PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

On Certain Mechanical Properties of Metals Considered in relation to the Periodic Law

W. Chandler Roberts-Austen

Phil. Trans. R. Soc. Lond. A 1888 **179**, 339-349
doi: 10.1098/rsta.1888.0013

XIII. *On certain Mechanical Properties of Metals considered in relation to the Periodic Law.*

By W. CHANDLER ROBERTS-AUSTEN, *F.R.S., Professor of Metallurgy in the Normal School of Science and Royal School of Mines, South Kensington, Chemist and Assayer of the Royal Mint.*

Received and Read March 15, 1888.

[PLATE 18.]

THE influence exerted by a small quantity of metallic or other impurity on a mass of metal is shown by a remarkable series of phenomena the nature of which has hitherto been but little studied, although the effect produced by the presence of such added matter is widely recognised by metallurgists. There are many cases in which a small quantity of impurity has so entirely altered the appearance and the physical properties of a metal as to lead, in the absence of other evidence, to its being mistaken for a distinct elemental substance. The valuable mechanical properties conferred upon metals by associating them with small, but definite, amounts of other metals constitute the main reason why metals devoted to industrial use are seldom employed in a state of purity. A familiar instance of the influence of a small quantity of a metalloid on a mass of metal is presented by the extraordinary change in the properties of pure iron which attends the introduction into the metal of a small quantity of carbon. There is no fact in metallurgy of which the importance is more widely recognised, and when BERGMAN,* in 1781, experimentally demonstrated that the differences between pure iron, steel, and cast-iron depend on the presence or absence of carbon, he expressed his astonishment at the smallness of the amount of carbon capable of producing such effects, and he stated that the explanation of the phenomenon presented a "difficulty of difficulties"; and the problem has certainly not been solved in the century which has elapsed since BERGMAN wrote.

In other directions the evidence as to the importance of the action of traces of impurity is just as strong. This is indicated by the fact, referred to by Sir HUSSEY VIVIAN,† that "one thousandth part of antimony converts first-rate 'best selected'

* 'De Analysi Ferri, Opuscula Physica et Chemica,' by TORBERN BERGMAN, vol. 3, 1783: or *French translation* (from the Swedish): 'Analyse du Fer,' by M. GRIGNON. Paris, 1783.

† Lecture delivered at Swansea in 1880.

copper into the worst conceivable," and by the observation of Mr. PREECE,* that "a submarine cable made of the copper of to-day," the necessity for employing pure metal being recognised, "will carry twice the number of messages that a similar cable of copper would in 1858," when less importance was attached to the presence of foreign matter in the copper. It may be well to refer to a but little known case in which the change in the structure of a metal produced by the presence of a minute quantity of foreign matter becomes at once evident by comparing the fractured surfaces of the pure and impure masses. Bismuth, when pure, has a fracture which shows large brilliant mirror-like crystalline planes; but, if only the $\frac{1}{1000}$th part of tellurium be present, the fracture is, as a specimen submitted to the Society showed, entirely different, being minutely crystalline and lighter in colour than pure bismuth.

The mode of action of these small quantities of impurity is still very obscure, but it should be remembered that Professor W. SPRING, of Liége, has recently given evidence† in favour of the view that molecular polymerization may take place even in a *solidified* alloy, and MATTHIESSEN,‡ in a classical series of researches on the electrical resistance of alloys, communicated to this Society nearly thirty years since, was led to the view that in many cases the constituent metals of alloys exist in the form of allotropic modifications, the quantities of the metal producing a rapid decrement in conductivity being too small to enable the effect to be explained by attributing it to the formation of chemical compounds.

In the present paper, attention is directed to the way in which the tenacity and extensibility of metals may be affected by small quantities of metals and metalloids, with the view of showing that the relations between these small quantities of the elements and the masses of metal in which they are hidden are under the control of the Law of Periodicity, which, as originally expressed, states that "the properties of the elements are a periodic function of their atomic weights." CARNELLEY§ has set forth at some length the reasons for supplementing the law as follows:—"The properties of the *compounds* of the elements are a periodic function of the atomic weights of their constituent elements"; and the question arises, may the law be so extended as to govern the relations between the constituent metals of alloys, in which, as is well known, the atomic proportions are often far from simple.

The influence of a small quantity of one metal on another is so marked that it appeared well to approach the consideration of the problem by investigating the nature of the change so effected in the mechanical properties of metals. Gold was the metal selected as a basis for the experiments, mainly because it can be more readily brought to a high degree of purity than any other metal: the accuracy of the results of the experiments are not likely to be disturbed by the oxidation of the gold

* 'Instit. Civil Engineers Trans.,' vol. 75, part 1, 1883.

† 'Bull. de l'Acad. Roy. de Belgique,' vol. 11, 1886.

‡ 'Phil. Trans.,' vol. 150, 1860, p. 85; and vol. 154, 1864, p. 167.

§ 'Phil. Mag.,' vol. 8, 1879, p. 368.

or by the presence of occluded gases: it possesses considerable ductility and tenacity; and the amount of the metallic or other impurity added to the precious metal can be determined with rigorous accuracy. With the exception of iron, gold has received more attention than any other metal in relation to the effects of impurities upon it, and much information upon the subject is scattered through the works of the older chemists; but the first systematic experiments were made, by the direction of the Lords of the Committee of Privy Council, by Mr. HATCHETT in 1803, who endeavoured to ascertain "the chemical effects produced on gold by different metallic substances when employed in certain proportions as alloys." He obtained results of great interest, which were communicated to the Royal Society*; but in his time the importance of submitting metals to mechanical tests was not appreciated; his observations were thus mainly directed to ascertaining whether gold is rendered hard and brittle by the presence of foreign metals. The gold he employed was only of commercial purity, and he specially examined the effect of impurities on the *standard* gold used for coinage, which contains 916·7 parts of pure gold and 83·3 of copper per 1000 parts. He showed, by means of bending and hammering the gold, that small quantities of certain metals render it very brittle, and he concluded that "the different metallic substances which have been employed in the present experiments appear to affect gold nearly in the following decreasing order:—

1. Bismuth.
2. Lead.
3. Antimony.

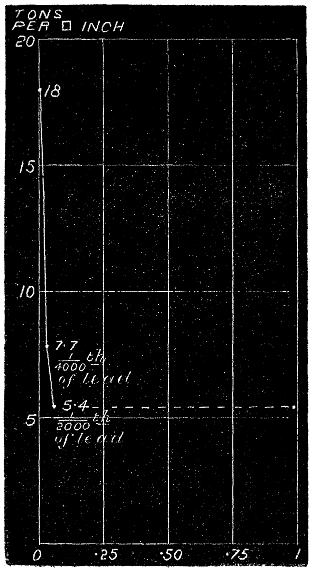
} These are nearly equal in effect.

4. Arsenic.
5. Zinc.
6. Cobalt.
7. Manganese.
8. Nickel.
9. Tin.
10. Iron.
11. Platinum.
12. Copper.
13. Silver."

In 1886, in a lecture delivered at the Royal Institution,† I pointed out that standard gold breaks with a load of 18 tons to the square inch, and elongates 34 per cent. before breaking. If the standard gold has only $\frac{1}{2000}$th part of lead added to it, it becomes very fragile, and breaks, as is indicated by the following diagram, with a stress of about $5\frac{1}{2}$ tons to the square inch, instead of the 18 tons borne originally. It is remarkable that $\frac{1}{100}$th part of lead added to gold does not appear to diminish

* 'Phil. Trans.,' 1803, Part 1, p. 43.

† ROBERTS-AUSTEN, 'Roy. Inst. Proc.,' 1886; and 'Engineering,' May 28, 1886.



Percentage of lead.

its tenacity more than $\frac{1}{2000}$th part. Professor KENNEDY has kindly made further experiments on pure gold to which $\frac{1}{500}$th part of lead had been added; and his results substantially confirm those just referred to, for he found that the breaking load of the contaminated gold was 1·84 ton per square inch, and the elongation unmeasurable.

In the experiments which follow, pure gold was in all cases melted under a pure form of charcoal; a certain amount of the metallic impurity to be added was carefully weighed, on a delicate assay-balance, and tightly wrapped in pure gold foil. This little packet was held in a charred splinter of wood, and rapidly submerged in the molten gold. It was found better not to stir the gold, but to thoroughly mix the contents of the crucible by giving it a swinging motion. The gold was then poured through an atmosphere of coal gas into an iron mould lined with lamp-black, and the resulting bars had the following dimensions :—3·5 inches length, 0·295 inch breadth, 0·205 inch thickness, the sectional area of the bars being therefore 0·0605 square inch. The length varied in some cases. The results of analyses of different parts of the bars showed that the mixing had rarely been defective, but there was evidence in some cases that liquation had disturbed the homogeneity of the metal, though not to any serious extent.

The test-pieces were made in the Assay Department of the Royal Mint, by Mr. GROVES, whose careful manipulation and great experience in melting the precious metals were of much service to me.

In the case of very volatile metals, such as potassium and cadmium, a rich alloy with gold was first prepared by fusion in an atmosphere of pure hydrogen. The alloy so formed was analysed, and the necessary amount of it added to pure gold in the manner already described so as to give approximately $\frac{2}{10}$ per cent. of foreign metal in the solidified mass. It may here be pointed out that the purity of the gold employed had been well established by careful comparison with gold purified by myself in 1873* for use as Trial-plates in connection with the coinage of this country,† the purity of which has been recognised by no less an authority than M. STAS. The amount of foreign matter added to the gold could therefore be readily ascertained with minute accuracy by the ordinary method of assay, except in the case of metals of the platinum group. It should be observed, however, that the method of assay, which consists in eliminating impurities and in comparing the weight of the purified gold with that of the portion of metal taken for assay, does not enable the assayer to distinguish whether an impurity is metallic or a metallic oxide. However carefully the experiments were conducted, it was at times found impossible to prevent the small amount of added metal from being oxidised to a certain extent during the casting of the bars. The error thus occasioned is believed to be but small, and was proved not to be serious in the case of those metals whose oxides can be reduced by hydrogen, by laminating or breaking in fragments the portion of metal to be submitted to assay and heating it to bright redness in a stream of pure and dry hydrogen.

The testing-machine used in the following experiments belongs to the Metallurgical Laboratory of the Royal School of Mines, and is of the form devised by Professor GOLLNER, and used by himself at Prague, and by Professor BÖCK at Leoben. It is a double lever vertical machine, adapted only for testing short pieces of metal, and working up to a stress of 20 tons.‡ The pieces of metal tested were not provided, as they should have been, with enlarged ends, but they nevertheless seldom broke within the jaws of the machine, and when they did the result was rejected.

The purest gold attainable has a tenacity of 7·00 tons per square inch, and an elongation of 30·8 per cent. Professor KENNEDY found that a less pure sample, which contained 999·87 parts of fine gold in 1000, broke with a load of 6·29 tons per square inch, and elongated 18·5 per cent. before breaking.

In selecting tenacity as the property to be tested with a view to ascertain the effect of the added matter, the following considerations presented themselves :—

Professor SPRING has built up alloys by compressing the powders of the constituent metals; and, by pointing to the evidence of molecular mobility in solid alloys, he has done much to show the close connection which exists between cohesion and chemical affinity. RAOUL PICTET has concluded that there is an intimate relation between the melting-points of metals and the lengths of their molecular oscillations, the length of the oscillations diminishing as the melting-point increases, and, as CARNELLEY has pointed out, "we should expect that those metals which have the highest melting-points would also be the most tenacious." It is known that the melting-points of metals are altered by the presence of small quantities of foreign matter; their

* 'Chem. Soc. Journ.,' vol. 27, 1874, p. 197.

† Cantor Lectures, 'Soc. Arts Journ.,' vol. 32, 1884.

‡ This machine is described by Professor KENNEDY, F.R.S., 'Instit. Civil Engineers Proc.,' vol. 88, 1886–87, part 2.

cohesion is also thereby altered: the degree of cohesion may thus be investigated either by change of temperature or by mechanical stress, being, as it is, some function of each of these. It might have been well to ascertain the amount of change in the melting-point of gold produced by the presence of different elements in small quantity, but, unfortunately, slight variations in high melting-points are very difficult to determine with any approach to accuracy, and it appeared to be better to ascertain the effect of metallic and other impurity on the cohesion of the gold as indicated by the amount of force externally applied in an ordinary testing-machine, and in that way to ascertain whether the effect of added metals is amenable to any known law.

In the following experiments only the purest gold I could prepare was employed. It broke with a load of 7·00 tons per square inch, and elongated 30·8 per cent. (on 3 inches) before it fractured, as recorded in the diagrams, Plate 18, Nos. I. and II., subsequently referred to. The effect on the tenacity of gold produced by adding to it about $\frac{2}{10}$ per cent. of various metals and metalloids is shown in the following Table, in which the results are arranged according to the tensile strengths:—

Name of added element.	Tensile strength.	Elongation, per cent. (on 3 inches).	Impurity, per cent.	Atomic volume of impurity.	Reduction of area at fracture, per cent.
	Tons per sq. in.				
Potassium . .	Less than 0·5	Not perceptible	Less than 0·2	45·1	Nil.
Bismuth . . .	0·5 (about)	,,	0·210	20·9	,,
Tellurium . .	3·88	,,	0·186	20·5	,,
Lead	4·17	4·9	0·240	18·0	Very slight.
Thallium . . .	6·21	8·6	0·193	17·2	15
Tin	6·21	12·3	0·196	16·2	Not measured.
Antimony . .	6·0 (about)	qy.	0·203	17·9	54
Cadmium . . .	6·88	44·0	0·202	12·9	See note †
Silver	7·10	33·3	0·200	10·1	,,
Palladium . .	7·10	32·6	0·205	9·4	75
Zinc	7·54	28·4	0·205	9·1	74
Rhodium . . .	7·76	25·0	0·21 (about)	8·4	See note †
Manganese . .	7·99	29·7	0·207	6·8	60
Indium . . .	7·99	26·5	0·290	15·3	72
Copper . . .	8·22	43·5	0·193	7·0	See note †
Lithium . . .	8·87	21·0	0·201	11·8	60
Aluminium . .	8·87	25·5	0·186	10·6*	46

The figures given in the fourth column show that there is some divergence in the amounts of impurity added to the gold. That this is not of much importance in these preliminary experiments may be inferred from the fact, already mentioned (on p. 342), that the $\frac{1}{2000}$th part of lead appears to produce nearly the same diminution in tenacity as the $\frac{1}{500}$th part; a mere trace of certain metals, moreover, will greatly diminish the tenacity of gold.

[* This is the value given by LOTHAR MEYER. MALLETT's determination of the density of pure aluminium would give 10·45.

† These test-pieces drew out after the manner of pitch, that is, as a viscous solid.—August 4, 1888.]

The results are also graphically represented in the accompanying diagrams (Plate 18, Nos. I. and II. The tests were made with great care by Dr. E. J. BALL, Assistant in the Metallurgical Laboratory of the Royal School of Mines.

It will be evident, from the figures given in the Table, that certain mechanical properties of gold are greatly affected by the addition, in small quantities, of potassium, bismuth, tellurium, and lead, while other metals, such for instance as silver and palladium, hardly produce an alteration. The change in the structure of the precious metal is, in some cases, very remarkable, as drawings submitted to the Society showed. Pure gold has a silky fracture, while gold containing the $\frac{1}{500}$th part of lead, tellurium, bismuth, or antimony shows a well-developed crystalline structure, the crystalline planes diverging from a line in the centre of the fractured bar. The character of the fracture does not appear to be closely related to that of the added metal, as lead, thallium, and indium, which produce marked crystalline structure in gold, are, amongst metals, almost colloidal when pure. In these cases, then, the influence exerted by the added impurity can hardly be considered to be only due to a power to develop crystalline form. The question now arises, does this power to produce fragility correspond with any other property of metals in accordance with which they may be classified ?

The facts represented in the Periodic Law were, in 1879, graphically represented by LOTHAR MEYER in his well-known curve of the elements. By adopting atomic weights as abscissæ and atomic volumes as ordinates, he showed that the elements can be arranged in a curve resembling a series of loops, the highest points of which are occupied by cæsium, rubidium, potassium, sodium, and lithium, while the metals which are most useful for industrial purposes occupy the lower portions of the several loops.

An examination of the results obtained in my experiments, so far as they have yet been carried, shows that not a single metal or metalloid which occupies a position at the base of either of the loops of LOTHAR MEYER's curve diminishes the tenacity of gold. On the other hand, the fact is clearly brought out that metals which do render the gold fragile all occupy high positions in MEYER's curve. This would appear to show that there is some relation between the influence exerted by the metallic impurities and either their atomic weights or their atomic volumes. It seems hardly probable that it is due to atomic weight, because copper, with an atomic weight of 63·2, has nearly the same influence on the tenacity of pure gold as rhodium, with an atomic weight of 104, or as aluminium, the atomic weight of which is 27. The atomic volume is of course obtained by dividing the atomic weight by the specific gravity of the element, and it at once becomes evident, from the tabulated results and from the diagrams which graphically represent them, that the metals which diminish the tenacity and extensibility of gold have high atomic volumes, while those which increase these properties have either the same atomic volume as gold or a lower one. Further, silver has the same atomic volume as gold, 10·2, and its presence in small quantity has very little influence, one way or the other, on the tenacity or extensibility of the metal. When the metals are ranged in order of atomic volumes, potassium, which renders gold very brittle, assumes the position to which its very high atomic volume of 45 entitles it. Aluminium, indium, and lithium occupy somewhat abnormal positions on the diagram, for they possess high atomic volumes and yet they appear to increase the tenacity of gold, although they reduce its capability of being elongated.

The influence of cadmium in increasing the extensibility is very remarkable. Arsenic, again, has a higher atomic volume than gold, and should therefore render gold somewhat fragile. Several experiments were made with it, and the bars proved to be very fragile, but the results are not embodied in the table, as the bars did not appear to be uniform in composition. The influence of zirconium is also noteworthy. A fine specimen of crystalline zirconium was obtained from Messrs. HOPKIN and WILLIAMS, but the metal appears to unite itself with gold with great difficulty. When wrapped in the foil and added to gold, purposely kept considerably above its melting-point, the foil melted and released the zirconium, most of which fell, through the molten metal, to the bottom of the crucible, and remained there when the gold was poured out. After several attempts, an amount of material, which subsequently proved, on assay, to be about 0·2 per cent., was alloyed with the gold, and a perfectly sound bar obtained, which appeared to have extraordinary strength, for it broke with a load of 12 tons per square inch, pure gold breaking at 7 tons. Its fracture was remarkably close-grained, and it elongated 12 per cent. before breaking. If subsequent experiments should confirm this high tenacity, the result would be opposed to the view set forth in this paper, as zirconium has a high atomic volume, and should diminish the tenacity of gold.

It may be added that it was useless to employ anything but chemically pure gold, and the supply available only amounted to 40 ounces. As the preparation of gold of high purity occupies a considerable amount of time, it was considered best to publish the results already obtained. The effects of 0·2 per cent. of nickel, cobalt, iron, and platinum, which occupy very low positions on MEYER's curve, have severally been tried with *standard* gold, and do not appear to reduce either its tenacity or extensibility, and there is no reason to assume that they will behave differently in the case of *pure* gold.

Allusion has already been made to the close connection which exists between the tenacity of metals and their melting-points, and CARNELLEY has pointed out that the melting-points are inversely as the atomic volumes, "the only important exceptions to the rule being arsenic, selenium, tin, antimony, tellurium, thallium, lead, and bismuth." It can hardly be a matter of chance that, as my experiments prove, all these elements (with the exception of selenium, about the effect of which I am at present uncertain) diminish the coherence of gold, and there are but few others that do so—a fact which is alone sufficient to point to there being some connection between the action of minute quantities of impurities and the Periodic Law.

It would be difficult to suggest any explanation as to the mode of action of the various elements until the influence of each element in small but varying quantities, both singly and in association, has been investigated. Questions of much industrial interest present themselves, especially in connection with iron; with regard to this metal, the evidence as to the action of other elements upon it would appear to tend in the same direction as in the case of gold, although the question is greatly complicated by the relations of iron to oxygen, and by the presence of occluded gases. It may be sufficient for the present to point out that the atomic volume of iron is 7·2; carbon, the atomic volume of which is small (4·0), when present in quantities varying from 0·2 to 1 per cent. increases its tenacity. Silicon, notwithstanding that it has a larger atomic volume (11·1) than iron, apparently increases its tenacity, although little can as yet be said as to its influence in very small quantities. The same observation applies to small quantities of manganese. This metal has an atomic volume of 6·8, and when present in very large quantities, 12 to 15 per cent., confers great extensibility on iron. Sulphur and phosphorus, on the other hand, have large atomic volumes, 15·1 and 13·2 respectively, and both these elements have, as is well known, a prejudicial effect on the qualities of iron.

It should not be forgotten that the knowledge of the effect produced on metals by small quantities of added matter has had a remarkable effect on the development of chemistry, mainly by sustaining the belief of the early chemists in the possibility of "ennobling" base metals or "degrading" precious ones. This is specially evident from the writings of GEBER, BIRINGUCCIO, GELLERT, and ROBERT BOYLE; and it is hardly strange that, in the absence of a knowledge of analysis, they should have believed in the efficacy of a transmuting agent, when it is remembered that in the specimens submitted to the Society the presence of $\frac{1}{500}$th part of such metals as lead, bismuth, and potassium has entirely altered the appearance of the fractured surfaces of pure gold.

ADDENDUM,

August 1, 1888.

The test-pieces were all cast in the same mould, and their sectional area was about 0·06 of a square inch; the sixth column of the Table, p. 344, gives the reduction per cent. in sectional area of many of the test pieces at the point of fracture, so far as it was possible to measure them, but the irregular nature of the fractured surface rendered the measurements for the most part untrustworthy, and it would therefore be of but little use to plot these data on a curve. The behaviour of several of the test-pieces under longitudinal stress resembled that of a viscous solid, and in such pieces the fracture was wedge-shaped, with a more or less sharp edge, the section remaining rectangular.

In some cases, notably in that of the test-pieces containing palladium and lithium, the fractures revealed the presence of a minute cavity, which, doubtless, determined the point of fracture, and, to some extent, therefore, affected the tenacity. With reference to this point, it is worthy of remark that Professor BAUSCHINGER, of Munich, has demonstrated, by the aid of a remarkable series of test-pieces of iron and steel exhibited at the Nuremberg Exhibition of 1882, that the presence of a minute defect at the point at which fracture ultimately takes place, while not greatly affecting the tensile strength of the test-piece, may nevertheless prevent the metal from contracting to so small an area as would have been the case if the metal had been perfectly sound. The elongation of the test-pieces (given in the third column of the Table, p. 344) and the atomic volume of the added impurity are plotted in diagram No. II., Plate 18, which agrees closely with diagram No. I., representing tensile strength and atomic volume. Cadmium exhibits marked irregularity in both diagrams, but the only striking difference between the two diagrams is presented by tellurium and bismuth, the former of which seems to be more prejudicial to the elongation of gold than to its tenacity. It may be added that some of the metals, zinc and rhodium for instance, although possessing smaller atomic volumes than gold, appear to diminish its elongation while they increase the tenacity of the precious metal. This diminution, though not very marked, causes an irregularity in the portion of the diagram occupied by metals with smaller atomic volumes than gold.

Mode of Purifying the Gold employed in the Experiments.

The gold employed in the foregoing experiments was purified by a method which was adopted, after much careful consideration, by the author of this paper in the preparation of the "Trial Plate" of gold which, by the direction of the Lords Commissioners of H.M.'s Treasury, was to supplement the "Standard Trial Plate," the use of which, for verifying the composition of the coinage, has been prescribed by law since the 17th year of King Edward IV. The purity of the gold so prepared has been recognised by M. STAS, and Mr. LOCKYER has also satisfied himself of its high degree of purity by a comparison of photographs of its spectrum. The gold, having been used in the Assay Office of the Mint throughout a long period of years, had already been purified many times, and the only metallic impurities liable to have become associated with it were silver, platinum, and lead; and those only in very minute quantities. This gold was dissolved in nitro-hydrochloric acid, the excess of acid being driven off by slow evaporation. Platinum and the allied metals were carefully sought for, but were not detected, and the chloride of gold was then dissolved in a large quantity of distilled water, so that each gallon contained about one ounce of metal. This solution was allowed to rest for three weeks, when the finely-divided chloride of silver was separated by careful decantation of the supernatant solution. The last traces of chloride of silver are only thrown out of solution when chloride of gold is rendered very dilute. A warm solution of oxalic acid was then added, to precipitate the gold; the first and last portions of the gold precipitated were rejected, the middle portion being carefully washed with hot hydrochloric acid of sp. gr. 1·1, afterwards melted, with the addition of bisulphate of potash, in a clay crucible and cast in a stone mould.

There are other methods of obtaining pure gold, which are, in some respects, more simple, and the best of these is, perhaps, that which involves the precipitation of gold from its chloride by the passage of a stream of pure sulphurous anhydride. The author believes, however, that the method above described is the most trustworthy, a view which is confirmed by Messrs. HOFMANN and KRÜSS, who, in a recent paper,* state the results of submitting to a careful examination certain methods employed for separating gold from other metals, and they conclude that oxalic acid is the best reagent for separating gold from platinum, which was the metal the presence of which the author was most anxious to avoid. In discussing the results obtained by Messrs. HOFMANN and KRÜSS, Mr. W. BETTEL† points out that for large quantities of gold sulphurous anhydride is not a suitable precipitant.

* 'LIEBIG's Annalen,' vol. 238, 1887, p. 66.

† 'Chemical News,' vol. 56, 1887, p. 133.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

DIAGRAM I _ TENSILE STRENGTH AND ATOMIC VOLUMES

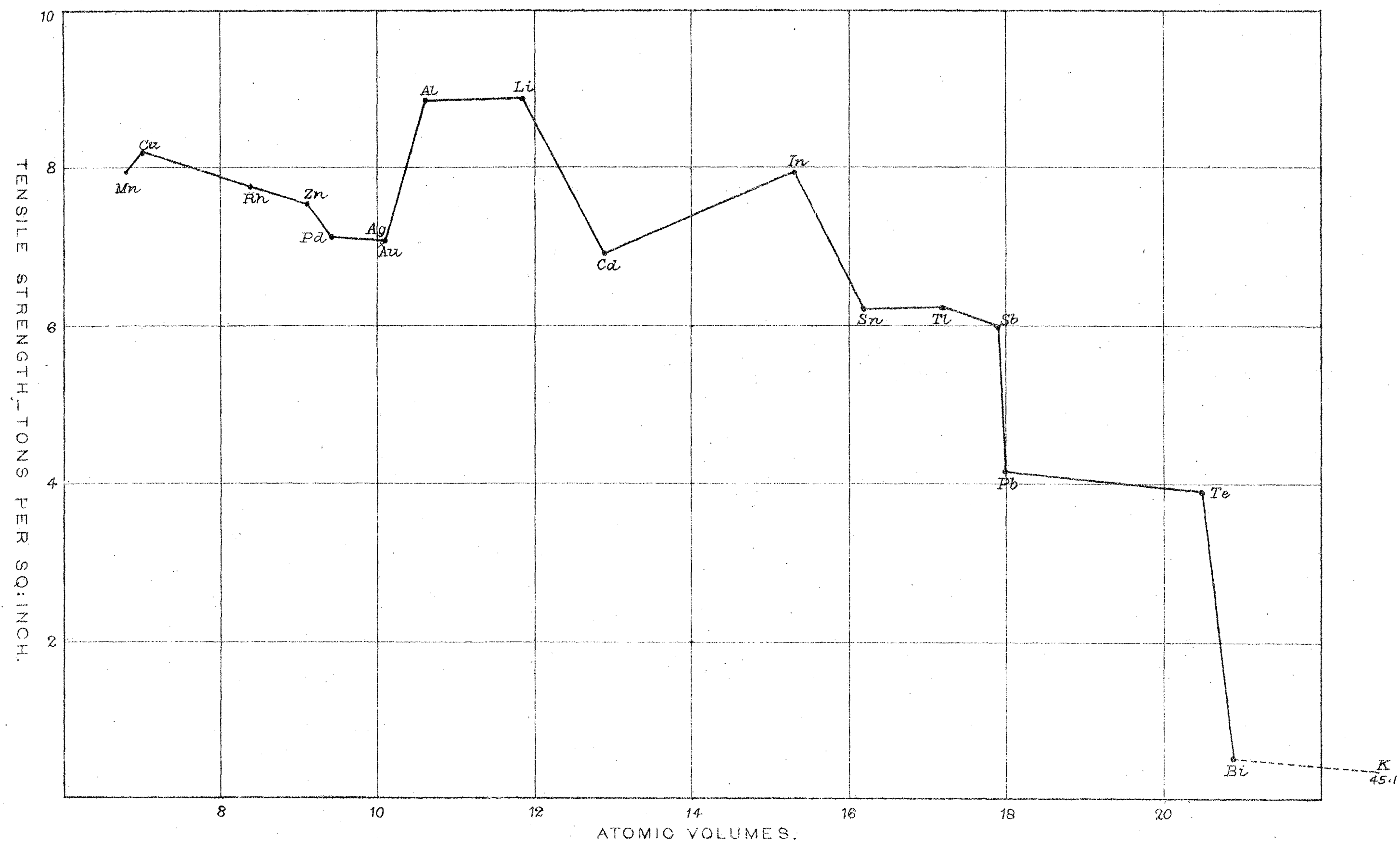


DIAGRAM II _ ELONGATION AND ATOMIC VOLUMES