reached, when it suddenly drops again, indicating the maximum stress the bar will bear. To keep the beam floating, the travelling weight must be now rapidly run back to reduce the load until the rupture of the bar finally takes place, at a few tons less than the maximum stress, and this reading gives the "breaking load" in *the reduced sectional area.* Between the elastic limit and the maximum stress the bar stretches very rapidly; and when the maximum load is about reached, local reduction of area becomes very marked, and the sample of a ductile material rapidly "necks" down at the weakest point before final rupture takes place, as shown at A (fig. 11). If it is desired to determine the true elastic limit as distinct from the yield point, a pair of very fine dividers must be held in the two little distance marks on the test bar, and at the faintest sign of any stretching the load must be released to see if the bar returns to its original length. If no permanent stretch has taken place, slight increments of load are put on and taken off until a slight permanent set has taken place, which may be taken as marking the elastic limit. With careful work, fairly accurate results can be obtained by this method; but if scientific accuracy is required, a special instrument known as an extensometer must be used, which, in the form designed by Ewing, is capable of measuring an extension of $\frac{1}{250000}$ of an inch in a bar.

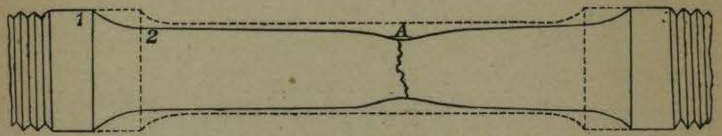

FIG. 11.—Sample of Steel before and after fracture.

The bar having been broken, is removed from the machine, the reduced area in both halves at the point of fracture is carefully measured with the screw micrometer, and the reduction in area calculated from these measurements and expressed in percentages of contraction of the original area.

The elongation is determined by placing the two pieces of the broken bar carefully together and pressing the fractured ends close, and then measuring the length between the two distance marks. From the increase in length, in the original distance marked off, the percentage elongation on this given length is obtained. It is of great importance, in giving the percentage of elongation, to state the original length on which it is calculated; as, owing to the large local elongation which frequently takes place at the point of fracture, this, if distributed over 6 or 8 inches, would give a very different percentage result to what it would do if the length were only 2 or 3 inches.

For the determination of hardness by Brinell's method, the most convenient arrangement is shown in fig. 12 whenever a compression testing machine is available. In this A and A′ are compression blocks, there being placed on the lower one a small block, D, made of steel, with a cavity in the centre of the upper surface where the ball is to rest. The test specimen, B, is placed between the upper block, A, and the ball, C, and then the pressure is applied in the usual way until the required amount of loading is reached.

Fig. 13 shows a special Brinell machine designed for applying the pressure; it consists of four springs within a drum, with a screw-wheel arrangement, by means of which the loading operation is performed. The maximum pressure can then be read off on an indicator scale, empirically graduated, which is combined with the spring system.

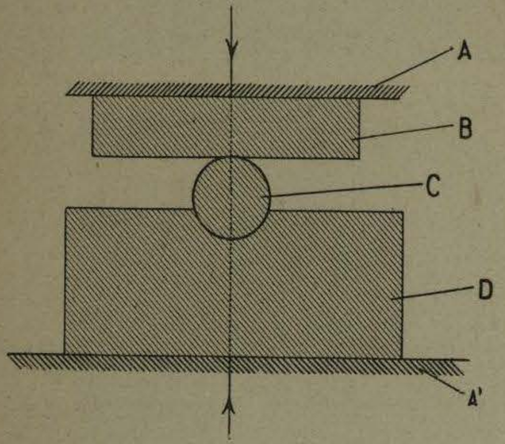

FIG. 12.—Brinell's method of Testing.

A A′, compression blocks. C, hardened steel ball.
B, test piece. D, steel block.

Impact Tests.—During recent years very many methods have been devised by engineers for testing metals by impact, with a view of showing up weaknesses under sudden shocks or alternating stresses, which are not clearly indicated by the ordinary tensile tests.

The methods at present more or less used by engineers and metallurgists may be divided broadly into the following classes, according to the number and position of the notches and supports and method of applying the load.

(1) One notch in the centre of the bar: two supports: fracture effected by a series of blows of a falling weight. (*Seaton* and *Jude.*)

(2) One notch in the centre of the bar: two supports: fracture effected by one blow of a falling weight. (*Fremont.*)

(3) One notch, not necessarily in the centre: one support:

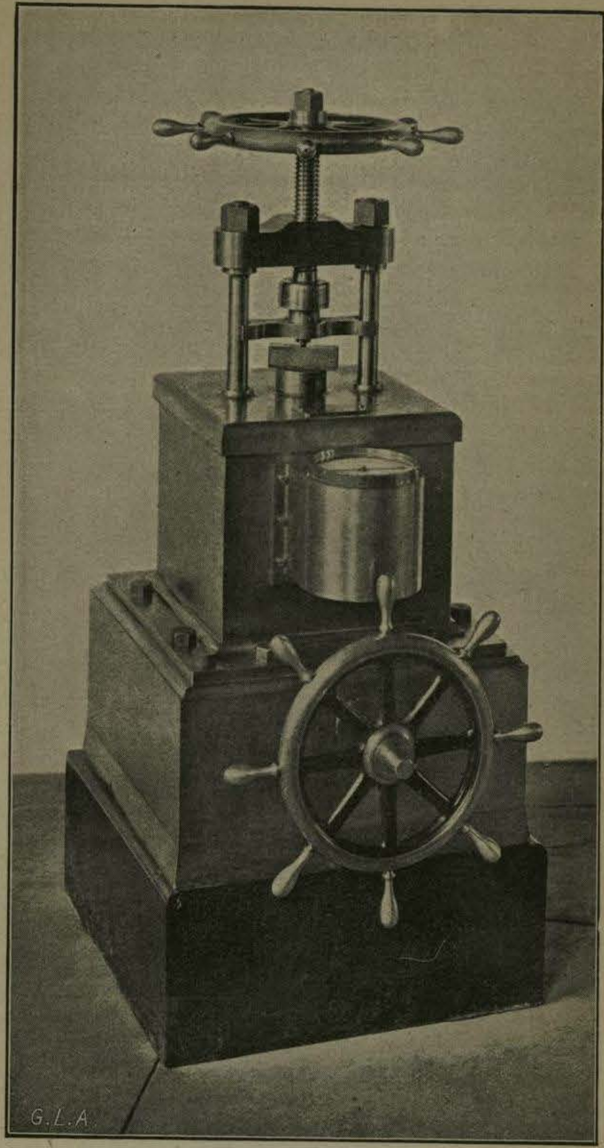

FIG. 13.

fracture effected by one blow on overhung portion from a falling pendulum or weight. (*Izod.*)

(4) Two opposite notches, not necessarily in the centre: one support: fracture effected by a series of blows of a falling weight on overhung portion. (*Brinell.*)

(5) Same as (4), but with an arrangement for reversing the bar after every blow. (*Kirkaldy.*)

The following is a description of the method of applying the test in the case of methods (1), (3), and (5):—

In the Seaton and Jude method a bar is taken, 4 in. long and ½ in. square in section, and a V notch ⅛ in. deep is cut in the centre of one side. The bar is supported on a bearing at each end, the notch being downwards, and is broken by a series of blows from a falling weight striking it on the centre. The weight and height of drop can be varied according to the metal under test. The energy absorbed in breaking the samples is calculated into foot-pounds. In the case of ductile steels requiring a number of blows, say seventy or more, the actual energy absorbed can be obtained to within one blow, that is, one-seventieth or so of the total energy, but in the case of brittle steels requiring only one to three blows, the error is still one blow, equal at least to one-third of the total, or even if one-half the last blow be taken as the breaking weight, the error would still be one-sixth of the total.

In the Izod method, a sample of the same shape and dimensions as used in the Seaton and Jude method with a V notch is used; this is supported at one end in a clip or vice and held vertically. Fracture is effected by one blow of a pendulum striking the overhung portion, and the residual energy in the pendulum is measured by the arc through which it swings after fracturing the sample. In this method an exact measure of the energy expended in fracturing the sample, within a very slight error, is obtained.

In the Kirkaldy method, the test piece is of the same dimensions as that used by Seaton and Jude, but instead of the V notch, it has two opposite circular grooves, each ⅛ in. deep at the centre of the bar. The test bar is supported in a suitable block or vice at one end and fractured by a series of blows from a falling weight on the overhung portion, but after every blow the entire block is turned over by a cam attachment, so that blows are delivered alternately on each side of the test bar. In this method, as in the Seaton and Jude, the force required to fracture the bar is calculated into foot pounds, and the degree of accuracy largely depends upon the number of blows which are required to produce fracture; owing, however, to the reversal after each blow, the number of blows required to produce fracture, even in very brittle steels, is comparatively large, and consequently the error is not very considerable, and in moderately ductile steels is inappreciable.

Various types of impact testing machines have been designed by Stanton and Bairstow[1] of the National Physical Laboratory, and described in a paper before the Institution of Mechanical Engineers, and have proved useful in the detection of brittleness and low elastic resistance in materials.

Harbord[2] has recently examined various methods of impact testing on notched bars of different classes of steels, and, in view of the irregularities disclosed with duplicate specimens of the same material, it is a serious question how far these tests, showing such variations, should be relied upon by engineers to differentiate between the physical properties of different materials.

Colour.—The colour of metals is influenced by their purity, and it is often possible to detect the presence of small quantities of impurity by the slight variation of colour produced. When light is reflected several times between two more or less parallel plates of the same polished metal, intense colours are produced,[3] copper and gold appearing purple; silver, golden yellow; while steel and zinc appear blue. It is well known that gold viewed by reflected light appears green; and Prof. Turner[4] has recently shown some interesting experiments illustrating the fact that when heated to 550° the green colour disappears and white light is transmitted. He has also shown that silver leaf when heated in air or oxygen to 400° becomes remarkably transparent, transmitting white light. Copper leaf remains opaque if heated in a reducing atmosphere to 500°, but when heated in air for about an hour to 250°, or for a much shorter time at higher temperatures, it becomes transparent and transmits a brilliant green light.

The lustre of metals is due to their great power of reflecting light. It varies with the nature of the metal and the degree of polish.

Fusibility.—All metals are fusible. On account of the difficulty experienced in determining high temperatures, until comparatively recently, it was only possible to ascertain the melting-points of the metals that fuse at temperatures below 1000° with any degree of accuracy; but owing to the great development which has taken place in scientific pyrometry during the last few years, temperatures over 1500° can now be determined with fair accuracy.

The melting-points of the more important metals are given in the table on p. 67.

When strongly heated, metals pass from a brownish-red to a clear red colour, which gradually increases in luminosity and transparency to a dazzling white. The temperatures corresponding to the different colours have been estimated by Howe to be—

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[1] *Inst. Mech. Eng.*, Nov. 1908.

[2] *Inst. Mech. Eng.*, paper read Nov. 20, 1908.

[3] Jamin's *Cours de Physique*, 1866, iii. p. 693.

[4] *Nature*, vol. lxxviii. p. 60, May 21, 1908.

Dull red	550°–625°
Full cherry	700°
Light red	850°
Full yellow	950°–1000°
Light yellow	1050°
Very light yellow	1100°
White	1150°

On solidifying from a molten state, metals frequently exhibit excrescences due to the expulsion of absorbed gases. This expulsion often occurs shortly before the solidification, and causes a sudden outburst of metal through the surface. In this way silver, when molten, absorbs oxygen, and expels it on solidification. In the case of steel, the evolution of gas continues long after the metal has solidified on the surface.

When a metal passes from the liquid to the solid state, it either does so suddenly, or it passes through an intermediate pasty stage. This fact is occasionally of great metallurgical importance. Thus, white pig-iron is more suitable for dry puddling than is grey pig-iron, as the former becomes very pasty, whilst the latter does not.

On solidification after melting, metals always crystallise. Crystallisation also occurs when metals are condensed from a state of vapour, or are deposited by the electrolytic decomposition of metallic solutions. Metals most frequently crystallise in the cubic system. This is the case with platinum, gold, silver, copper, lead, and iron, and probably with tin and zinc. Tin also crystallises in the tetragonal system, and the iron-manganese carbide *spiegeleisen* crystallises in the rhombic system. Antimony, arsenic, and zinc crystallise in the hexagonal system, whilst bismuth crystallises in rhombohedra resembling cubes. Tin and zinc are thus dimorphous—that is, they may be developed according to two systems of crystallisation. The crystallisation of metals is of great importance, as the formation of crystals, due to continued vibration, intense cold, sudden alterations of temperature, or the presence of impurities, may render a metal absolutely useless for certain purposes. Crystallisation may serve to indicate impurities, as in the case of a film of antimony produced in lead refined by steam; or to separate metals, as in the case of Pattinson's process of desilverising lead.

Welding is the property possessed by some metals of adhering when subjected to an external force, such as hammering. These metals, on cooling from the molten state, pass through a plastic stage before becoming perfectly solid. This property is exhibited in a marked degree by iron and platinum at a white heat. Welding may also be effected, though to a less degree, when two clean surfaces of metal are brought into intimate contact in the cold.

Acoustic properties.—The sound emitted by metals when struck is greatly affected by the presence of impurities. Thus, in the case of lead, the presence of antimony tends to heighten the sound emitted. Owing, it is supposed, to the sliding of the crystal faces over one another, tin at ordinary temperatures, and zinc after heating to 160°, emit a sound or "cry" when bent.

Properties common to Fluids and Solid Metals.—Réaumur, so long ago as 1713, defined with singular clearness the conditions under which metals prove to be ductile. The relation between the behaviour of solid metals and fluids has long been recognised, not in the sense that atomic motion is common to solids and fluids, but from a wider view, for there is much experimental evidence as to the properties that are common to fluids and solid metals, the characteristics of which, at first sight, seem widely separated. A solid has a definite external form, which either does not change, or only changes with extreme slowness when left to itself, and in order to change this form rapidly it is necessary to submit it to a considerable stress. A liquid, on the other hand, can be said to have no form of its own, as it always assumes that of the containing vessel; the mobility of its particles is extreme, its resistance to penetration is very small, and its free surface is always a plane when the mass is left at rest. Then there is the colloid condition, which intervenes between the liquid and crystalline solid state, extending into both, and probably affecting all kinds of solid and liquid matter in a greater or less degree. The colloid or jelly-like body does present a certain amount of resistance to change of shape. Such a substance is well imitated by a sphere of thin india-rubber partly filled with water. Lastly, there is the gaseous condition of matter.

Metals are usually regarded as typical solids; it is easy, however, to trace the analogies of their behaviour under certain conditions with that of fluids. The transition from the liquid to the solid state is marked by the same phenomena in the case of many metals as are observed in certain fluids. For instance, metals on solidifying reject impurities, and exhibit the property of surfusion. This leads up to the relations between solid metals and fluids, and the following list shows the classes in which the properties common to fluids and solid metals may be grouped:—

1. Flow under pressure.
2. Changes due to compression.
3. Absorption of liquids.
4. Surface tension.
5. Absorption of gases.
6. Diffusion.
7. Vaporisation.

Water, on passing from the liquid to the solid state, undergoes a partial purification, the ice first formed being sensibly more free from colouring matter or suspended particles than the water from which it separates.

Many metals, on freezing, similarly eject impurities. In the case of alloys, saturated solutions of one metal in another appear to be formed, and excess of metal ejected, a fact which was studied with much care by Dr Guthrie. The prominent facts are perhaps best illustrated by reference to a solidified mixture of copper, antimony, and lead. The results of some experiments conducted, in the laboratory of the Royal School of Mines, by Dr E. J. Ball[1] show that when a molten mixture of these metals is solidified, a definite atomic alloy of copper and antimony, which possesses a beautiful violet tint, first forms, and, after saturating itself with lead up to a certain point, ejects the rest of the lead, driving it to the centre of the mass so as to form a sharp line of demarcation between the outer violet circle and the grey centre. It thus presents a direct analogy to the comparatively colourless ice which first forms from coloured water. There is yet another remarkable analogy between the freezing of certain fluids and the solidification of some metals. Water may, as is well known, be cooled down to − 8° C. without solidification, but agitation immediately determines the formation of ice, and, at the same time, a thermometer plunged in the water rises to zero. Faraday stated,[2] in 1858, that fused acetic acid, sulphur, phosphorus, many metals, and many solutions would exhibit the same effect. Tin also may be cooled to several degrees below its solidifying point without actually freezing; and Dr Van Riemsdijk[3] of Utrecht has observed that a globule of gold or silver in a fused state will pass below its solidifying point without actually solidifying, but the slightest touch with a metallic point will cause the metal to solidify, and the consequent release of its latent heat of fusion is sufficient to raise the globule to the melting-point again, as is indicated by a brilliant glow which the button emits.

The result of Raoult's investigations on the lowering of the freezing-point of solutions led him to the conclusion that one molecular proportion of any substance dissolved in 100 molecular proportions of any solvent whatever lowers the freezing-point of that solvent 0·62° C. This had not been tested in the case of solutions of metals in metals until Heycock and Neville[4] began an elaborate investigation of the subject. Their research dealt first with the lowering of the freezing-points of various metals by the addition to them of certain other metals, and, second, with the molecular weights of metals when in solution. The results of their experiments when compared with the empirical laws of Coppet and Raoult may be briefly stated as follows:—

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[1] *Journ. Chem. Soc.*, vol. liii. (1888), p. 167.

[2] *Experimental Researches in Chemistry and Physics*, p. 379.

[3] *Ann. de Chim. et de Phys.*, t. xx. (1880), p. 66.

[4] *Journ. Chem. Soc.*, vol. lv. (1889), p. 666; vol. lvii. (1890), pp. 376 and 656.

They are in accordance with the law "that for moderate concentration the fall in the freezing-point is proportional to the weight of the dissolved substance present in a constant weight of solvent." By making the assumption that the molecule of zinc or of mercury is monatomic when in solution in tin, they confirm the second law, "That when the falls produced in the same solvent by different dissolved substances are compared, it is found that a molecular weight of a dissolved substance produces the same fall whatever the substance is." But the third law, which states "That if a constant number of molecular weights of the solvent be taken, then the fall is independent of the nature of the solvent," they found to be probably incorrect, and theoretical considerations indeed would lead us to expect this.

In a research of much interest, Ramsay[1] has determined the molecular weight of a number of metals by Raoult's vapour pressure method—that is, he ascertained the depression of the vapour pressure of the solvent produced by a known weight of dissolved substance, and he finds that although sodium behaves irregularly, yet "it would appear legitimate to infer that in solution, as a rule, the atom of a metal is identical with its molecule, as the physical properties of those metals which have been vaporised would lead us to suppose."

Now to pass to solid metals. It is the common experience that a counterfeit shilling, consisting principally of lead, does not "ring" when thrown on a wooden surface. In 1726 Louis Lemery observed that lead is, under certain conditions, almost as sonorous as bell-metal.[2] He communicated the fact to Réaumur, who, being much struck by it, investigated the conditions under which lead becomes sonorous, and submitted the results to the French Academy.[3] He pointed out that, in describing a body which is not sonorous, it is usual to say that it is as "dull as lead," an expression which has become proverbial. Nevertheless, he adds, under certain conditions, lead has a property both novel and remarkable, for it emits surprisingly sharp notes when struck with another piece of lead. He showed that it was necessary that the lead should be formed by casting into a segment of a sphere—that is, mushroom-shaped. The lead must be free from prominences, and must be neatly trimmed. The effect is less marked if the lead be very pure than if ordinary commercial lead be used, but it is only a question of degree. Réaumur showed that the sonorous lead might be rendered dull by hammering it. His remarks have been overlooked in late years. He was led to the belief that in cast lead there must be an arrangement of the

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[1] *Journ. Chem. Soc.*, vol. lv. (1889), p. 521. See also Tammann, *Zeit. für physikal. Chemie*, 1889, p. 441.

[2] Hoefer, *Histoire de la Chimie*, ii. p. 383.

[3] *Histoire de l'Académie Royale des Sciences*, *Année* 1726 [vol. for 1728, p. 243].

interior of the mass which the hammer cannot impart, because lead fashioned by hammering into the same form as the sonorous cast mass is dull, and, more important still, he held that the fibrous and granular structure of the lead is modified in a manner which makes it probable that the sound is due to the shape of the grains and to the "way in which they touch each other"; further, the blows of the hammer not only change the arrangement of the fibres, but they alter the shape of the grains; "the round grains are rendered flat, they are compelled to elongate and fill the interstitial spaces which previously existed between them. The particles are no longer free to vibrate; hence the lead is dull." These facts acquire additional interest if they are compared with the observations in Prof. Osborne Reynolds' paper on "Dilatancy in Granular Matter." Réaumur's description shows that he fully appreciated the theoretical importance of the kind of facts depending on the transfer of metallic matter from one position to another, which we now consider to be characteristic of the "flow" of metals; at any rate, Lemery's experiment may be made the starting-point of the remarks which follow.

A solid may be very brittle, and may yet, if time be given to it, flow from one point to another. A stick of sealing-wax, or even of glass, supported at its ends, in a few weeks bends at the ordinary atmospheric temperature, although at any given point of its flow it would have been easy to snap it with a slight application of force. A tuning-fork may be made from pitch, which will nevertheless subside into a shapeless mass at the ordinary temperature. A much thinner strip of pure lead of the same breadth as the sealing-wax also bends at the ordinary temperature with its own weight, the ends being supported. Lord Kelvin has, however, pointed out that a gold wire, sustaining half the weight which would actually break it, would probably not rupture in a thousand or even a million years—that is to say, there would be no "flow" ending in disruption; if, however, force be suitably applied, metals will flow readily. First, examine the case of a metal under force applied so as to compel it to flow through a hole, as it points to the analogy of an ordinary viscous fluid. If a vessel (1, fig. 14) provided with a cylindrical hole in its base be filled with lead, the lead will, at the ordinary pressure, remain there, but if extra pressure be applied the lead will prove by its behaviour that it is really a viscous solid, as it flows readily through the orifice; the end of the jet is rounded, and, as has been shown by the beautiful researches of the late M. Tresca of Paris,[1] all the molecules which compose the original block place

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[1] These researches extend through a long series of memoirs; those relating to the flow of metals are well summarised in the *Proc. Inst. Mech. Engineers*, 1867, p. 114, and in the Report of the Science Conferences held in connection with the Loan Collection of Scientific Apparatus (Physics and Mechanics), London, 1876, p. 252.

themselves in the jet absolutely as the molecules of a flowing jet of a viscous fluid would. If the metal has a constant "head," as it would be termed in the case of water—that is, if the vessel be kept filled with solid lead up to a certain level—then there will be a continuous stream, the length depending on the constancy with which the "head" and the pressure are maintained. If, on the other hand, the "head" is diminished so that nearly all the solid lead has been allowed to flow away (2, fig. 14), there is a folding of the jet, and vertical corrugations, exactly such as would characterise the end of the flow of certain other viscous fluids, and finally the jet forms a distinct funnel-shaped tube concentric with the jet. It is also seen that, when the formation of these cavities takes place, the jet is no longer equal to the full diameter of the orifice, as shown in 2, fig. 14, the formation of the contracted vein is manifest, and the new analogy is thus obtained between the flow of solids and of liquids.

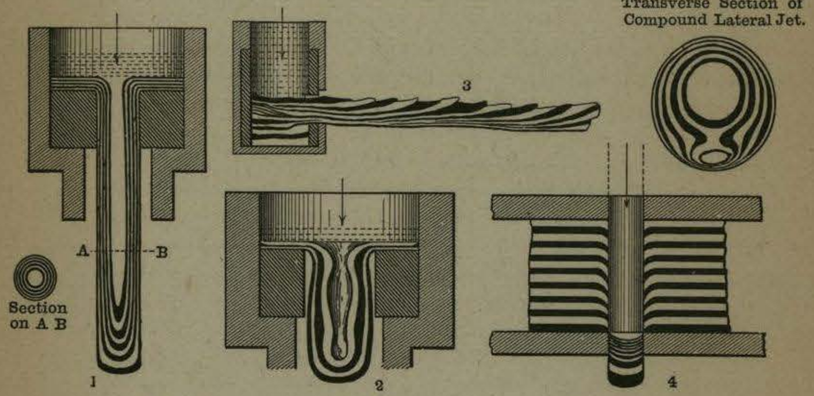

Fig. 14.

In punching a disc from a solid plate of metal supported by a die plate (4, fig. 14), as in the operation of coining, the portion cut out proves to be thinner than the plate from which it has been removed. Since the density of a metal is not increased by pressure except by the obliteration of pores, as has already been stated, it follows that the metal must have flowed in a plastic state laterally from the disc into the plate, the remaining metal becoming so thin that its resistance to shearing is less than the pressure on the punch.

In 3, fig. 14, the effect is shown of a compound jet of lead flowing through a lateral orifice in a cylindrical vessel.

In the case of planing surfaces of metals by cutting tools, similar effects may be traced, and it is interesting to compare the flow of metal in 4, fig. 14, which represents the penetration of a cutting tool through a plate of metal, with the flow of metal under the action of a tool used for planing (fig. 15). In this case the lines of flow are made evident by the deformation of lines traced vertically on the side of the block of metal submitted to the tool. The shifting of the material and the connection of the lines, F, in the shaving, with those, E, of the original block, will be evident from the diagram. Every artificer knows how complicated in form the shavings may be, and varied problems relating to their production have been studied by M. Tresca.[1]

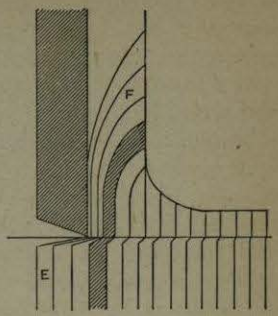

Fig. 15.

The application of this fact, that solid metals flow like viscous fluids, is of great importance in industry, and the production of complicated forms by forging or by rolling iron and steel and other metals entirely depends on the flow of the metal when suitably guided by the artificer. The lines of flow in iron may be well shown by polishing a surface of the metal, and by submitting it to the action of a solution of mercuric chloride, which etches the surface, or better, to the slow action of chromic acid solution, the result in either case being, that any difference in the hardness of the metal, or in the chemical composition, or want of continuity, caused by the presence of traces of entangled slag, reveals the manner in which the metal has flowed. The sketches illustrate the direction of flow in the following cases. Fig. 16 is a

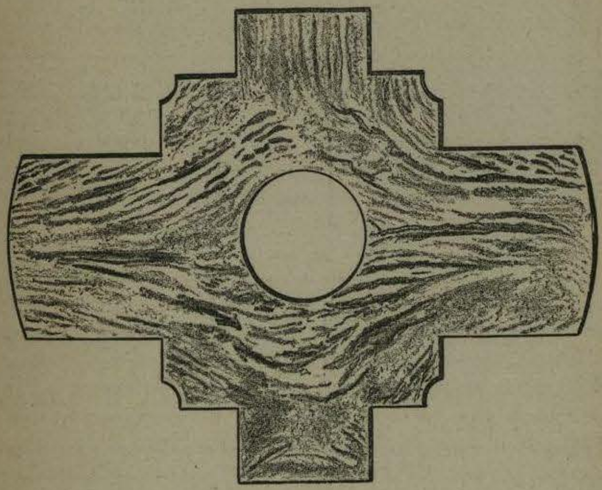

Fig. 16.

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[1] *Mémoires de l'Académie des Sciences*, vol. xxvii., No. 1, 1880.

section of a forged cross-head, and figs. 17 and 18 are sections of rails.

The experiments of M. Tresca were not made on "steel"; it is therefore interesting to compare the etched section of the old rail, fig. 17, the result of the complicated welding of puddled iron, with a basic-Bessemer rail, rolled from steel which has been cast, and which is therefore free from entangled slag. Fig. 18 represents a section of such a rail.

A very striking illustration of the importance of the flow of metals, when used in construction, is afforded by some observations of Sir B. Baker in a paper on the Forth Bridge.[1] He says: "If the thing were practicable, what I should choose as the material for the compression members of a bridge would be 34- to 37-ton steel, which had previously been squeezed endwise, in the direction of the stress, to a pressure of about 45 tons per square inch, the steel plates being held in suitable frames to prevent distortion." He adds: "My experiments have proved that 37-ton steel so treated will carry as a column as much load as 70-ton steel in the state in which it leaves the rolls—that is to say, not previously pressed endwise. . . . At least one-half of the 42,000 tons of steel in the Forth Bridge is in compression, and the same proportion holds good in most bridges, so the importance of gaining an increased resistance of 60 per cent. without any sacrifice in the facility of working, and safety, belonging to a highly ductile material can hardly be exaggerated."

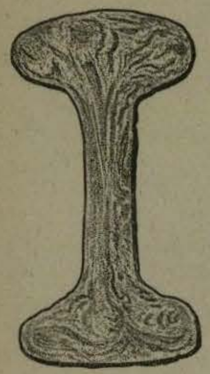
FIG. 17.

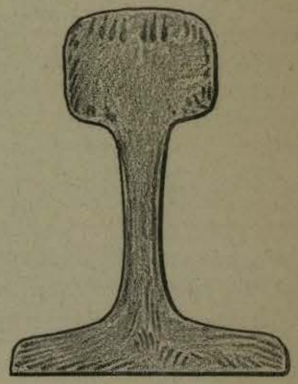
FIG. 18.

The very ancient mechanical art of striking coin is wholly dependent on the flow of metals. There is a popular belief that the impression imparted to discs of metal during coinage is merely the result of a permanent compression of the metal of which the disc is made. Striking a coin, however, presents a case of moulding a plastic metal, and of the true flow of metal, under pressure, into the sunken portions of the die. A medal struck from a series of discs will serve to show, when the discs are separated, the way the metal flows into the deepest portion of the die. If the alloy used be too hard, or if the thickness of the metal required to flow be insufficient, the impression will always be defective, no matter how many blows may be given by the press.

If one side of the coin be ground away, so as to leave a flat surface, and if the disc be then struck between plain polished dies surrounded by a steel collar, so as to prevent the escape of the metal, the impression on the disc will be driven through the thickness of the metal, and will then appear on both sides. In industrial art the property of flow of metals is very important. The "spinning" of articles in pewter is a familiar instance.

The production of complicated forms, like a jelly mould, from a single sheet of copper, under the combined drawing and compressing action of the hammer, is a still more remarkable case.

The flow of metals is illustrated very curiously in one phase of Japanese art metal-work, to which reference will be made subsequently.

The flow of metals when submitted to compression has hitherto been alone considered, but the effect of traction has also been examined, for when a viscous metal such as iron or soft steel is submitted to stress by pulling its ends in opposite directions, it stretches uniformly throughout its length, and the metal truly flows when the yield point is reached. The limit of elasticity of a solid body marks the moment at which the body begins to permanently stretch, under the influence of the longitudinal stress to which it is submitted. There are many materials which do not stretch sensibly when their limit of elasticity is reached; in very hard steel, for instance, the breaking-point and the limit of elasticity practically coincide. Further, it must be observed that every minute variation in composition is sufficient to change the property of a body, and to cause what was a viscous body to break close to the limit of elasticity.

The particles of a metallic powder left to itself at the ordinary atmospheric pressure will not unite; by "augmenting the number of points of contact in a powder" the result may be very different. The powders of metals may weld into blocks, as will subsequently be described, and it will be seen that experiments on the compression of finely divided metals afford important evidence as to the relation between solid metals and fluids. Faraday discovered, in 1850, that two fragments of ice pressed against each other will unite, their tendency to union being considerable when the fragments are near their melting-point. Ice owes its movement in glaciers, not to viscosity, but to regelation, and the union of fragments of ice under compression is also due to regelation. The facts which have been appealed to, and the theories which have been formed,

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[1] *Journ. Iron and Steel Inst.*, 1885, p. 497.

respecting the regelation of ice, are well known; it may, however, be observed that bismuth, like ice, expands on solidifying; and though Faraday failed to establish the existence of a property similar to regelation in bismuth, Wrightson has satisfied himself, by experimental evidence, that regelation exists in bismuth. In explaining Spring's results (p. 74) there is this difficulty: the union of the particles of the metals cannot, in all cases, be due to viscosity, because viscous bodies are always capable of being stretched, and we find the welding taking place between the compressed powders of bodies, such as zinc and bismuth, which, when submitted to traction, will not stretch. Spring therefore asks, "Is it possible that regelation may have something to do with the union of the powders?" and he urges, "Is it safe to conclude that regelation is peculiar to ice alone?" "It is difficult to believe," he adds, "that in the large number of substances which Nature presents to us, but one exists possessing a property of which we can find only minute traces in other bodies. The sum of our chemical and physical knowledge is against such a belief, and therefore the phenomenon of regelation may be pronounced in ice without being absolutely wanting in other bodies. To ascertain whether this is so, it is necessary to submit other bodies to the conditions under which the phenomenon can be produced." "What," he asks, "are these conditions?" and he answers, "The pressure supported by the body, a certain degree of temperature, and time."

Both Helmholtz and Tyndall have shown that when the pressure is weak the regelation of ice is effected slowly. Spring points out that nitrate of sodium and phosphate of sodium, in powder, left to themselves in bottles, become coherent; and if the coherence in these and other chemical compounds is but weak, it is simply because the points of contact between the particles of powder are but few. If, on the other hand, metallic or other powder be submitted to strong compression, the spaces between the fragments become filled with the débris of the crushed particles, and a solid block is the result. Finally, it may be urged that this union of powders of solid metals under the influence of pressure—that is to say, the close proximation of the particles—can be compared to the liquefaction of gases by pressure. At the first view this comparison may appear rash or strained, but it is not so if the views of Clausius on the nature of gases and liquids be accepted. In a gas the molecules are free, but if by pressure at a suitable temperature the molecules are brought within the limit of their mutual attraction, the gas may be liquefied, and, under suitable thermal conditions, solidified. The mechanical pulverisation of a metal merely detaches groups of molecules from other groups, because the mechanical treatment is imperfect, but the analogy between a solid and a gas has, in this sense, been established; filing "coarsely gasifies" the mass, but pressure solidifies it.

It is possible that in some of the compressed metallic blocks the particles are not actually united by the pressure, which may, nevertheless, develop the kind of "mutual attraction" contemplated by Lord Kelvin as existing between two pieces of matter at distances of less than 10 micromillimetres.

Another analogy between metals and fluids is presented by the power which certain solid metals possess of taking up fluids, sometimes with a rapidity which suggests the miscibility of ordinary fluid substances. In reference to this, an interesting paper was published, so long ago as 1713, by the Dutch chemist Homberg,[1] "On Substances which Penetrate and which Pass Through Metals without Melting Them." He enumerates several substances which will pass through the pores of metals without disturbing the particles, and he points out that mercury penetrates metals without destroying them. The rapidity with which mercury will pass through tin is remarkable. A bar 1 inch wide and ½ inch thick will be penetrated by mercury in thirty seconds, so that it breaks readily, although before the addition of the mercury the bar would bend double without any sign of fracture.

In relation to surface tension, there is an interesting property belonging to a hard drawn rod or thick wire of 13-carat gold, the gold being alloyed with silver and copper in the following proportions:—

Gold	54·17
Copper	33·33
Silver	12·50
	100·00

If such a rod be touched with a solution of chloride of iron or certain other soluble chlorides, it will in a short time, varying from a few seconds to some minutes, break away, the fracture rapidly extending for a distance of some inches.

Occlusion of Gases.—With reference to the absorption of gases by metals, Sainte Claire-Deville and Troost discovered that hydrogen would pass through a plate of platinum, prepared from the fused metal or through iron, at a red heat; and it was well known that molten silver had the power of absorbing many times its own volume of oxygen. In Deville's experiments a new kind of porosity was imagined, more minute than that of graphite and earthenware, an intermolecular porosity due entirely to dilatation. Graham[2] showed that when gas penetrates the substance of the metal there is previous absorption and possibly liquefaction of the gas. Since his time it has been abundantly recognised that the presence of an element which is capable of reappearing with the elastic tension of a gas must materially affect the

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[1] *Mém. de l'Acad. Royale des Sciences*, 1713 (vol. for 1739, p. 306).

[2] *Proc. Roy. Soc.*, vol. xvi. p. 422; vol. xvii. p. 212 and p. 500. *Trans. Roy. Soc.*, 1886, pp. 399–439.

mechanical properties of a metal. Palladium is known to possess the power of occluding gas—hydrogen—in the most marked degree. By slow cooling from a red heat in an atmosphere of hydrogen, palladium foil or wire occludes no less than 900 volumes of hydrogen. Similarly, gold is found to occlude, that is, *retain when solid*, 0·48 of its volume of hydrogen and 0·2 of its volume of nitrogen, silver occludes 0·7 of its volume of oxygen, and wrought copper occludes 0·306 volume of hydrogen.

It is, however, in relation to the metallurgy of iron that the occlusion of gases is of importance. It is well known that at the conclusion of the Bessemer process, oxygen from the air blown through the metal becomes intimately associated with the iron; and Müller[1] has given strong evidence in support of the view that gases are dissolved in iron. Hydrogen is usually present in iron, chiefly as gas, sometimes as ammonia,[2] and in certain cases probably in some non-gaseous state. It does not appear to be in strong chemical combination, as it can easily be expelled. This may happen on solidification of the metal, by heating *in vacuo*, or by the action of a drill, which appears to release entangled or loosely-held hydrogen. The escape of gas can be prevented by increasing the pressure during solidification, and by the addition, before solidification, of silicon, manganese, or aluminium. The hydrogen probably remains in the cold iron after it is solidified. Cailletet[3] extracted from electrolytic iron, in which the metal probably exists in a distinct molecular form, nearly 250 times its volume of hydrogen by heating *in vacuo*. Graham proved that carbonic oxide is dissolved by iron, and that that gas probably plays an important part during the conversion of iron into steel in the ordinary process of cementation. It is certain that the presence of silicon and manganese appears to enable the iron to retain carbonic oxide, as well as hydrogen and nitrogen, in solution.

In an appendix to his paper on the "Determination of the Allotropic Changes of Iron by the Measurement of the Variations in Electric Resistance," Boudouard[4] gave some analyses of the gases given off on heating different varieties of steel *in vacuo*. Among the gases so examined were carbonic oxide, hydrogen, nitrogen, and oxygen, which he found in carbon and some chrome steels, whilst from steels containing tungsten, manganese, and nickel he obtained no gas.

Oxygen not only exists in steel as occluded gas, but in the form of oxide; and Law[5] has recently shown the great influence this has on the physical properties of the steel, especially in the case of tin plates. He described the appearance of oxide of iron under the microscope as consisting of minute black specks distributed throughout the mass of the metal. These can only be seen if the specimen has received a perfect polish and requires a magnification of at least 1000 diameters; besides these oxide patches, a certain amount of oxide exists in solution in the iron.

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[1] *Iron*, 1883, vol. xxi. p. 115, and vol. xxii. 244; 1884, xxiii. p. 161.

[2] Recognised by many observers; notably by Regnard, *Comptes Rendus*, vol. lxxxiv. (1877), p. 260.

[3] *Comptes Rendus*, vol. lxxx. (1875), p. 319.

[4] *Journ. Iron and Steel Institute*, 1903, i. p. 371.

[5] *Journ. Iron and Steel Inst.*, 1907, ii. p. 98.

In a number of determinations, the oxgyen was found to vary from 0·021 per cent. in good steels to 0·046 in bad steels; these quantities seem extremely small, but it must be remembered that 0·046 per cent. of oxygen corresponds to 0·2 per cent. of ferrous oxide, which is an appreciable amount of impurity for steels. It is interesting to note that oxide of iron, when present in steel, has a powerful influence on its liability to corrosion, increasing this to a considerable extent.

The Diffusion of Metals.—The results of a research on the diffusion of certain liquid and solid metals in each other, which occupied the attention of the author from time to time, were the subject of the annual "Bakerian Lecture"[1] for 1896. Until this investigation was undertaken very little attention had been devoted to the consideration of the molecular movements which enable two or more molten metals to mix spontaneously and form a truly homogeneous fluid mass. A single example of such spontaneous mixing, borrowed from Mint practice, may be sufficient. In preparing the alloy of gold and copper used for coinage, some 1100 ozs. of gold and 100 ozs. of copper are melted at a time in a crucible, and the results of assays on pieces of metal which represent the first and last portions poured from the crucible need not differ by more than $\frac{1}{10000}$th part. Such a fluid mass of gold owes its singular uniformity in composition not only to the mechanical stirring by which the blending of the gold and copper is roughly effected, but also to the fact that the metals dissolved in each other become spread or diffused uniformly by a spontaneous process. It is well known that such molecular movement occurs when salts are dissolved in water, and the rate at which various salts dissolve and diffuse in water has been accurately measured by Graham.

Very little has, however, been done as regards the measurement or even the consideration of the molecular movements in fluid metals, and the absence of direct evidence upon the point is probably explained by the want of a sufficiently accurate experimental method. An eminent physicist, Ostwald, has stated, with reference to the diffusion of salts, that "to make accurate experiments in diffusion is one of the most difficult problems in practical physics," and the difficulties are obviously increased when working with metals at high temperatures. It is, moreover, well known

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[1] *Phil. Trans.*, vol. clxxxvii. (1896), A. p. 383.