

largely used for the separation of silver or gold from base metallic oxides.

Metallic lead is to metals generally what oxide of lead is to metallic oxides. It accordingly is available as a solvent for so to say licking up small particles of metal diffused throughout a mass of slag or other dross, and uniting them into one regulus. This naturally leads us to consider the process of "cupellation," which discounts the solvent powers of both metallic lead and its oxide. This process serves for the extraction of gold and silver from their alloys with base metals such as copper, antimony, &c. The first step is to fuse up the alloy with a certain proportion of lead, which is determined by the weight of base metal to be eliminated, and is always sufficient to produce a lead-alloy of low fusing point. This alloy is heated on a shallow dish-shaped bed of bone earth to redness, and at this temperature subjected to the action of air. The base metals (copper, &c.) are oxidized away, the first portions as an infusible scum containing little oxide of lead, the latter in the form of a solution in molten litharge. Lead is, in general, less oxidizable than the other base metals; hence the last instalment of liquid litharge which runs off is pure, and the ultimately remaining regulus consists of silver and gold only. These latter may be separated by nitric acid or boiling oil of vitriol, which converts the silver into soluble salts and leaves the gold.

Oxide of iron, and also binoxide of manganese, are used for the decarburization of pig-iron. The oxygen of the reagent burns the carbon of the pig into carbonic acid, while the metal of the reagent becomes iron and FeO or MnO respectively, the oxides uniting with the silica added as such, or formed by the oxidation of the silicon of the pig, into a fusible slag.

Iron pyrites, FeS₂, is employed for the preliminary concentration of traces of gold diffused throughout slags or base ores. The reagent, through the action of the heat, gives up one-half of its sulphur, which reduces part of the metallic oxides present. The gold and silver unite with what is left of protosulphide of iron (FeS) into a mat, which is then worked up for the noble metals.

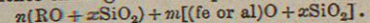
Fluxes.—Practically speaking, all ores are contaminated with more or less of gangue, which in general consists of infusible matter, and consequently, if left unheeded in the reduction of the metallic part of the ore, would retain more or less of the metal disseminated through it, or at best foul the furnace. To avoid this, the ore as it goes into the furnace is mixed with "fluxes" so selected as to convert the gangue into a fusible "slag," which readily runs down through the fuel with the regulus and separates from the latter. The quality and proportion of flux should, if possible, be so chosen that the formation of the slag sets in only after the metal has been reduced and molten; or else part of the basic oxide of the metal to be extracted may be dissolved by the slag and its reduction thus be prevented or retarded. Slags are not, as one might be inclined to think, a necessary evil; if an ore were free from gangue we should add gangue and flux from without to produce a slag, because one of its functions is to form a layer on the regulus which protects it against the further action of the blast or furnace gases. Fluxes may be arranged under the three heads of (1) fluor-spar (which is *sui generis*), (2) basic fluxes, and (3) acid fluxes.

Fluor-spar owes its name to the facility with which it fuses up at a red heat with silica, sulphates of lime and barium, and a few other infusible substances into homogeneous masses. It shows little tendency to dissolve basic oxides, such as lime, &c. One part of fluor-spar liquefies about half a part of silica, four parts of sulphate of lime, and one and a half parts of sulphate of baryta. Upon these facts its wide application in metallurgy is founded.

Carbonate of soda (or potash) may be said to be the most powerful of basic fluxes. It dissolves silica and all silicates into fusible masses. On the other hand, borax may be taken as a type for the acid fluxes. At a red heat, when it forms a viscid fluid, it readily dissolves up all basic oxides into fusible complex borates. Now the gangue of an ore in general consists either of some basic material such as carbonate of lime (or magnesia), ferric oxide, alumina, &c., or of silica (quartz) or some more or less acid silicate, or else of a mixture of the two classes of bodies. So any kind of gangue might be liquefied by means of borax or by means of alkaline carbonate; but neither of the two is used otherwise than for assaying; what the practical metal-smelter does is to add to a basic gangue the proportion of silica, and to an acid ore the proportion of lime, or, indirectly, of ferrous or perhaps manganous oxide, which it may need for the formation of a slag of the proper qualities. The slag must possess the proper degree of saturation. In other words, taking SiO₂ + nMeO (where MeO means an equivalent of base) as a formula for the potential slag, n must have the proper value. If n is too small, i.e., if the slag is too acid, it may dissolve up part of the metal to be brought out as a silicate; if n is too great, i.e., the slag too basic, it may refuse to dissolve, for instance, the ferrous oxide which is meant to go into it, and this oxide will then be reduced, and its metal (iron in our example) contaminate the regulus. In reference to the problem under discussion, it is worth noting that oxides of lead and copper are more readily reduced to metals than oxide of iron Fe₂O₃ is to FeO, the latter more readily to FeO than

FeO itself to metal, and FeO more readily to metal than manganous oxide is. Oxide of calcium (lime) is not reducible at all. The order of basicity in the oxides (their readiness to go into the slag) is precisely the reverse.

Most slags being, as we have seen, complex silicates, it is a most important problem of scientific metallurgy to determine the relations in this class of bodies between chemical composition on the one hand and fusibility and solvent power for certain oxides (CaO, FeO, SiO, &c.) on the other. Now the composition of a silicate can be stated in an infinite number of ways; but there must be one mode of formulation which reduces the law to its simplest terms. The mode adapted by metallurgists is something like the following. If we start with the quantity H₂O of muriatic acid or the quantity H₂SO₄ of sulphuric acid, it is clear that to convert either into a normal salt we require such a quantity of base as will convert the H₂ of the acid completely into water; but the quantity of base that does so is that containing one atomic weight of oxygen. Hence it is reasonable to define the quantities K₂O of potash, Na₂O of soda, CaO of lime, MgO of magnesia, FeO of ferrous oxide, $\frac{1}{2}$ Al₂O₃ (=alO) of alumina, $\frac{1}{2}$ Fe₂O₃ (=FeO) of ferric oxide, as representing each "one equivalent" of base also in reference to silica, although silica has a characteristically indefinite basicity. Most slags are alloys or compounds of silicates of Al₂O₃ or Fe₂O₃, and of silicates of protoxides (CaO, &c.), hence their general composition is



This introduction will enable the reader to understand the following mode of classifying and naming composition in silicates.

Name.	Formula.	Oxygen Ratio.		x
		Base.	Acid.	
I. Singulo-silicates.....	SiO ₂ +1MO	1	1	$\frac{1}{2}$
II. Bi-silicates.....	SiO ₂ +1MO	1	2	$\frac{1}{3}$
III. Tri-silicates.....	SiO ₂ +1MO	1	3	$\frac{1}{4}$

The names are the metallurgic ones; scientific chemists designate Class I. as orthosilicates, Class II. as metasilicates, Class III. as sesquosilicates. In the formulae M stands for K, Ca, Fe, &c., or for al— $\frac{1}{2}$ Al, Fe— $\frac{1}{2}$ Fe, &c.; or, shortly, MO for one equivalent of base as above defined. It should be possible to represent each quality of a silicate as a function of $\frac{x}{m}$, and of the nature of the individual bases that make up the RO and (fe or al) O respectively. Our actual knowledge falls far short of this possibility. The problem, in fact, is a very tough one, the more so as it is complicated by the existence of aluminates, compounds such as Al₂O₃.3CaO, in which the alumina plays the part of acid, and the occasional existence of compounds of fluorides and silicates in certain slags. The following notes on the fusibility of simple silicates are taken from Plattner's researches. Of the lime silicates, the tri-silicate melts at 2100° C., the bi-silicate at 2150°.

Magnesia silicates are most refractory. The bi-silicate and tri-silicate melt in the oxyhydrogen flame at 2250°.

Of manganous silicates, the easily fusible bi-silicate is yellow or red; the tri-silicate is more refractory.

Of cuprous (Cu₂O) silicates, the bi-silicate is violet, and melts pretty easily; the singulo-silicate is red, dense, and rather refractory.

Cupric silicates, as slags, hardly exist,—the CuO being always reduced to at least Cu₂O.

Lead silicates all melt readily into yellowish transparent glasses. But they have no standing as slags.

As regards the ferrous silicates, the singulo-silicate (orthosilicate) fuses at 1790° (this is about the composition of iron-puddling slag); the bi-silicate is less readily fusible.

Ferric silicates (unmixed) do not exist as slags,—the Fe₂O₃ being reduced in the fire to 1FeO, although Fe₂O₃ occasionally replaces part of the Al₂O₃ in complex silicates.

Alumina silicates are all infusible in even the hottest furnace fires. They begin to soften in the oxyhydrogen flame at about 2400°. But certain aluminates, for instance the salt 3CaO.1Al₂O₃, according to Sefström, melt at furnace heats.

The fusing points of mixtures of two simple silicates cannot be calculated from those of the components. In many cases it is lower than either of the latter two. Thus for instance most magnesia-lime silicates fuse,—the bi-silicate combination (Mg, Ca)OSiO₂ most readily.

Alumina silicates become fusible by addition of a sufficient proportion of silicate of lime at about 1918°. The singulo-silicate and bi-silicate combinations melt into grey glasses. Magnesia acts like lime, and so, in a more limited sense, do ferrous and manganous oxides; but their double compounds with Al₂O₃ and silica are more viscid when fused.

Plattner's work is a bold attempt to deal synthetically with the problem here presented, but it does not go the length of even an approximate solution. No one seems to have done much to continue it; hence in the meantime the metallurgist has, for his

¹ Few slags contain more than traces of alkalies.

guidance, to rely on the very numerous analyses which have been made of slags actually produced (by the rule of thumb) in successful metallurgical operations. For some of such slags also Plattner has determined the fusing points. He found for (1) Freiberg lead slag, 9RO, 3alO, 8SiO₂; oxygen-ratio, 3:4; melting-point at 1317° C.; (2) Freiberg crude slag, 15RO, 3alO, 18SiO₂; oxygen-ratio, 1:1; melting-point at 1331° C.; (3) Freiberg black-copper slag, 24FeO, Al₂O₃, 15SiO₂; oxygen-ratio, 9:10; melting-point at 1338° C.; (4) High-furnace slag, 6CaO, 3alO, 9SiO₂; oxygen-ratio, 1:1; melting-point at 1431° C.¹

Metallurgic Assaying.—To assay an ore originally meant to execute a set of tentative experiments on a small scale in order to find out the proper mode of working it practically. But nowadays the term is always used in the sense of an analysis carried out to determine the money-value of an ore. For this purpose, in many cases it is sufficient to determine the percentages of the metals for which the ore is meant to be worked. But sometimes nothing short of a complete analysis will do. This holds more especially of ores of iron. As this metal is cheap, the value of an ore containing it depends as much on the nature and relative quantities of the impurities as on the percentage of metal. The proved absence of sulphur and phosphorus may be worth more than an additional 5 per cent. of iron, which latter again would perhaps not compensate for the proved presence of a large percentage of uncombined silica.

An assay to be of any value must start with a fair sample of the object of sale. The fulfilment of this condition in all cases is difficult. The general method is, from say a given ship load of ore, to take out (say) half a ton of ore from a large number of different places and to crush this large sample into small fragments of uniform size, which are well shovelled up together. From different parts of this ore-heap a sample of the second order—amounting to, say, 20 lb—is then drawn, and rendered more homogeneous by finer powdering and mixing. From this sample of the second (or perhaps from one of the third) order quantities of 1 or 2 lb are bottled up for assaying. At the same time the moisture of the ore is determined, on a large scale, by some conventional method, such as the drying of 1 or 2 lb in an open basin at 100° C., and weighing of the residue as dry ore. This is done at the sampling place by the firms concerned. The assayer further pounds up and mixes his sample, and then proceeds to determine the percentages of moisture and metal in his own way. He has always the choice between two methods, the dry and the wet. For the majority of gold or silver ores, and for cobalt and nickel ores almost as a rule, certain dry-process tests are preferred as the most exact analytically. In almost all other cases it may be said that the wet method is susceptible of the higher degree of precision, yet even in some of these cases the old dry-process tests are preferred to the present day. For instance, all copper ores in the British Isles are sold by the result of the Swansea assay, a kind of imitation of the process of sulphurous copper-ore smelting; and this, singularly, is adhered to even in the case of such cuprififerous materials as are worked by the wet way, although the Swansea assay is well known to lose about 1 per cent. of the copper present. A copper-smelter therefore had better buy 5 per cent. than 10 per cent. copper-pyrites cinders, because in the first case he pays only for the copper present. To compensate for this anomaly, empirical methods have been contrived for calculating prices. (W. D.)

METALS. The earliest evidence of a knowledge and use of metals is found in the prehistoric implements of the so-called Bronze and Iron ages. In the earliest periods of written history, however, we meet with a number of metals in addition to these two. The Old Testament mentions six metals—gold, silver, copper, iron, tin, and lead. The Greeks, in addition to these and to bronze, came also to know mercury; and the same set of metals, without additions, forms the list of the Arabian chemists of the 8th and of the Western chemists of the 13th century. During the 15th century Basilius Valentinus discovered antimony; he also speaks of zinc and bismuth, but their individuality was established only at a later period. About 1730–40 the Swede Brand discovered arsenic and cobalt (the former is not reckoned a metal by modern chemists), while the Englishman Ward recognized the individuality of platinum. Nickel was discovered in 1774 by Cronstedt, manganese in 1774 by Scheele. The brothers D'Elhujart, in 1783, prepared tungsten; Hjelm, in 1782, isolated molybdenum from molybdic oxide, where

¹ For further information on slags, see Berthier, *Traité des essais par la voie sèche*; Winkler, *Erfahrungssätze über die Bildung der Schlacken*, Freiberg, 1827; Plattner, *Vorlesungen über allgemeine Hüttenkunde*, i. 28 sq.; Percy, *Metallurgy*.

its existence had been conjecturally asserted by Bergmann in 1781. Uranium, as a new element, was discovered by Klaproth in 1789; but his metallic "uranium," after having been accepted as a metal by all chemists until 1841, was then recognized as an oxide by Péligot, who subsequently isolated the true metal. Tellurium was discovered by Müller von Reichenbach in 1782 (again by Klaproth in 1798); titanium, by Klaproth in 1795; chromium, by Vauquelin in 1797; tantalum, by Hatchett in 1801, and by Ekeberg in 1802. Palladium, rhodium, iridium, and osmium (which four metals always accompany platinum in its ores) were discovered, the first two by Wollaston in 1803, the other two by a number of chemists; but their peculiarity was established chiefly by Smithson Tennant.

After Davy, in 1807 and 1808, had recognized the alkalies and alkaline earths as metallic oxides, the existence of metals in all basic earths became a foregone conclusion, which was verified sooner or later in all cases. But the discovery of aluminium by Wöhler in 1828, and that of magnesium by Bussy in 1829, claim special mention. Cadmium, a by no means rare heavy metal, was discovered only in 1818, by Stromeyer.

Of the large number of discoveries of rare metals which have been made in more recent times only a few can be mentioned, as marking new departures in research or offering other special points of interest. In 1861 Bunsen and Kirchhoff, by means of the method of spectrum analysis, which they had worked out shortly before, discovered two new alkali-metals which they called cesium and rubidium. By means of the same method Crookes, in 1861, discovered thallium; Reich and Richter, in 1863, indium; and Lecoq de Boisbaudran, in 1875, gallium. The existence of the last-named metal had been maintained, theoretically, by Mendelejeff, as early as 1871. The existence of vanadium was proved in 1830 by Sefström; but what he, and subsequently Berzelius, looked upon as the element was, in 1867, proved to be really an oxide by Roscoe, who also succeeded in isolating the true metal.

The development of earlier notions on the constitution of metals and their genetic relation to one another forms the most interesting chapter in the history of chemistry (see ALCHEMY). What modern science has to say on the matter is easily stated: all metals properly so called (i.e., all metals not alloys) are elementary substances; hence, chemically speaking, they are not "constituted" at all, and no two can be related to each other genetically in any way whatever. Our scientific instinct shrinks from embracing this proposition as final; but in the meantime it must be accepted as correctly formulating our ignorance on the subject. All metallic elements agree in this that they form each at least one basic oxide, or, what comes to the same thing, one chloride, stable in opposition to liquid water. This at once suggests an obvious definition of metals as a class of substances, but the definition would be highly artificial and objectionable on principle, because when we speak of metals we think, not of their accidental chemical relations, but of a certain sum of mechanical and physical properties which unites them all into one natural family. What these properties are we shall now endeavour to explain.

All metals, when exposed in an inert atmosphere to a sufficient temperature, assume the form of liquids, which all present the following characteristic properties. They are (at least practically) non-transparent; they reflect light in a peculiar manner, producing what is called "metallic lustre." When kept in non-metallic vessels they take the shape of a convex meniscus. These liquids, when exposed to higher temperatures, some sooner others later, pass into vapours. What these vapours are like is not known in many cases, since, as a rule, they can be produced only at

very high temperatures, precluding the use of transparent vessels. Silver vapour is blue, potassium vapour is green, many others (mercury vapour, for instance) are colourless. The liquid metals, when cooled down sufficiently, some at lower others at higher temperatures, freeze into compact solids, endowed with the (relative) non-transparency and the lustre of their liquids. These frozen metals in general form compact masses consisting of aggregates of crystals belonging to the regular or rhombic or (more rarely) the quadratic system. But in many cases the crystals are so closely packed as to produce an apparent absence of all structure. Compared with non-metallic solids, they in general are good conductors of heat and of electricity. But their most characteristic, though not perhaps their most general, property is that they combine in themselves the apparently incompatible properties of elasticity and rigidity on the one hand and plasticity on the other. To this remarkable combination of properties more than to anything else the ordinary metals owe their wide application in the mechanical arts. In former times a high specific gravity used to be quoted as one of the characters of the genus; but this no longer holds, since we have come to know of a whole series of metals which float on water. Let us now proceed to see to what degree the mechanical and physical properties of the genus are developed in the several individual metals.

Non-Transparency.—This, in the case of even the solid metals, is perhaps only a very low degree of transparency. In regard to gold this has been proved to be so; gold leaf, or thin films of gold produced chemically on glass plates, transmit light with a green colour. On the other hand, those infinitely thin films of silver which can be produced chemically on glass surfaces are absolutely opaque. Very thin films of liquid mercury, according to Melsens, transmit light with a violet-blue colour; also thin films of copper are said to be translucent. Other metals, so far as we know, have not been more exactly investigated in this direction.

Colour.—Gold is yellow; copper is red; silver, tin, and some others are pure white; the majority exhibit some modification or other of grey.

Reflexion of Light.—Polished metallic surfaces, like those of other solids, divide any incident ray into two parts, of which one is refracted while the other is reflected,—with this difference, however, that the former is completely absorbed, and that the latter, in regard to polarization, is quite differently affected.¹ The degree of absorption is different for different metals. According to Jamin, the remaining intensity, after one and ten successive perpendicular reflexions respectively from the metal-mirrors named, is as follows (original intensity = 1):—

	Silver.		Speculum Metal.		Steel.	
	1 R.	10 R.	1 R.	10 R.	1 R.	10 R.
Red.....	.929	.478	.692	.035	.609	.007
Yellow.....	.905	.339	.632	.010	.599	.006
Violet.....	.867	.242	.599	.006	.599	.006

This shows the great superiority of silver as a reflecting medium, especially in the case of repeated reflexion.

Crystalline Form.—Most (perhaps all) metals are capable of crystallization, and in most cases isolated crystals can be produced by judiciously managed partial freezing. The crystals belong to the following systems:—*regular system*—silver, gold, palladium, mercury, copper, iron, lead; *quadratic system*—tin, potassium; *rhombic system*—antimony, bismuth, tellurium, zinc, magnesium.

Structure.—Perhaps all metals, in the shape which they assume in freezing, are crystalline, only the degree of

¹ This may be the cause of the peculiarity of metallic lustre.

visibility of the crystalline arrangement is very different in different metals, and even in the same metal varies according to the slowness of solidification and other circumstances.

Of the ordinary metals, antimony, bismuth, and zinc may be mentioned as exhibiting a very distinct crystalline structure: a bar-shaped ingot readily breaks, and the crystal faces are distinctly visible on the fracture. Tin also is crystalline: a thin bar, when bent, "creaks" audibly from the sliding of the crystal faces over one another; but the bar is not easily broken, and exhibits an apparently non-crystalline fracture.—Class I.

Gold, silver, copper, lead, aluminium, cadmium, iron (pure), nickel, and cobalt are practically amorphous, the crystals (where they exist) being so closely packed as to produce a virtually homogeneous mass.—Class II.

The great contrast in apparent structure between cooled ingots of Class I. and of Class II. appears, however, to be owing chiefly to the fact that, while the latter crystallize in the regular system, metals of Class I. form rhombic or quadratic crystals. Regular crystals expand equally in all directions; rhombic and quadratic ores expand differently in different directions. Hence, supposing the crystals immediately after their formation to be in absolute contact with one another all round, then, in the case of Class II., such contact will be maintained on cooling, while in the case of Class I. the contraction along a given straight line will in general have different values in any two neighbouring crystals, and the crystals consequently become, however slightly, detached from one another. The crystalline structure which exists on both sides becomes visible only in the metals of the first class, and only there manifests itself as brittleness.

Closely related to the structure of metals is their degree of "plasticity" (susceptibility of being constrained into new forms without breach of continuity). This term of course includes as special cases the qualities of "malleability" (capability of being flattened out under the hammer) and "ductility" (capability of being drawn into wire); but it is well at once to point out that these two special qualities do not always go parallel to each other, for this reason amongst others that ductility in a higher degree than malleability is determined by the tenacity of a metal. Hence tin and lead, though very malleable, are little ductile. The quality of plasticity is developed to very different degrees in different metals, and even in the same species it depends on temperature, and may be modified by mechanical or physical operations. A bar of zinc, for instance, as obtained by casting, is very brittle; but when heated to 100° or 150° C. it becomes sufficiently plastic to be rolled into the thinnest sheet or to be drawn into wire. Such sheet or wire then remains flexible after cooling, the originally only loosely cohering crystals having got intertwined and forced into absolute contact with one another,—an explanation supported by the fact that rolled zinc has a somewhat higher specific gravity (7.2) than the original ingot (6.9). The same metal, when heated to 205° C., becomes so brittle that it can be powdered in a mortar. Pure iron, copper, silver, and other metals are easily drawn into wire, or rolled into sheet, or flattened under the hammer. But all these operations render the metals harder, and detract from their plasticity. Their original softness can be restored to them by "annealing," i.e., by heating them to redness and then quenching them in cold water. In the case of iron, however, this applies only if the metal is perfectly pure. If it contains a few parts of carbon per thousand, the annealing process, instead of softening the metal, gives it a "temper," meaning a higher degree of hardness and elasticity (see below).

What we have called plasticity must not be mixed up

with the notion of softness, which means the degree of facility with which the plasticity of a metal can be dis-counted. Thus lead is far softer than silver, and yet the latter is by far the more plastic of the two. The now famous experiments of Tresca (*Comptes Rendus*, lix. 754) show that the plasticity of certain metals at least goes considerably farther than had before been supposed. He operated with lead, copper, silver, iron, and some other metals. Round disks made of these substances were placed in a closely fitting cylindrical cavity drilled in a block of steel, the cavity having a circular aperture of two or four centimetres below. By means of an hydraulic press, applied to a superimposed piston, a pressure of 100,000 kilos was made to act upon the disks, when the metal was seen to "flow" out of the hole like a viscid liquid. In spite of the immense rearrangement of parts there was no breach of continuity. What came out below was a compact cylinder with a rounded bottom, consisting of so many layers superimposed upon one another. Parallel experiments with layers of dough or sand plus some connecting material proved that the particles in all cases moved along the same tracks as would be followed by a flowing cylinder of liquid. Of the better known metals potassium and sodium are the softest; they can be kneaded between the fingers like wax. After these follow first thallium and then lead, the latter being the softest of the metals used in the arts. Among these the softness decreases in about the following order:—lead, pure silver, pure gold, tin, copper, aluminium, platinum, pure iron. As liquidity might be looked upon as the *ne plus ultra* of softness, this is the right place for stating that, while most metals, when heated up to their melting points, pass pretty abruptly from the solid to the liquid state, platinum and iron first assume, and throughout a long range of temperatures retain, a condition of viscous semi-solidity which enables two pieces of them to be "welded" together by pressure into one continuous mass. Potassium and sodium might probably be welded if their surfaces could be kept clear of oxide.

According to Prechtl, the ordinary metals, in regard to the degree of facility or perfection with which they can be hammered flat on the anvil, rolled out into sheet, or drawn into wire, form the following descending series:—

Hammering.	Rolling into Sheet.	Drawing into Wire.
Lead.	Gold.	Platinum.
Tin.	Silver.	Silver.
Gold.	Copper.	Iron.
Zinc.	Tin.	Copper.
Silver.	Lead.	Gold.
Copper.	Zinc.	Zinc.
Platinum.	Platinum.	Tin.
Iron.	Iron.	Lead.

To give an idea of what can be done in this way, it may be stated that gold can be beaten out to leaf of the thickness of $\frac{3}{3200}$ mm.; and that platinum, by judicious work, can be drawn into wire $\frac{1}{30000}$ mm. thick.

By the hardness of a metal we mean the resistance which it offers to the file or to the engraver's tool. Taking it in this sense, it does not necessarily measure, e.g., the resistance of a metal to abrasion by friction. Thus, for instance, 10 per cent. aluminium bronze is scratched by an edge-tool made of ordinary steel as used for knife-blades. And yet it has been found that the sets of needles used for perforating postage stamps last longer if made of aluminium bronze than they do if made of steel.

Elasticity.—All metals are elastic to this extent that a change of form, brought about by stresses not exceeding certain limit values, will disappear on the stress being removed. Strains exceeding the "limit of elasticity" result in permanent deformation or (if sufficiently great) in rupture. Where this limit lies is in no case precisely known. According to Wertheim¹ (who has done more for our knowledge of the subject than any one else) and Hodgkinson,

¹ *Annales de Chimie et de Physique* [III.], vol. xii.

the real law seems to be pretty much as indicated by the two curves on the accompanying diagram, where, in reference to a metallic wire, stretched by an appended weight, the abscissa always means the numerical value P of the weight, the ordinate of the upper curve—the total elongation caused by P, the ordinate of the lower curve that part of the elongation which remains when P is removed, so that the piece of the ordinate between the two curves gives the temporary ("elastic") expansion. From P=0 up to a somewhat indefinite point (a or A) both curves are nearly straight lines, the lower almost coinciding in its beginning with the axis of abscissa; from that point onwards these two curves approach each other, and at a short distance from the point of rupture they rapidly converge towards intersection. For any value of P which lies fairly on the safe side of A, we have approximately

$$\lambda = \frac{P}{E} \cdot \frac{l}{g}$$

where λ means the elastic (or substantially the total) expansion, l the length, and g the square section of the wire or cylindrical bar operated upon. The reciprocal of e (viz. $E=1/e$) is called the "modulus of elasticity."

Wertheim has determined this constant for a large number of metals and alloys. He used three methods: one was to measure the elongations produced, in a wire of given dimensions, by a succession of charges; the other two consisted in causing a measured bar to give off a musical note by (a) longitudinal and (b) transversal vibration, and counting the vibrations per second. The following table gives some of his results. Column 2 gives the constant E for millimetre and kilogramme. Hence 1000/E is the elongation in millimetres per metre length per kilo. Column 3 shows the charge causing a permanent elongation of 0.05 mm. per metre,—which, for practical purposes, he takes as giving the limit of elasticity; column 4 gives the breaking strain. Values of E in square brackets [] are derived from vibration experiments; the rest from direct measurements of elongations. Numbers in round brackets () do not necessarily refer to the same specimen as the other data.

Name	E.	For Wire of 1 Square mm. Section, Weight (in Kilos) causing	
		Permanent Elongation of 0.05 mm.	Breakage.
Lead, drawn.....	1,803	0.25	2.1
" annealed.....	1,727	0.20	1.8
Tin, drawn.....	[3,923]	0.45	(2.45)
" annealed.....	[4,066]	0.20	2.24
Cadmium, drawn.....	[5,751]		
" annealed.....	[4,777]		
Gold, drawn.....	8,132	13.5	27
" annealed.....	5,855	8.0	10
Silver, drawn.....	7,358	11.3	29
" annealed.....	7,141	2.6	16
Zinc, pure, cast in mould.....	9,021		
Zinc, ordinary, drawn.....	8,735	0.75	13
" annealed.....	[9,467]	1.00	
Palladium, drawn.....	11,759	13	27
" annealed.....	9,789	under 5	
Copper, drawn.....	12,449	12	40
" annealed.....	10,519	under 3	30
Platinum wire, medium thickness, drawn.....	17,004	(26)	
" annealed.....	15,518	(14)	34
Platinum wire, thick, drawn.....	15,987		23
" annealed.....	15,622		61
Iron, drawn.....	20,869	32	47
" annealed.....	20,794	under 5	> 61
Nickel, drawn.....			2 x 61
Cobalt, ²	7,040		
Aluminium ³	10,700		
Aluminium bronze ⁴	8,543		
Brass ⁵	10,788		
German silver ⁶			

The above numbers may be assumed to hold for temperatures from 15° to 20° C. Wertheim executed determinations also at other temperatures; but, as his numbers do not appear to reveal the true

² From Du Brery. ³ Approximate, by H. St. Clair Deville. ⁴ From deflexion of hammered bar of 5 mm. thickness, charged in the middle; determined by W. Dittmar. ⁵ Composition, ZnCu₂ (Wertheim). ⁶ Composition, Zn₂Cu₁₂Ni₂ (Wertheim).

