metals from the action of acids, which is, probably, the only use it can be applied to.

COATING WITH NICKEL.—Nickel is very easily deposited; and may be prepared for this purpose by dissolving it in nitric acid, then adding cyanide of potassium to precipitate the metal; after which the precipitate is washed and dissolved by the addition of more cyanide of potassium. Or the nitrate solution may be precipitated by carbonate of potash; this should be well washed, and then dissolved in cyanide of potassium; a proportion of carbonate of potash will be in the solution, which we have not found to be detrimental. This latter method of preparing the nickel plating solution is simple, and, therefore, has our recommendation. The

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* Polytechni. Constah. 1855.

metal is very easily deposited; it yields a color approaching to silver, which is not liable to tarnish on exposure to the air. A coating of this metal would be very useful for covering common work such as gasaliers, and other gas-fittings, and even common plate. The great difficulty experienced is to obtain a positive electrode: the metal is very difficult to fuse, and so brittle that we have never been able to obtain either a plate or a sheet of it. Could this difficulty be easily overcome, the application of nickel to the coating of other metals would be extensive, and the property of not being liable to tarnish would make it eminently useful for all general purposes. We coated articles with nickel in 1845, which were exposed to the air for many years without tarnish, and when last seen by the author exhibited no change.

ANTIMONY, ARSENIC, TIN, IRON, LEAD, BISMUTH, AND CADMIUM.—We have deposited these metals from their solutions in cyanide of potassium; but not for any useful application.

IRON.—Iron may be very easily deposited from its sulphate: dissolve a little crystalline sulphate of iron in water, and add a few drops of sulphuric acid to the solution: one pair of Smee's battery may be used to deposit the iron upon copper or brass. The metal in this pure state has a very bright and beautiful silver color.

LEAD.—Lead may be deposited from a solution of an acid salt, such as the acetate, but requires some management or strength of battery: it may also be deposited from its solution in potash or soda.

ALUMINIUM AND SILICIUM.—Since the publication of the former edition of this work, new methods have been discovered for obtaining the base or metal of alumina and silica, or clay and sand, in the metallic state possessing extraordinary properties. One of the methods successfully adopted, is by fusing in a small crucible some chloride or fluoride of aluminium, and when in fusion, inserting two steel poles in connection with a battery which reduces the salt, giving small globules of the metal aluminium.

Attempts have also been made to deposit the metals from their cyanous solution as coating upon other metals in the usual way. We have not ourselves tried any experiments upon these metals, but we take the following results of experiments from Mr. G. Gore of Birmingham, who seems to have given the subject a good deal of attention:

"It has long been known to chemists that all kinds of clay, stone, and sand, of which the earth is composed, consist of metals combined with oxygen, carbonic acid, sulphuric acid, and other non-metallic elements, forming therewith oxides, carbonates, sulphates, etc.; thus clay is an oxide of aluminium, sand an oxide of silicium, limestone a carbonate of calcium; but the separation of the metallic bases from the non-metallic elements with which they are combined has been a matter of so great difficulty, that few chemists have put themselves to the trouble of accomplishing it, and those who have done so have made use of the most powerful means and reducing agents, such as large voltaic batteries, potassium, etc., and have then obtained them in a state of alloy or combination with mercury. Sir Humphrey Davy, the discoverer of most of these bases, in his experiments on the decomposition of the alkalies and earths, used a powerful battery, consisting of 500 pairs of plates, and then succeeded in obtaining them combined with mercury, from which they were afterwards separated. Wöhler and Berzelius, in their discoveries of the means of separating the metals aluminium and silicium from their respective compounds, clay and sand, used a high temperature and potassium, and then succeeded in obtaining them in the condition of dull metallic powders, nearly infusible.

"By a means recently discovered, and described in the March number of the *Philosophical Magazine* for this year, I have succeeded in depositing the metals aluminium from clay, and silicium from sandstone, each in a perfect metallic condition, by dissolving pipe-clay, common red sand, pounded stone, etc., in various chemical liquids, and passing currents of electricity from ordinary small voltaic batteries through the solutions.

"My attention has since been directed to produce simple processes, whereby any person not possessing a knowledge of chemistry may readily coat articles with those metals, and thus cause the discovery to be immediately applied to human benefit in the arts and manufactures, and the following are the results of my experiments:

"To coat articles of copper, brass, or German silver, with aluminium, take equal measures of sulphuric acid and water, or take one measure each of sulphuric and hydrochloric acids and two measures of water; add to the water a small quantity of pipe-clay, in the proportion of 5 or 10 grs. by weight to every ounce by measure of water (or ½ oz. to the pint): rub the clay with the water until the two are perfectly mixed, then add the acid to the clay solution, and boil the mixture in a covered glass vessel one hour. Allow the liquid to settle, take the clear, supernatant solution, while hot, and immerse in it an earthen porous cell, containing a mixture of one measure of sulphuric acid and ten measures of water, together with a rod or plate of amalgamated zinc; take a small Smee's battery, of three or four pairs of plates, connected together intensity fashion, and connect its positive pole by a wire, with a piece of zinc in the porous cell. Having perfectly cleaned the surface of the article to be coated, connect it by a wire with the negative pole of the battery, and immerse it in the hot clay solution; immediately abundance of gas will be evolved from the whole of the immersed surface of the article, and in a few minutes, if the size of the article is adapted to the quantity of the current of electricity passing through it, a fine white deposit of aluminium will appear all over the surface. It may then be taken out, washed quickly in clean water, and wiped dry, and polished; but if a thicker coating is required, it must be taken out when the deposit becomes dull in appearance, washed, dried, polished. and re-immersed; and this must be repeated at intervals, as often as it becomes dull, until the required thickness is obtained. With small articles it is not absolutely necessary, either in this or the following process, that a separate battery be employed, as the article to be coated may be connected by a wire with a piece of zinc in the porous cell, and immersed in the outer liquid, when it will receive a deposit, but more slowly than when a battery is employed.

"To coat articles with silicium, take the following proportions: three-quarters of an ounce, by measure, of hydrofluoric acid, ¼ oz. of hydrochloric acid, and 40 or 50 grs. either of precipitated silica, or of fine white sand (the former dissolves most freely), and boil the whole together for a few minutes, until no more silica is dissolved. Use this solution exactly in the same manner as the clay solution, and a fine white deposit of metallic silicium will be obtained, provided that the size of the article is adapted to the quantity of the electric current: common red sand, or indeed any kind of silicious stone, finely powdered, may be used in place of the white sand, and with equal success, if it be previously boiled in hydrochloric acid, to remove the red oxide of iron or other impurities.

"Both in depositing aluminium and silicium, it is necessary to well saturate the acid with the solid ingredients by boiling, otherwise very little deposit of metal will be obtained.

"Among the many experiments I have made upon this subject, the following are a few of the most interesting:—

"*Experiment* 1.—Boiled some pipe-clay in caustic potash and water, poured the clear part of the solution into a glass vessel, and immersed in it a small earthen porous cell, containing dilute sulphuric acid and a piece of amalgamated zinc; immersed a similar piece of bright sheet copper in the alkaline liquid, and connected it with the negative pole of a small Smee's battery of three pairs of plates, connected the zinc plate with the positive pole, and let the whole stand undisturbed all night; on examining it next morning I found the piece of copper coated with a white silver-like deposit of metallic aluminium.

"*Experiment* 2.—Obtained from a railway cutting in the town a small piece of the sand rock upon which Birmingham is built, boiled it in hydrochloric acid, to remove the red oxide of iron, washed it clean with water, and dissolving it by boiling it in a mixture of hydrofluoric acid, nitric acid, and water; immersed in this solution, a porous cell with dilute acid and zinc, as before; connected a piece of brass with the zinc by a wire, and suspended it in the outer liquid, which was kept hot by a small spirit lamp beneath; after allowing the action to proceed several hours, I found the piece of brass beautifully coated with white metallic silicium.

"*Experiment* 3.—Took one part, by weight, of the same sandstone, after being purified by the hydrochloric acid, and 2½ parts of carbonate of potash, fused them together in a crucible until all evolution of gas ceased, and a perfect glass was formed; poured out the melted glass, and when cold, dissolved it in water, and used this solution in the same manner as the former ones, allowing the action to proceed about 12 hours, when a good white deposit of metallic silicium was obtained.

"*Experiment* 4.—Took some stones with which the streets of Birmingham are macadamised, pounded them fine in a mortar, boiled the powder in hydrochloric acid, to purify it from iron, washed it well in water, and dissolved it by boiling an excess of it in a mixture of ¾ oz., by measure, of hydrofluoric acid, ½ oz. of water, and ½ oz. each of nitric and hydrochloric acids, until no more would dissolve; used the clear portion of this solution in the same manner as the former liquids, and readily coated in it a piece of brass with a beautifully white deposit either of aluminium or silicium. From these, and many other experiments which I have tried, it is quite clear that common metal articles may be readily coated with white metals, possessing similar characters to silver, from solutions of the most common and abundant materials, and thus bring within the purchase of the poorer classes articles of taste and cleanliness which are at present only to be obtained by the comparatively wealthy."

TIN.—Tin is easily deposited from a solution of protochloride of tin. If the two poles or electrodes be kept about two inches apart, a most beautiful phenomenon may be observed. The decomposition of the solution is so rapid that it shoots out from the negative electrode like tentacula, or feelers, towards the positive, which it reaches in a few seconds. The space between the poles seems like a mass of crystallized threads, and the electric current passes through them without effecting further decomposition. So tender are these metallic threads that when lifted out of the solution they fall upon the plate like cobweb. Seen through a glass they exhibit a beautiful crystalline structure. If a circular electrode of tin is used, and a small wire put in the centre of the chloride solution, the thread-like crystals will shoot out all round, and give quite a metallic confervæ. Tin may also be deposited from its solution in caustic potash or soda.

ANTIMONY.—In the deposition of antimony Mr. Gore has observed a curious and interesting phenomenon, that the metal during its deposition, and after some has been deposited, explodes occasionally, the particles being thrown about by the shock.

DEPOSITION OF ALLOYS.—Many attempts have been made to deposit alloys of metals from their solutions. That two or more metals can be deposited from a solution we have seen sufficient evidence; but the means to regulate the proportions of each, and to make such a process practical, have yet to be discovered. It is hardly possible to get a mixed solution of any two metals that are exactly equally decomposable; or, in other words, that the metals under the circumstances in which they are placed are exactly of equal conducting power. Hence the electric current will always travel through the one that offers the least resistance, and there will be none of the other metallic solution decomposed, or metal deposited, until the quantity of electricity is greater than the best conducting metal in the solution will allow to pass; then the other metal will be deposited in proportion to the extra electrical power that passes. As, for example, take a mixture of cyanide of gold, silver, and copper, in cyanide of potassium. The silver in this state is so much superior in its conducting power to the other salts, that all the silver may be deposited from the solution by a weak battery without any of the other metals. If the solution be afterwards heated, and the battery power kept so that no gas is allowed to escape from the articles, the gold may be deposited without any copper; but if the gas is allowed to flow from the article receiving the deposit, the copper will be deposited, and often more abundantly than the gold, as the escape of gas is not consistent with a reguline deposit of gold. We have thus deposited an alloy of gold and copper; we have also deposited gold and silver, but the alloy was very inferior and irregular. Alloys can be obtained from silver and palladium, from cyanide solutions, from zinc and copper, from a solution of their sulphates; but in no instance have we found good alloys, or alloys that could pass as such in name or appearance. We have seen articles, such as iron, covered with copper and zinc in this manner, or in alternate layers, and the articles having the coating heated in charcoal, by which means a brass of fair appearance was obtained, but the process is attended with practical difficulty, and the product cannot be called deposited brass.

Several patents have been taken out for the deposition of alloys of various sorts. The following, by Morris and Johnson, embraces a wide range, and being well described we will copy the specification:

"This invention consists in the employment of solutions composed of cyanide of potassium and carbonate of ammonia, to which are added cyanides, carbonates, and other compounds of metals, in proportions according to the amount of deposit required to be made.

"In order that the invention may be fully understood and carried into effect, the patentees proceed to describe the means pursued by them as follows: These improvements consist in the employment of solutions composed of carbonate of ammonia (the carbonate of ammonia of commerce, or the sesqui-carbonate of ammonia of chemists), and cyanide of potassium, to which are added carbonates, cyanides, or other compounds of metals, in various proportions. For the well-known alloy, brass, carbonate of ammonia and cyanide of potassium are used in the following proportions, namely—To each or every gallon of water are added 1 lb. of carbonate of ammonia, 1 lb. of cyanide of potassium, 2 ozs. of cyanide of copper, and 1 oz. of cyanide of zinc. These proportions may be varied to a considerable extent. Or the patentees take the before-named solution of carbonate of ammonia and cyanide of potassium, in the proportion of 1 lb. of each to one gallon of water; and they take a large sheet of brass of the desired quality, and make it the anode or positive electrode, in the aforesaid solution, of a powerful galvanic battery or magneto-electric machine, and a small piece of metal, and make it the cathode or negative electrode, from which hydrogen must be freely evolved. This operation is continued till the solution has taken up a sufficient quantity of the brass to produce a reguline deposit. The solution may be used cold; but it is desirable, in many cases, to heat it (according to the nature of the article or articles to be deposited upon) up to 212° Fahr. For wrought or fancy work about 150° Fahr. will give excellent results. The galvanic battery, or magneto-electric machine, must be capable of evolving hydrogen freely from the cathode or negative electrode, or article attached thereto. It is preferred to have a large anode or positive electrode, as this favors the evolution of hydrogen. The article or articles treated as before described will immediately become coated with brass. By continuing the process any desired thickness may be obtained. Should the copper have a tendency to come down in a greater proportion than is desired, which may be known by the deposit assuming too red an appearance, it is corrected by the addition of carbonate of ammonia, or by a reduction of temperature, when the solution is heated. Should the zinc have a tendency to come down in too great a proportion, which may be seen by the deposit being too pale in its appearance, this is corrected by the addition of cyanide of potassium or by an increase of temperature.

"The alloy, German silver, is deposited by means of a solution consisting of carbonate of ammonia and cyanide of potassium (in the proportions previously given for the brass), and cyanides or other compounds of nickel, copper, and zinc, in the requisite proportions to constitute German silver. It is however preferred to make the solution by means of the galvanic battery or magneto-electric machine, as above described for brass. Should the copper of the German silver come down in too great a proportion, this is corrected by adding carbonate of ammonia, which brings down the zinc more freely; and should it be necessary to bring down the copper in greater quantity, cyanide of potassium is added—such treatment being similar to that of the brass before described.

"The solutions for the alloys of gold, silver, and other alloys of metals, are made in the same manner as above stated, by employing anodes of the alloy or alloys to be deposited; or by adding to the solutions the carbonates, cyanides or other compounds, in the proportions forming the various alloys—always using in depositing an anode of the required alloy. These solutions are subject to the same treatment and control as those of the brass and German silver before described.

"The patentees claim the combination of the carbonate of ammonia, before named or other carbonates of ammonia and cyanide of potassium, as the ingredients for their solutions for depositing alloys of metals."

The expense of depositing common metals will remain a barrier to the use of electro-metallurgy in making such alloys as brass, a consideration which some patentees do not seem to consider. We have the following given as methods for mixing up solutions for depositing brass, which will prove our position:

"As an illustration of this invention we take the patentee's method of depositing a coating of brass by galvanic agency, in which he employs the following:—1. A solution of the double chloride of zinc and ammonia.—2. A solution of the double chloride of zinc and potassium.—3. A solution of the double chloride of zinc and sodium.—4. A solution of the double acetate of zinc and ammonia.—5. A solution of the double acetate of zinc and potassium.—6. A solution of the acetate of zinc and soda.—7. A saturated solution of carbonate of zinc, and carbonate of ammonia. —8. A solution of the double tartrate of zinc, and of potash, soda, or ammonia. (To one thousand parts of the solution of tartrate of zinc, indicating three degrees on the salinometer, thirty parts of hydrochlorate of ammonia, and eighty parts of hydrochloric acid must be added.)—9. A solution of citrate of zinc rendered soluble by an excess of citric acid.—10. A solution of tartrate of zinc in potash or soda. With each of the above solutions an analogous solution of copper must be mixed in the proportion suitable for obtaining the required depth of color."

Besides the ordinary electro-metallurgical operations, the public are from time to time told through the press that the process has been applied to the extraction of metals from their ores, but on examination the statement is invariably found to be incorrect, the metal being in all cases separated from the ore by means of an acid or acids, and the electro-metallurgical operations not applied till after this separation takes place; so that its application is altogether apart from the extraction of the metal from the ore. Such an application for common metals is *commercially* absurd; and nothing can exhibit the want of practical application so much as some of the patents taken out for this object. The greater number of these patents are intended for copper ores, upon which we will offer a few remarks. It will be seen from the principles of deposition, that, allowing the copper was all in solution to be deposited by a battery, the cheapest form known will give the loss of one ton of zinc and sulphuric acid to get one ton of copper, which would be upwards of £20 for the materials destroyed, while a ton of copper may be smelted by the ordinary process for half that sum. We give the following extract of a patent as an illustration, not because it is worse than others, but being more definite in its methods and battery than most of these patents, and the patentee an excellent electrician.

"Mr. Andrew Crosse, of Broomfield, the electrician, has just specified his patent for improvements in the extraction of metals from their ores. The apparatus employed for this purpose consists of a wooden or earthenware vessel capable of holding from 250 to 300 quarts, at a short distance above the bottom of which is a movable platinum frame covered with a netting of platinum wire, the meshes being about 1 inch each way. This frame is connected to the positive pole of a Daniell's battery by a platinum wire, covered with a non-conducting material throughout those parts of it exposed to the liquid in the vessel; the negative pole of the battery being connected to a copper wire, from which is suspended by three smaller wires, in the interior of the vessel, a bowl of wood lined with sheet copper and covered with a copper wire netting. The battery in connection with the apparatus should consist of 20 pairs of plates, each in a gallon glass vessel, filled with a saturated solution of sulphate of copper, to which has been added from 1-20th to 1-10th part of sulphuric acid.

The mode of operating is as follows: The vessel is partially filled with water acidulated with sulphuric acid—230 quarts of water and 5 quarts of sulphuric acid being a convenient quantity. About 15 lbs. of the copper ore, previously calcined and reduced to powder, is then stirred into the liquid in the vessel and allowed to subside, after which the platinum frame is lowered on to the surface of the ore, and the copper-lined bowl suspended in its place, when the electric current immediately begins to act; but it is preferred to allow the ore to remain four or five days in the acidulated water before applying the electric current. The liquid during the process should be kept heated even as high as the boiling point, by which the separation of the copper and its deposition in the bowl will be facilitated. The time occupied in effecting this is generally three or four days, when the whole of the copper is removed. The acid liquid and sediment, which will contain any other metals that may have been present, are run out through a plug-hole in the bottom of the vessel. The sediment should be tested to ascertain if it still contains any proportion of copper; and if so, it can be mixed with fresh calcined ore and again operated on. The liquid does not require any fresh quantity of acid to be added to it during the process, and afterwards it may again be similarly used.

Here we have 20 pairs of plates recommended to be used in the battery, making a destruction of 20 tons of zinc and acid for one ton of copper, and taking four days to deposit. Twenty-one tons of copper per week would be but a small quantity of copper made, compared with smelting; and at the ordinary per centage of ore to get this, there will have to be operated upon 300 tons of ore, requiring acres of tanks, heated according to specification, independent of the furnace for calcining. Having got the ore calcined and free of sulphur, it would be preferable to fuse it with carbonaceous matters and get the copper direct. Notwithstanding the commercial absurdity of all these applications and patents, still there are several ingenious adaptations worthy of the attention of the electro-metallurgist as a study in his profession.

DEPOSITION OF BRONZE.—The following solutions of different metals are given by Brunel, Bisson, and Gaugain, as being capable of giving a deposit of bronze:

50	parts	Carbonate of Potash.
2	"	Chloride of Copper
4	"	Sulphate of Zinc.
25	"	Nitrate of Ammonia.

A bronze plate is used as the positive electrode. The deposit given by this solution has been seen by Becquerel, who mentions that it bears comparison with any ordinary bronze in appearance.* A solution of the above materials in water strikes the ear as somewhat hypothetical: that a mixed solution of copper and zinc will give, under certain conditions, a compound deposit we know, and also that, with a quantity of other salts present, will give peculiar tints of color, a circumstance which may be obtained without a compound deposit. But the difficulty to be overcome is to proportion the deposit of different metals, so that we may make up a solution and battery that will deposit either Mantz's yellow metal, Stirling's yellow metal, gun metal, or common brass, at pleasure; and that we may be able to produce compounds that are constant and unvarying: so that, for example, we could deposit silver or gold of the standard quality, all which, notwithstanding the many statements that have been made in print, have yet to be discovered.

We have thus given a brief review of the practical operations of Electro-Metallurgy for the guidance of the student, who as he proceeds, will find that the difficulties which at first beset his path will gradually disappear: easier modifications of processes will suggest themselves, as all operators cannot with equal facility follow the same directions. New facts will reveal themselves to his inquiries; a wide field of interesting and profitable research will open up before his mind; and the steady and persevering experimenter and observer will not fail to reap an abundant harvest of honor and gratification, in being an instrument in promoting the knowledge of the working of the laws of Nature.

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* Progress of General Science, vol. ii.

CHAPTER XXXIII.

THEORETICAL OBSERVATIONS.

We have described at considerable length the practical details connected with the art of electro-metallurgy, without pausing to inquire into the philosophy of the action of the electric currents by which the effects are produced. It will be unnecessary to enter into a long discussion of the numerous theories that have been advanced from time to time to explain the action that takes place in a battery or decomposing cell, while the current is passing through the solution—a brief reference to the more commonly received opinions being sufficient for the present purpose.

Action of Sulphate of Copper on Iron.—In order to convey our ideas accurately, let us suppose that the solution undergoing decomposition is sulphate of copper. This salt is composed of sulphuric acid and copper, which may be represented as SO^4+Cu: these are held together according to the law of chemical affinity; but if iron is put into the solution, the combination of the acid and copper will be dissolved by the attraction of the acid to the iron, for which it has a stronger affinity than for the copper. Hence iron, put into sulphate of copper, decomposes it thus:

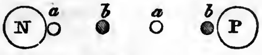
$$Cu, SO^4 + Fe = Fe, SO^4 + Cu.$$

Were we to put a piece of copper into a solution of sulphate of copper, there would be no action, the forces being equal; but if by any means we were to communicate to this piece of copper a higher attractive force for the SO^4 than that of the copper which is already in union with it, we should cause the acid to leave the copper it was originally combined with, and to combine with the new piece of copper. Bearing these general principles in view, we shall proceed to state the different opinions of authors on this subject.

Faraday's Theory of Electrolysis.—Professor Faraday says—"Passing to the consideration of electro-chemical decomposition, it appears to me that the effect is produced by an *internal corpuscular* action, excited according to the direction of the electric current, and that it is due to a force either *superadded to*, or *giving direction to*, the *ordinary* chemical affinity of the bodies present. The body under decomposition (say sulphate of copper), may be considered as a mass of acting particles, all those which are included in the course of the electric current contributing to the final effect; and it is because the ordinary chemical affinity is relieved, weakened, or partly neutralized by the influence of the electric current in one direction parallel to the course of the latter, and strengthened or added to in the opposite direction, that the combining particles have a tendency to pass in opposite courses.

"In this view the effect is considered as *essentially dependent* upon the *mutual chemical affinity* of the particles of opposite kinds. Particles *aa* could not be transferred or travel from one pole N, towards the other pole P, unless they found particles of the opposite kind, *bb*, ready to pass in the contrary direction; for it is by virtue of their increased affinity for those particles, combined with their diminished affinity for such as are behind them in their course, that they are urged forward.

Fig. 589.

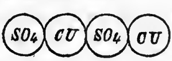


"I conceive the effects to arise from forces which are *internal*, relative to the matter under decomposition, and not *external*, as they might be considered, if directly dependent upon the poles. I suppose that the effects are due to a modification by the electric current of the chemical affinity of the particles, through or by which that current is passing, giving them the power of acting more forcibly in one direction than in another, and consequently making them travel by a series of successive decompositions, in opposite directions, and finally causing their expulsion or exclusion at the boundaries of the body under decomposition, in the direction of the current, *and that* in larger or smaller quantities, according as the current is more or less powerful."*

In the above figure, the particles *aa* may be termed copper Cu, and the particles *bb*, sulphuric acid SO^4, which will enable us to follow the comparison of the different views.

Graham's Theory of Electrolysis.—Professor Graham supposes that the compound particles, such as sulphate of copper, possess polarity, so that the particles in the battery or decomposition cell will stand in relation to each other in a polar chain, as in Fig. 590.

Fig. 590.



He then represents electrotyping by the porous cell system, as follows:

"The liquids on either side of the porous division may also be different, provided they have both a polar molecule. Thus, in Fig. 591 the polar chain is composed of molecules of hydrochloric acid, extending from the zinc to the porous division at *a*, and of molecules of chloride of copper from *a*, to the copper plate. When the Cl of molecule 1 unites with zinc, the H of that molecule unites with the Cl of molecule 2 (as indicated by the connecting bracket below); the H of molecule 2 with the Cl of molecule 3; the Cu of molecule 3 with the Cl of molecule 4; and the Cu of this molecule being the last in the chain, is deposited upon the copper plate. Dilute sulphuric acid in contact with an amalgamated zinc plate, and the same acid fluid saturated with sulphate of copper in contact with the copper plate, are a combination of fluids of most frequent application."† According to this theory

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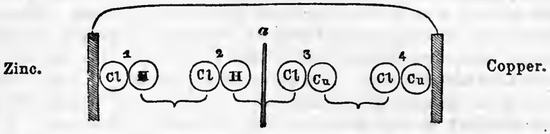
* Faraday's Experimental Researches, vol. i. paragraphs 518, 519, 524.

† Graham's Elements of Chemistry, 2d edition, 1859.

all the particles between the zinc and copper during the action of the batteries will be performing a whirling motion; for, when the Cl of molecule 1 is liberated, the H of 1 will combine the Cl of 2, which compound molecule must whirl round to be in its proper polar position, which will necessitate that interchange distinctly referred to by Professor Faraday—a mutual transfer of the elements; the Cl will pass towards the zinc plate, and the H and Cu towards the copper plate.

Fig. 591.



DANIELL'S AND MILLER'S VIEWS.—Theories varying little from these were held by the late Professor Daniell, till, by a series of interesting experiments, in company with Professor Miller, he found that there is no mutual transfer of the elements; that the negative element, or that represented above as Cl or SO^4, is transferred from the copper to the zinc, or in a decomposition cell from the negative electrode to the positive electrode: but the positive element—that represented by H or Cu—is not transferred; therefore, the theories of Professors Faraday and Graham are opposed to a fundamental truth experimentally proved. Professors Daniell and Miller conclude their paper, read before the Royal Society, by the following observations:

"These facts are, we believe, irreconcilable with any of the molecular hypotheses which have been hitherto imagined to account for the phenomena of electrolysis, nor have we any more satisfactory at present to substitute for them; we shall therefore prefer leaving them to the elucidation of further investigations to adding one more to the already too numerous list of hasty generalizations."*

In this paper, the authors state that they found certain positive elements transferred in small proportions; thus, potassium from sulphate of potash in $\frac{1}{3}$ of an equivalent; barium, from nitrate of barytes, $\frac{1}{6}$ equivalent; and magnesia, from sulphate of magnesia, $\frac{1}{12}$ equivalent. This was a difficulty for forming any theory, but we have shown that this difficulty does not exist.

In all cases where two liquids are separated by a porous diaphragm, there is a mutual transfer of the liquids in distinct ratios, according to time, either by what is called endosmosis, or by a diffusion; and the rate of transfer is materially affected by a galvanic current passing through them. From observations and operations made on a large scale, and from experiments on various kinds of

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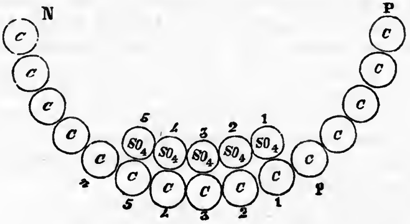
* Philosophical Transactions, Part I. for 1844.

solutions, we believe that the fractional transfers of Professors Daniell and Miller are the results of endosmosis or diffusion, and not of electrolytic transfer. According to recent experiments by Professor Graham, diffusion takes place in definite proportions. We believe that no transfer of any base or positive element takes place by electrolysis.

Proposed Theory.—Having carefully considered the various phenomena attending electrolysis, in the decomposition of metallic salts, we think that the electricity is conducted through the solution by the base, or positive element, in the electrolyte, which it does as if it was a solid chain of particles—or wire. We have already said, that if to a solution of sulphate of copper we put a piece of iron, the acid in union with the copper will leave it and combine with the iron. If a piece of copper be put into the same solution, no change will take place; but if we by any means give to this copper an increased tendency to unite with the acid, it will attract the acid from the copper in solution by virtue of this increased attraction. Suppose two wires coming from a battery are placed in a solution of sulphate of copper, thus, (Fig. 592): the double row representing the compound atoms of sulphate of copper forming the electrolyte: C C the copper or positive element, and SO^4 the sulphuric acid or negative element of the solution. The two single rows C C, etc., at each end of the double row, represent the wire or solid conductors of the electricity, from the battery to the decomposition cell: the last particle of the single rows *p n* nearest the double row may be viewed as the electrodes. The sulphuric acid SO^4, and the copper C, in solution, are held together by their affinity for each other.

Fig. 592.



Now let it be supposed that an equivalent of electricity leaves the positive terminal of the battery P, and passes along the solid particles of the conductor, that particle upon which the electricity is, must be for the time in a higher state of excitement than the other particles. When the electric current comes to the last particle of the solid chain *p*, which is in contact with the electrolyte, its increased excitement causes it to attract and combine with the acid particle SO^4 nearest it; the electricity being dynamic, passes to the first basic particle C1, giving it an exalted excitement, which causes it to unite with the acid particle $SO^4$2, the electric force passing to C2, which becomes excited in turn, and takes the particles $SO^4$3; and so on through the chain till the last particle C5, which, having no further acid to combine with, gives its electricity to the solid conductor, or electrode *n*, and passes along to the battery, the particle C5 being thus left adhering to the solid chain of particles, or electrode.

By this we observe that every equivalent of decomposition will carry an equivalent of acid to the positive electrode, without taking the metallic element to the other or opposite electrode. This is exactly the fact of the case, the result that takes place in all solutions undergoing decomposition by the current, and also in the battery between the zinc and copper. In these explanations we have spoken of electricity as a material substance, passing along the line, being more easily conceived than the theory of vibrations, etc.; but the effects are the same, and we have seen no phenomena in electric decomposition which are inconsistent with the views here given.

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