PRACTICAL METALLURGY

AN ELEMENTARY TEXT-BOOK

For the Use of Classes under Subject 19 of the Syllabus issued by the Board of Education, Secondary Branch, South Kensington

BY

ALFRED ROLAND GOWER, F.C.S.

SCIENCE MASTER IN THE MUNICIPAL TECHNICAL SCHOOLS,
AND TO THE SCHOOL BOARD, BARROW-IN-FURNESS

NEW EDITION

LONDON:
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11 HENRIETTA STREET, W.C.
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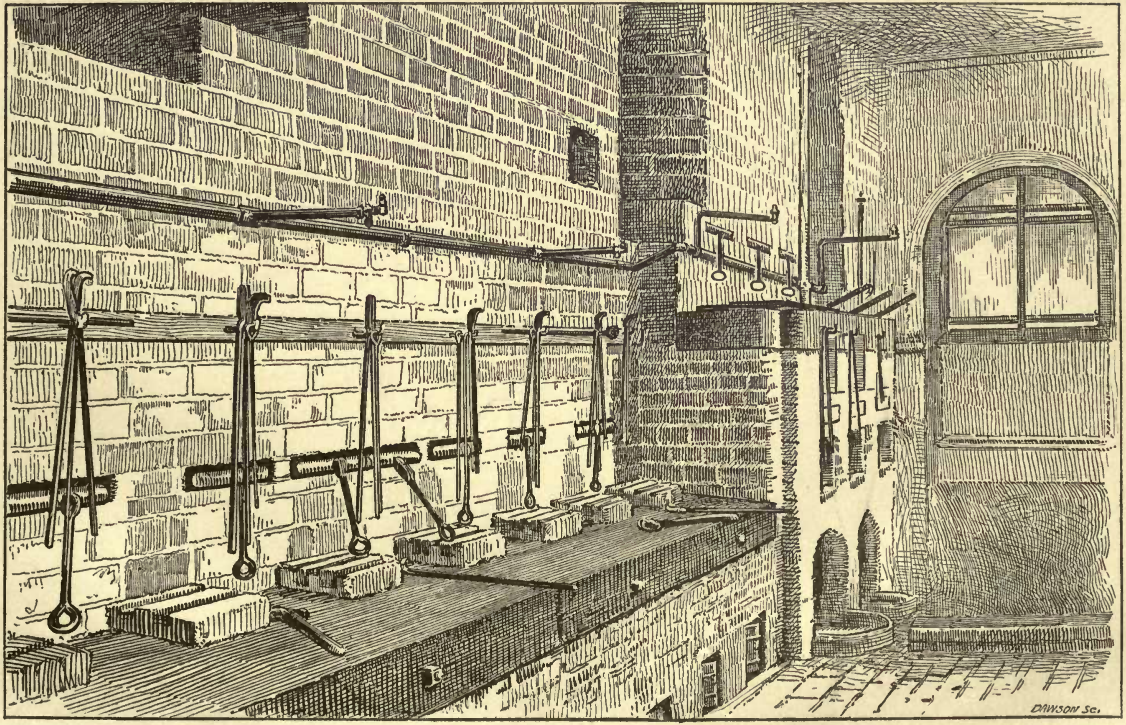
DAWSON Sc.

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General

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PREFACE.

THE re-issue of this small work is intended to meet the requirements of the Elementary and Advanced Students in classes under Subject 19, Practical Metallurgy, of the Board of Education, Secondary Branch, South Kensington.

In it is arranged a series of typical experiments illustrative of the subjects in the Syllabus.

Part I. treats of such experiments as may be readily performed in a metallurgical laboratory, with the aid of balances turning with ·5 grain when loaded with 500 grains in each pan, and contains all that is necessary for a student presenting himself for the elementary examination.

In Part II. many of the experiments are such as would require a balance turning with ·005 grain when loaded with 100 grains in each pan, and they, together with those described in Part I., will be found sufficient to enable students to pass in the advanced examination.

The book has been brought up to date by the introduction of some experiments on cementation as applied to iron, and others on the treatment of gold ores by the chlorination processes.

I have added, in the form of an Appendix, a very brief description of most of the various ores, &c., with which students entering for the Advanced and Honours Theoretical Examination are expected to be acquainted, in the hope that it may be useful in discriminating and naming metallurgical minerals. A table of equations of the principal reactions which take place in metallurgical operations has also been appended.

The importance of students in Practical Metallurgy having some previous knowledge of theoretical chemistry cannot be overestimated, at least as far as combining proportion, valency, and the various laws and theories that are to-day received in chemical philosophy, as no useful knowledge of Practical Metallurgy can be acquired unless upon this foundation.

I take this opportunity of thanking my friend, Mr. F. J. Hardy, for the able manner in which he has sketched the illustrations for these pages, and also of expressing my indebtedness to my old and valued friend, Mr. A. Adams, for examining the proof-sheets, and for various suggestions so kindly given.

A. R. GOWER.

BARROW-IN-FURNESS,
1902.

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PART I.

INTRODUCTION.

As all metallurgical processes and assays depend more or less upon chemical action, it is necessary that the metallurgist should be acquainted with at least a general outline of chemical combination and nomenclature, and especially those branches of chemistry that treat of metallic oxides, sulphides, carbonates, silicates, and phosphates. The terms oxidising agent and reducing agent should also be clearly understood.

A knowledge of chemistry is necessary to enable the assayer to bear in mind the object of his experiments, and the reason for the addition of the various reagents and fluxes employed; it will also teach him that when the gangue is acid a basic flux should be added, and in like manner if the gangue is basic the flux must be of an acid character. He should also know that slags or silicates with one base are less fusible than those with two or more bases. The selective power of some elements for each other should be known, *e.g.*, the superior affinity of copper for sulphur, of iron for oxygen and silica, and of nickel for arsenic.

The substances used in metallurgical operations are divisible into five classes:—(1), Reducing agents, or substances that so act upon compounds as to reduce them to a lower state of oxidation; (2), oxidising agents, which give up oxygen to the substance under treatment; (3), desulphurising agents which remove sulphur from the compound body, and which are frequently also oxidising agents; (4), sulphurising agents which give up sulphur to the substance under treatment; (5), fluxes, which are added to the material to make it more fusible, or to unite with the extraneous matter to form a fusible slag.

In the first class, or reducing agents, may be placed :—(1), Hydrogen gas; (2), carbon and carbon monoxide; (3), fats, oils, &c. Hydrogen is not used in metallurgical operations, but is a very valuable reducing agent in the laboratory. Carbon is used in the form of vegetable charcoal, blacklead or graphite, and anthracite. Fats, oils, &c., may be looked upon as combinations of the other two, hydrogen and carbon, and include resin, starch, sugar, gum, &c.

The second class, or oxidising agents, comprise oxygen from the air, carbon dioxide, litharge, white lead and red lead, potassium nitrate, copper oxide, potassium and sodium oxides and carbonates, and some metallic sulphates. Oxygen gas is the reagent most largely used, not only on account of its widespread distribution and accessibility, but also on account of the energy of its affinities. Carbon dioxide yields half its oxygen and becomes carbon monoxide. The lead oxides are useful as yielding their oxygen to less oxidisable metals. Potassium nitrate or saltpetre is a very energetic oxidising agent, as it liberates oxygen in a nascent state when raised to a red heat. Copper oxide is capable of yielding oxygen and being reduced to metallic copper or cuprous oxide.

The third class, or desulphurising agents, include oxygen, oxidising agents as potassium nitrate, litharge, potassium and sodium carbonates, and iron. Oxygen and oxidising agents remove sulphur by forming sulphurous and sulphuric anhydrides. Potassium and sodium carbonates are employed with carbon as desulphurising agents, and metallic iron is used largely to decompose lead sulphide.

Of the fourth class, sulphur is the most important in assaying, but iron and copper pyrites are largely used in metallurgical operations. Galena, cinnabar, and stibnite, are occasionally used.

Of the fifth class, or fluxes, the most common are silica, glass, borax, lime, china-clay, potassium carbonate, sodium carbonate, nitre or saltpetre, argol or tartar, fluor-spar, common salt, magnesia, and potassium cyanide.

Silica ($Si\,O_2$) is added when the extraneous matter is basic, as lime ($Ca\,O$), alumina ($Al_2\,O_3$), oxide of iron ($Fe_2\,O_3$), &c., and, under the influence of heat, combines to form fusible silicates or slags. Quartz and white sand are examples of silica that may be used.

Glass is a polybasic silicate containing sixty to eighty per cent of SiO_2, and varying quantities of CaO, Al_2O_3, potash (K_2O), and soda (Na_2O), and occasionally small amounts of Fe_2O_3, manganese oxide (MnO_2), magnesia (MgO), and lead oxide (PbO). It is often used as a flux to form a more fusible slag, or simply to cover the surface of the contents of the crucible and to exclude the air.

Borax ($Na_2B_4O_7 + 9\,OH_2$) is largely used as a flux when melting gold (Au) and silver (Ag), as it combines with the base metals and removes them in the slag. It loses water when heated, swells up, melts, and becomes vitreous.

Lime (CaO) is used as a flux to remove silica and forms a fusible silicate of lime.

China-clay, or kaolin (Al_2O_3, $3\,SiO_2$, $2\,H_2O$), is a pure variety of clay, and is used as a flux when the gangue is not sufficiently fusible, in which case it forms a multiple silicate which are more fusible than single silicates.

Potassium carbonate (K_2CO_3) and sodium carbonate (Na_2CO_3) form fusible compounds with metallic oxides when heated. They are very fusible, and are able, by virtue of their fluidity, to retain in suspension a large portion of infusible substances, and allow such metals as gold and silver to settle to the bottom of the crucible. A mixture of equal parts of K_2CO_3 and Na_2CO_3 is generally used, and is called fusion mixture.

Nitre (KNO_3) forms very fluid slags, and becomes converted into K_2CO_3 when heated in the presence of excess of charcoal.

Tartar, or argol ($\bar{T}o\,Ho\,Ko$), is a crude cream of tartar, which is deposited during the fermentation of wine, being insoluble in alcohol, and which contains potassic tartrate; it therefore contains a large amount of carbon, and is generally used with KNO_3.

Fluor-spar (CaF_2) is used as a flux for barytes, or heavy spar, gypsum, and for bone ash.

Salt ($NaCl$), when heated with some metallic sulphates, causes them to melt with the evolution of chlorides frequently volatile.

Magnesia (MgO) is used with lime when the gangue is acid, and requires some basic material.

Potassium cyanide (KCy) is used in the tin assay, both as a reducing agent and flux. It forms very fusible slags.

The name crucible is given to vessels made of fireclay which have been baked in a kiln or oven, and which are used for some metallurgical operation. Vessels made of charcoal, plumbago, iron, porcelain, and platinum, bear the same name, and are employed in assaying for various purposes. The clay crucibles, or, as they are generally called, *pots*, are of different makes, and are distinguished by the name of the district whence the clay is derived: *e.g.*, Cornish crucibles, London crucibles, and Stourbridge crucibles. The crucibles are made of various mixtures of raw and burnt clay, usually consisting of two-thirds raw, and the remainder of burnt clay, ashes, plumbago, &c. When plumbago is added they are called blacklead, or plumbago crucibles, and possess the advantage of having smooth surfaces, and of being able to stand without cracking excessive change of temperature. Clay crucibles should be capable of standing a high temperature without softening, should be able to undergo great changes of temperature without cracking, they should not be much attacked by substances fused in them, and they should be impermeable to liquids and gases. Crucibles are sometimes lined with charcoal, when they are said to be brasqued. Iron crucibles are occasionally used in the assay of galena; porcelain and platinum crucibles are used for deflagrations and ignitions, in cases where the result has to be accurately weighed.

Scorifiers are shallow vessels, with thick walls, made of fireclay, into which is introduced any alloy from which it is desirable to remove the base metals, by causing them to unite with the silica of the scorifier, and form a fusible slag. (Fig. 1.)

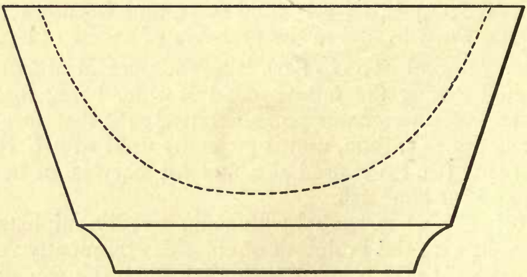

Fig. 1.

Cupels are small vessels in which assays of gold and silver are made, which operation is called cupellation. Cupels are made of the ashes of burnt bones, finely powdered and sieved, and made of the proper shape by being moistened and forced into an iron mould. If the bone ash is not of a sufficient degree of fineness the cupels easily break, and some of the assay is lost by sinking into the pores while the cupellation is proceeding.

The material of which an assay is to be made should first be reduced to a state of fine powder by means of a mortar and pestle (Fig. 2), and sifted through a sieve sufficiently fine. Sieves are called by the number of meshes in a linear inch: thus, a 60 sieve would have sixty meshes to the linear inch, and an 80 sieve would have eighty meshes, and so on. The operation of washing, or vanning, is often resorted to, in order to remove most of the gangue, or extraneous matter, before an assay of the ore proper is made. This is especially the case with tin ore, for if too much silica is present the ore is not completely reduced.

Fig. 2.

REDUCTION OF OXIDES.

The oxides of most metals are reduced to a metallic state by the action of heat and carbon. The oxides of the metals, mercury (Hg), silver (Ag), and gold (Au), are reduced by heat without the aid of any other reducing agent. The heat, however, required to reduce the oxides in the presence of carbon varies with the different metals. The temperature required for lead is comparatively low, that for copper and iron is higher, and that for tin and zinc very high. In all the experiments in this section, except Experiment 4, carbon is the reducing agent employed, which, however, in Experiment 9, is supplemented by potassium cyanide. When reduction occurs at a low temperature the carbon forms carbon dioxide, but at a higher temperature carbon monoxide, or a mixture of the two is formed. In Experiment 4, the heat to which the red lead is subjected is sufficient to reduce it to a lower state of oxidation, and, therefore, the reducing agent is heat.

The following metals are reduced from their oxides by heat alone :—Gold (Au), iridium (Ir), mercury (Hg), platinum (Pt), palladium (Pd), rhodium (Rh), ruthenium (Ru), silver (Ag).

Experiment 1.—Weigh out 300 grs. of litharge (PbO) and 12 grs. of finely powdered wood charcoal (C), mix well together on a piece of glazed paper, and introduce into a small crucible; heat in wind furnace (Fig. 3, see also Frontispiece), with a moderate fire, for about 7 minutes. The reaction takes place at a red heat, lead (Pb) is reduced, and carbonic anhydride (CO_2) liberated, according to the equation :—

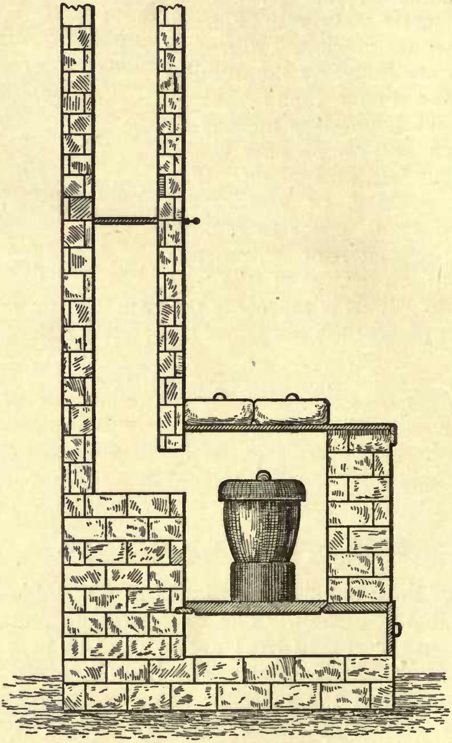

Fig. 3.

$$2\ PbO + C = CO_2 + 2\ Pb.$$

When the contents of the crucible appear liquid, pour into hemispherical mould (Fig. 4), allow to cool, and weigh the button of lead. The above equation gives for the reaction of this experiment two products, namely, metallic lead and gaseous carbonic anhydride, to produce which the whole of the material introduced is necessary. If, therefore, any other substance is produced, the experiment is faulty, and should be repeated. The substance that might possibly be produced is silicate of lead, which is a glassy, yellow substance, which does not pour so readily as lead from the crucible. It has the composition $2\,PbO, SiO_2$, and is formed by the combination of the acid silica of the crucible with the basic oxide of lead. If any of this silicate is formed it must be at the expense of the lead, and, consequently, the weight of the lead obtained will fall short of the quantity obtainable from the 300 grs. of litharge taken. If no silicate is formed, the crucible may be used for another experiment, after removing any shots of metal that may have adhered to the inside.

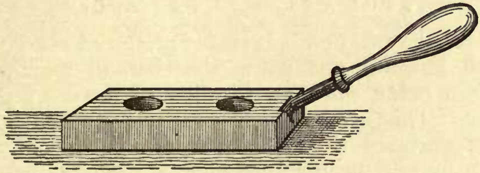

Fig. 4.

It may be ascertained by a very simple calculation what the weight of the lead obtained should be. As the sum of the atomic weights* of PbO is to the atomic weight of Pb, so is 300 grs. (the quantity of litharge taken) to the quantity of lead produced.

$$\begin{array}{rcl} Pb &=& 207 \\ O &=& 16 \\ \hline PbO &=& 223 \end{array} \qquad \begin{array}{cccccccc} & PbO & & Pb & & PbO & & Pb \\ \text{As} & 223 & : & 207 & :: & 300 & : & x \end{array}$$

$$\frac{207 \times 300}{223} = 278 \text{ grs. Pb.}$$

If the weight of the button of lead corresponds somewhat to the above quantity, making allowance for a small quantity of impurity in the litharge, the next experiment may be proceeded with.

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* See Appendix C for table of atomic weights.

Experiment 2.—Take 300 grs. of PbO and 25 grs. of charcoal. Mix well together, transfer to crucible, and heat as before for about 7 minutes. Pour into mould, and describe the appearance of the product. In this experiment the mass is not altogether melted, but consists of a quantity of charcoal, amongst which the reduced lead is distributed as fine shots.

The lead may be separated from the unused charcoal by turning the whole out into a dish containing water, when the charcoal, owing to its inferior specific gravity, may be washed away. The chemical action may be expressed by the equation :—

$$2\,PbO + 2\,C = CO_2 + 2\,Pb + C.$$

As before, the two new substances produced are Pb and CO_2. In this case, however, one-half of the charcoal remains unused, the other half being sufficient to allow of the chemical changes taking place. This excess of charcoal acts mechanically in preventing the particles of lead from uniting together, and so forming one button, as in Experiment 1. There should be the same quantity of lead produced as in the former experiment, there having been the same quantity of litharge taken, none of which has escaped reduction.

Experiment 3.—Take 300 grs. of litharge and 6 grs. of charcoal. Mix, and heat in crucible for about 5 minutes, and pour into mould. On examination the product will be found to consist of two parts: the bottom and central portions of lead, and the remaining portion of fused litharge. The chemical change may be thus expressed :—$4\,PbO + C = CO_2 + 2\,Pb + 2\,PbO$; showing that two parts of PbO are in excess of the charcoal taken to reduce it. It is particularly necessary in this case to observe the rule as to temperature, owing to the increased tendency to form silicate, from the fact of PbO, the base of the silicate, being melted in contact with the silica of the crucible. Fused litharge and silicate of lead have very much the same appearance, but they may be readily distinguished by breaking. The fracture of the litharge is crystalline, while that of the silicate is vitreous.

Experiment 4.—Take 300 grs. of red lead (Pb_3O_4),* melt in a crucible, and pour into mould. The product is crystallised litharge; the time required is about 5 minutes. This is an example of reducing to a lower state of combination, while the first three experiments were examples of complete reduction and

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* The red lead of commerce is more correctly represented by Pb_4O_5.—VALENTIN.

separation of the metal. The litharge may now be crushed in a mortar, when it will be observed that it has the same appearance as that which was taken for reduction in the former cases, the crystalline appearance of the fused litharge being lost by crushing. The litharge should be weighed, and compared with the calculated quantity, which may be ascertained in the same manner as before. Equation :—

$$Pb_3O_4 = 3\,PbO + O.$$

As the sum of the atomic weight of red lead is to the molecular weight of the litharge produced, so is 300 to the actual weight in grs. of litharge formed.

$$\begin{array}{r} Pb_3 = 621 \\ O_4 = 64 \\ \hline Pb_3O_4 = 685 \\ \hline 3\,Pb = 621 \\ 3\,O = 48 \\ \hline 3\,PbO = 669 \\ \hline \end{array}
\qquad
\begin{array}{cccccccc} & Pb_3O_4 & & 3\,PbO & & Pb_3O_4 & & PbO \\ \text{As} & 685 & : & 669 & :: & 300 & : & x \end{array}$$

$$\frac{669 \times 300}{685} = 291{\cdot}5 \text{ grs. } PbO.$$

Experiment 5.—Weigh out 300 grs. of red lead and sufficient charcoal to reduce it according to the equation :—

$$Pb_3O_4 + 2\,C = 2\,CO_2 + 3\,Pb.$$

Mix well together, and heat in crucible for about 7 minutes; pour into round mould and weigh the lead obtained. Calculate the quantity of charcoal required. First get the molecular weight of Pb_3O_4 and twice the atomic weight of C :—

$$\begin{array}{r} Pb_3 = 621 \\ O_4 = 64 \\ \hline Pb_3O_4 = 685 \\ \hline 2\,C = 24 \\ \hline \end{array}
\qquad
\begin{array}{cccccccc} & Pb_3O_4 & & 2\,C & & Pb_3O_4 & & C \\ \text{As} & 685 & : & 24 & :: & 300 & : & x \end{array}$$

$$\frac{24 \times 300}{685} = 10{\cdot}5 \text{ grs. charcoal.}$$

As the powdered charcoal is not pure carbon, but contains earthy matter and moisture, a little more than demanded by the equation should be taken, viz., 12 grs.

The calculation of the quantity of lead produced should also be made, thus:—

$$\begin{array}{cccccccc} & Pb_3O_4 & & 3\,Pb & & Pb_3O_4 & & Pb \\ \text{As} & 685 & : & 621 & :: & 300 & : & x \end{array}$$

$$\frac{621 \times 300}{685} = 272 \text{ grs. } Pb.$$

Experiment 6.—Take 300 grs. of cupric oxide ($\mathrm{Cu\,O}$), and sufficient charcoal to reduce it according to the equation:—

$$\mathrm{Cu\,O + C = CO + Cu}.$$

When reduced and melted pour into mould. A higher temperature will be required for this experiment than for any of the preceding ones. The C combines with the oxygen in a different proportion, as shown by the equation, carbon monoxide (CO) being formed, and not $\mathrm{CO_2}$ as in the other experiments where lead was the metal dealt with. $\mathrm{CO_2}$ cannot exist at high temperatures, but is immediately converted into two parts of CO by taking up another atom of C. The required amount of charcoal may be calculated by ascertaining the molecular weight of cupric oxide and the atomic weight of C.

$$\begin{array}{r} \mathrm{Cu} = 63 \\ \mathrm{O} = 16 \\ \hline \mathrm{Cu\,O} = 79 \\ \hline \\ \mathrm{C} = 12 \\ \hline \end{array} \qquad \begin{array}{cccccccc} & \mathrm{Cu\,O} & & \mathrm{C} & & \mathrm{Cu\,O} & & \mathrm{C} \\ \text{As} & 79 & : & 12 & :: & 300 & : & x \end{array}$$

$$\frac{12 \times 300}{79} = 43 \text{ grs. of charcoal.}$$

As before, a little excess of charcoal should be taken to allow for impurities.

The quantity of copper that should be produced may be ascertained in the same way.

$$\begin{array}{ccccccc} \mathrm{Cu\,O} & & \mathrm{Cu} & & \mathrm{Cu\,O} & & \mathrm{Cu} \\ 79 & : & 63 & :: & 300 & : & x \end{array}$$

$$\frac{63 \times 300}{79} = 239 \text{ grs. Cu.}$$

Experiment 7.—Take 100 grs. of zinc oxide ($\mathrm{Zn\,O}$) and sufficient charcoal to give reaction:—

$$\mathrm{Zn\,O + C = Zn + CO}.$$

Mix well together and place in crucible in a hot fire for about half an hour. For calculation of charcoal required:—

$$\begin{array}{r} \mathrm{Zn} = 65 \\ \mathrm{O} = 16 \\ \hline \mathrm{Zn\,O} = 81 \\ \hline \\ \mathrm{C} = 12 \\ \hline \end{array} \qquad \begin{array}{cccccccc} & \mathrm{Zn\,O} & & \mathrm{C} & & \mathrm{Zn\,O} & & \mathrm{C} \\ \text{As} & 81 & : & 12 & :: & 100 & : & x \end{array}$$

$$\frac{12 \times 100}{81} = 15 \text{ grs. charcoal.}$$

Zinc is a metal that requires a high temperature for its reduction, and it is also one of the most volatile metals. The heat necessary to reduce the oxide is greater than that required to vaporise the metallic zinc, therefore, instead of collecting and forming a button in the crucible, it passes away as zinc fume and condenses as zinc oxide in the flue and around the top of the crucible. It must be understood that zinc oxide is reduced as the other metallic oxides have been in the former experiments, but in this case the metal is not collected. When it is desired to collect the reduced zinc the operation must be performed in a closed retort, which, of course, must be made of some material, as fireclay, that will withstand the temperature. The volatilised zinc may be seen burning with its characteristic blue flame combining with the O of the air, and forming zinc oxide (ZnO). If the proper quantity of charcoal is taken, and the zinc oxide is pure, the crucible may be taken from the fire quite clear, as it will be seen from the equation, that only two substances are formed, the gas, CO, and the metal zinc, which is in a gaseous state. It may be noted that CO is formed, owing to the high temperature employed, and not CO_2, as in the earlier experiments.

Experiment 8.—Take 500 grs. of tin oxide (SnO_2) and 100 grs. of anthracite. The *putty powder* of commerce may be used for the SnO_2, and the anthracite should be powdered and passed through a 60 sieve. Heat in a small blacklead crucible for 20 minutes at a high temperature. Remove from the fire and stir round the inside of the crucible with a piece of wood. This detaches any small shots of metal that may have been adhering to the sides and causes them to collect at the bottom of the crucible. Replace the crucible in the fire for 10 minutes; pour into mould, and when cold turn into a dish containing water. Wash away the excess of anthracite and fuse remainder in small clay crucible with 30 grains of carbonate of soda (Na_2CO_3); pour when melted, and weigh the button of tin.

$$SnO_2 + 2\,C = 2\,CO + Sn.$$

To find the quantity of tin :—

$$\begin{array}{lcccccccc} \mathrm{Sn}=118 & & & & & & & & \\ \underline{\mathrm{O_2}=\ \ 32} & & \mathrm{SnO_2} & & \mathrm{Sn} & & \mathrm{SnO_2} & & \mathrm{Sn} \\ \underline{\underline{\mathrm{SnO_2}=150}} & \text{As} & 150 & : & 118 & :: & 500 & : & x \end{array}$$

$$\frac{118 \times 500}{150} = 393 \text{ grs. Sn.}$$

To find the percentage 393 ÷ 5 = 78·6 per cent.

The temperature required to reduce tin oxide is high, while that required to melt it is low, tin being one of the most fusible of metals.* Anthracite is used in the tin reduction process in preference to charcoal on account of its superior density, which prevents its being burnt away to the same extent as charcoal would be at the high temperature used in these reductions.

Experiment 9.—Take 100 grs. of tin oxide ($Sn\,O_2$), and 100 grs. of potassium cyanide ($K\,Cy$), and 30 grs. of anthracite. Place in clay crucible, and heat for 10 or 15 minutes. Pour into mould, detach slag, and weigh tin.

$$Sn\,O_2 + K\,Cy = K\,Cy\,O + Sn.$$
$$Sn\,O_2 + 2\,C = 2\,CO + Sn.$$

This is the first experiment in which a slag had been produced, and it consists of potassium cyanate ($K\,Cy\,O$), together with the impurities of the tin oxide. The $K\,Cy$ and the anthracite are the reducing agents, and the reduction should be as complete, and consequently the percentage of tin as great, as before.

Experiment 10.—Take a lump of hematite ($Fe_2\,O_3$) about the size of a walnut, and after weighing place in a crucible, cover with powdered charcoal, and heat at low temperature for one hour. The crucible should be kept covered with a piece of coke or a fireclay lid, allowed to cool and the contents turned out, when the piece of hematite will be found reduced to iron, and its colour changed from red to black. The heat should not be sufficient to fuse either the hematite or the iron. Although the product is iron, it is not malleable on account of its non-homogeneity. This is an example of a metal with a high melting point, but whose oxides are reduced at a much lower temperature. The varieties known as *puddler's ore*, *red ochre*, or *kidney ore*, may be used in this experiment. The reaction may be expressed by the equation:—

$$2\,Fe_2\,O_3 + 3\,C = 3\,CO_2 + 4\,Fe.$$

Or more correctly by:—

$$Fe_2\,O_3 + 3\,CO = 3\,CO_2 + 2\,Fe.$$

For in this case the reducing agent is CO.

Weigh the reduced iron and calculate the percentage.

---

* See Appendix B.

From the equation we see that 160 parts of hematite yield 112 parts of iron, therefore 100 will yield in the same ratio.

$$\begin{array}{r} \mathrm{Fe_2} = 112 \\ \mathrm{O_3} = 48 \\ \hline \mathrm{Fe_2O_3} = 160 \\ \hline \end{array} \qquad \begin{array}{cccccccc} & \mathrm{Fe_2O_3} & & 2\,\mathrm{Fe} & & \mathrm{Fe_2O_3} & & \mathrm{Fe} \\ \text{As} & 160 & : & 112 & :: & 100 & : & x \end{array}$$

$$\frac{112 \times 100}{160} = 70 \text{ per cent Fe.}$$

Experiment 11.—Crush and pass through 60 sieve a sample of hematite; weigh out 200 grs., and mix with 50 grs. of charcoal and 100 grs. of powdered glass (free from lead). Lute* the lid on the crucible, dry gradually and heat for 1 hour at the highest furnace temperature. The equation expressing the change is the same as before:—

$$2\,\mathrm{Fe_2O_3} + 3\,\mathrm{C} = 3\,\mathrm{CO_2} + 4\,\mathrm{Fe}.$$

The action of the glass is to form a fusible slag, the advantage of which is that the metal, owing to its superior specific gravity (sp. gr.), sinks to the bottom and forms one button. The weight of the button divided by 2 gives the percentage of iron in the ore.

FORMATION OF OXIDES.

ALL metals may be made to combine with oxygen (O) although their affinities for that element differ widely. Some combine at all temperatures if in contact with the air, *e.g.*, barium (Ba), calcium (Ca), lithium (Li), potassium (K), sodium (Na), and strontium (Sr), and can only be reduced to a metallic state with difficulty. On the other hand, some metals possess so little affinity for O that they cannot be made to combine with it directly, and on the application of heat to their oxides they become reduced to the elementary state, *e.g.*, Au, Pt, and Ag.

The common metals unite with O when heated in the presence of air, *e.g.*, antimony (Sb), bismuth (Bi), copper (Cu), iron (Fe), lead (Pb), tin (Sn), zinc (Zn), &c.

It will be noticed that there are two oxides of lead that may

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* See Appendix A, note 1.

be formed by heating lead in contact with the air—the plumbic oxide, massicot or litharge (PbO), and the red oxide, red lead or minium (Pb_3O_4). PbO may also be obtained by heating lead nitrate, carbonate, or oxalate, in contact with air, when it is of a yellow colour. If the massicot is heated to a full red heat, it melts and forms the crystallised variety called litharge. If litharge is heated with many metallic oxides it yields fusible compounds, even though the metallic oxide may of itself be infusible, *e.g.*, Fe_2O_3, SnO_2, and ZnO.

Pb_3O_4 is produced by roasting the PbO for some time, when it becomes further oxidised. It is used largely as a pigment, and in the manufacture of glass. If heated to a bright red heat it is decomposed, O being given off and PbO remaining.

$$Pb_3O_4 = 3\ PbO + O.$$

Tin oxide (SnO_2) is prepared in the same way as PbO, and the crude oxide is removed as fast as formed, and then subjected to a further calcination for the production of putty powder, which is used for polishing.

The product of burning vapour of Zn has the composition ZnO; it is yellow when hot, and white when cold. It is used for the production of the pigment known as *zinc white.*

Cupric oxide (CuO) is produced when finely-divided copper is heated for some time in the presence of excess of air. The red oxide of copper, cuprous oxide (Cu_2O), is made by melting the black oxide with metallic copper in the proper proportions.

It is possible to produce Cu_2O by fusing two parts of CuO with one part of carbon, according to the equation :—

$$2\ CuO + C = CO + Cu_2O.$$

This operation is not, however, reliable, as very frequently some of the oxide is reduced to the metallic state, and the rest remains unaltered.

The pure variety of Cu_2O is used to impart a ruby colour to glass.

Experiment 12.—Weigh out 300 grs. of lead. Place in roasting dish (Fig. 5), and melt in muffle at a low temperature, when the surface of the lead will become oxidised. The oxide should be removed with an iron scraper, so as continually to expose fresh surface for oxidation, until the whole has been converted into oxide. The oxide formed has the same composition as litharge, but has not the same appearance. On examination it will be found to contain some unoxidised lead, which should be separated, remelted in the dish, and treated as before. This particular form of oxide of lead is termed *massicot*, and may be converted into litharge by fusion, in which case the melted mass may be poured into a mould, and compared with the result of Experiment 4. The change may be thus expressed:—

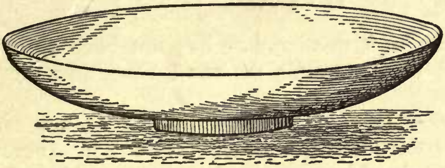


Fig. 5.

$$Pb + O = Pb\,O.$$

Care should be taken not to get the temperature too high during the process of oxidation, or the massicot will melt and combine with the substance of the dish, forming silicate of lead. The litharge formed from the fusion of the massicot may be made to take up another atom of O, and become converted into red lead, by first reducing it to powder, and then heating it in a roasting dish for an hour, with occasional stirring.

$$3\ Pb\,O + O = Pb_3\,O_4.$$

The massicot should have been weighed before melting, and the increase of weight noted. Every 207 parts of lead take up 16 parts of O from the air, therefore the ratio is as

$$\begin{array}{ccccccccl} Pb & & Pb\,O & & Pb & & Pb\,O & & \\ 207 & : & 223 & :: & 300 & : & x & & = 323 \text{ grs. } Pb\,O. \end{array}$$

Experiment 13.—Take 300 grs. of tin, and proceed as in the last experiment. The precautions as to heat need not be observed in this case, as the oxide of tin is infusible, consequently there is no risk of forming silicate. The increase in weight should be noted, and it will be found that every 118 parts of tin will take up 32 parts of O.

$$Sn + O_2 = Sn\,O_2.$$

Find the increase in weight of quantity taken.

$$\begin{array}{llllllll}
\mathrm{Sn} = 118 & & & & & & & \\
\mathrm{O_2} = \ \ 32 & & \mathrm{Sn} & \mathrm{Sn\,O_2} & & \mathrm{Sn} & \mathrm{Sn\,O_2} & \\
\hline
\mathrm{Sn\,O_2} = 150 & \text{As} & 118 : & 150 & :: & 300 : & x & = 381 \text{ grs. } \mathrm{Sn\,O_2}.
\end{array}$$

If, on weighing, this increase has not been obtained, it should be returned to the muffle for some time, and the mass stirred occasionally.

Experiment 14.—Melt 300 grs. of Zn at low temperature in a crucible covered with a loosely-fitting lid. Increase the temperature until the Zn is converted into zinc oxide, $\mathrm{Zn + O = Zn\,O}$.

This experiment is performed in a wind furnace.

As seen in Experiment 7, zinc may be readily converted into vapour by the application of heat, which vapour, coming in contact with the atmosphere, burns with its characteristic blue flame, forming zinc oxide. When this blue flame is no longer seen, remove crucible from the fire, and notice that the oxide is yellow while hot and white when cold.

Experiment 15.—Take 300 grs. of copper filings, and roast in muffle for 1 hour at a red heat, stirring occasionally. The red metallic copper will be converted into a black non-metallic mass of cupric oxide ($\mathrm{Cu\,O}$), $\mathrm{Cu + O = Cu\,O}$.

$$\begin{array}{llllllll}
\mathrm{Cu} = 63 & & & & & & & \\
\mathrm{O} \ \ = 16 & & \mathrm{Cu} & \mathrm{Cu\,O} & & \mathrm{Cu} & \mathrm{Cu\,O} & \\
\hline
\mathrm{Cu\,O} = 79 & \text{As} & 63 : & 79 & :: & 300 : & x & = 376 \text{ grs. } \mathrm{Cu\,O}.
\end{array}$$

Experiment 16.—Take 300 grs. of Cu and sufficient cupric oxide to form cuprous oxide, according to the equation :—

$$\mathrm{Cu + Cu\,O = Cu_2\,O}.$$

Cut the copper into small pieces, and mix with the cupric oxide. Place in crucible, and heat in wind furnace at a high temperature. This operation should be carefully watched, and the contents of the crucible poured immediately upon showing signs of fusion. There is, perhaps, no base which has so great an affinity for silica as cuprous oxide. When these are heated in contact, combination will be sure to take place, forming a fusible slag, having the composition $\mathrm{2\,Cu_2\,O, Si\,O_2}$. If this is allowed to remain in the crucible for even a few seconds at a high temperature, the crucible will be perforated and the contents lost. The cuprous oxide should be weighed, and the theoretical quantity calculated. The calculation for the cupric oxide required is—

$$\begin{array}{rccccccccl} & \text{Cu} & & \text{Cu O} & & \text{Cu} & & \text{Cu O} & & \\ \text{As} & 63 & : & 79 & :: & 300 & : & x & = & 376 \text{ grs. Cu O,} \end{array}$$

and for the cuprous oxide formed—

$$\begin{array}{rccccccccl} & \text{Cu} & & \text{Cu}_2\text{O} & & \text{Cu} & & \text{Cu}_2\text{O} & & \\ \text{As} & 63 & : & 142 & :: & 300 & : & x & = & 676 \text{ grs. Cu}_2\text{O.} \end{array}$$

FORMATION OF SULPHIDES.

SULPHUR may be made to combine with all the metals, but its affinity for the noble metals is so slight that their sulphides may be reduced by heat alone.

Lead and sulphur combine readily when heated together in a closed vessel, or they may be made to combine by heating $Pb\,O$ with excess of sulphur. In either case the resulting sulphide is brittle, and of a bluish grey colour. Its composition is expressed by $Pb\,S$.

Copper sulphide ($Cu_2\,S$) is formed by heating Cu and S together in a closed vessel, combination taking place with incandescence. The sulphide, when melted and poured, is of a grey colour and semi-metallic appearance.

When iron and sulphur are heated together, they unite in proportions varying with the heat employed; the composition, however, may be taken to be $Fe\,S$, when made in an open crucible. It is a brittle body of semi-metallic appearance with a grey fracture, and is used for the production of sulphuretted hydrogen ($H_2\,S$), which gas is liberated when the sulphide is treated with hydrochloric acid ($H\,Cl$) or dilute sulphuric acid ($H_2\,SO_4$).

The *coarse metal* and the *blue metal* of the Welsh method of copper smelting, may be produced by melting together iron and copper sulphides (FeS and Cu_2S) in proper proportions. The coarse metal contains 30 per cent to 35 per cent copper, and about the same quantity of iron and sulphur. The blue metal contains 55 per cent to 60 per cent of copper, 12 per cent to 16 per cent of iron, and about 20 per cent of sulphur.

Sulphide of tin, produced by the direct union of tin and sulphur, has a bluish colour, and is difficult to pulverise, being somewhat malleable. The product frequently contains some unaltered tin.

Experiment 17.—Take 1000 grs. of granulated lead, and sufficient sulphur to form lead sulphide (PbS), mix, and place in crucible. Heat at high temperature, having the crucible well down into the fire, and kept covered with a piece of coke. When all the lead is converted into sulphide, pour into hemispherical mould, allow to cool, and break to see crystals. The calculation for the sulphur required may, as before, be obtained from the equation :—

$$Pb + S = PbS.$$

$$\begin{array}{ccccccc} Pb & & S & & Pb & & S \\ 207 & : & 32 & :: & 300 & : & x = 46 \text{ grs. S.} \end{array}$$

The quantity of sulphide produced:—

$$\begin{array}{ccccccc} Pb & & PbS & & Pb & & PbS \\ 207 & : & 239 & :: & 1000 & : & x = 1154 \text{ grs. PbS.} \end{array}$$

The lead is granulated by first melting in a crucible or ladle, allowing it to cool down until nearly on the point of solidifying, and then pouring into a box which has been previously black-leaded, and violently shaking it, when the lead, which is brittle just below its melting point, breaks up into particles more or less fine, according to the skill with which this has been performed. The best method of making sulphides is to weigh out the theoretical quantity of flowers of sulphur and mix with small pieces of metal, and after heating for 5 minutes in a hot fire, drop into the crucible a lump of roll sulphur about as large as an almond. In a short time the sulphide should be poured.

Experiment 18.—Take 400 grs. of copper, and sufficient sulphur to form cuprous sulphide (Cu_2S). Proceed as in the last experiment, and when converted into sulphide pour into mould. Fracture when cold, examine, and weigh. There should be no metallic copper remaining. The calculation for the quantity of sulphur is obtained from the equation :—

$$2\,Cu + S = Cu_2S.$$

$$\begin{array}{ccccccc} 2\,Cu & & S & & Cu & & S \\ 126 & : & 32 & :: & 400 & : & x = 101 \text{ grs. S.} \end{array}$$

The quantity of sulphide produced:—

$$\begin{array}{cccccccc} \text{Cu} & & \text{Cu}_2\text{S} & & \text{Cu} & & \text{Cu}_2\text{S} & \\ 126 & : & 158 & :: & 400 & : & x & = 501 \text{ grs. Cu}_2\text{S.} \end{array}$$

Experiment 19.—Cut up into small pieces 400 grs. of hoop iron, and mix with sufficient sulphur to form ferrous sulphide (FeS). Proceed as before, and pour into mould. When cool, fracture, examine, and weigh.

$$Fe + S = FeS.$$

Quantity of sulphur required:—

$$\begin{array}{cccccccc} \text{Fe} & & \text{S} & & \text{Fe} & & \text{S} & \\ 56 & : & 32 & :: & 400 & : & x & = 228 \text{ grs. S.} \end{array}$$

Quantity of sulphide produced:—

$$\begin{array}{cccccccc} \text{Fe} & & \text{Fe S} & & \text{Fe} & & \text{Fe S} & \\ 56 & : & 88 & :: & 400 & : & x & = 628 \text{ grs. Fe S.} \end{array}$$

Experiment 20.—To make coarse metal. Take 200 grs. of Cu_2S and sufficient FeS to give reaction, as shown by the equation:—

$$Cu_2S + 3\,FeS = Cu_2S,\ 3\,FeS.$$

Crush finely, mix, and melt in crucible, and pour into round mould; when cold, break and examine fracture, comparing it with that of the ferrous sulphide. This corresponds somewhat with the product of the second stage of the Welsh copper-smelting process.

Quantity of FeS required:—

$$\begin{array}{cccccccc} \text{Cu}_2\text{S} & & 3\text{ Fe S} & & \text{Cu}_2\text{S} & & \text{Fe S} & \\ 156 & : & 264 & :: & 200 & : & x & = 334 \text{ grs. Fe S,} \end{array}$$

and the quantity of coarse metal produced:—

$$\begin{array}{cccccccc} \text{Cu}_2\text{S} & & \text{Cu}_2\text{S, 3 Fe S} & & \text{Cu}_2\text{S} & & \text{Cu}_2\text{S, 3Fe S} \\ 158 & : & 422 & :: & 200 & : & x \end{array}$$
$$= 534 \text{ grs. Cu S, 3 Fe S.}$$

Experiment 21.—To make blue metal. Take 200 grs. of Cu_2S and sufficient FeS to give reaction, as shown by the following equation:—

$$2\,Cu_2S + FeS = 2\,Cu_2S,\ FeS.$$

Crush finely, mix well together, and melt in crucible. Pour into round mould, allow to cool, and note the appearance. Compare the fracture with that of the coarse metal. This corresponds somewhat with the product of the fourth stage of the Welsh copper-smelting process.

Quantity of FeS required :—

$$\begin{array}{ccccccc} Cu_2S & & FeS & & Cu_2S & & FeS \\ 316 & : & 88 & :: & 200 & : & x = 55 \text{ grs. } FeS. \end{array}$$

Quantity of blue metal produced :—

$$\begin{array}{ccccccc} 2\,Cu_2S & & 2\,Cu_2S, FeS & & Cu_2S & & 2\,Cu_2S, FeS \\ 316 & : & 404 & :: & 200 & : & x \end{array}$$
$$= 255{\cdot}7 \text{ grs. } 2\,Cu_2S, FeS.$$

Experiment 22.—Mix with 200 grs. of granulated tin sufficient sulphur for the following equation :—

$$Sn + S = SnS.$$

Transfer to crucible, heat in fire until melted. Add a little roll sulphur, and pour the sulphide into a round mould. When cool, break and observe the appearance of the fracture. Weigh and compare with the calculated amount.

Quantity of sulphur required :—

$$\begin{array}{ccccccc} Sn & & S & & Sn & & S \\ 118 & : & 32 & :: & 200 & : & x = 54 \text{ grs. } S. \end{array}$$

Quantity of sulphide produced :—

$$\begin{array}{ccccccc} Sn & & SnS & & Sn & & SnS \\ 118 & : & 140 & :: & 200 & : & x = 237 \text{ grs. } SnS. \end{array}$$

REDUCTION OF SULPHIDES.

When the sulphides of the noble metals are heated, they become reduced to the metallic state; the common metals, however, require some body to be heated with them to combine with the sulphur and to liberate the metal.

A good example of the substitution of one metal for another in this way is shown in Experiments 23 and 25, where iron is made to combine with the sulphur, and at the same time the rarer metal is liberated. Some sulphides are completely reduced with nitre (KNO_3), and this is the case with sulphide of lead. In Experiment 24 an excess of nitre is taken which liberates the sulphur as SO_2, and oxidises the lead, which is then reduced by the C of the wood.

Alkaline carbonates partially decompose lead sulphide, and the reduction is complete when iron is added. In certain cases, when silicious lead ores are smelted in blast furnaces, iron, or iron producing material, is added to reduce the lead sulphide and form a fusible slag with the silica.

When sulphides are exposed to the prolonged actions of heat and air, they are decomposed, and the sulphur combines with oxygen, and passes off as SO_2. When lead sulphide is thus treated, a portion is oxidised to sulphate ($PbSO_4$), and the remainder is oxidised to PbO. The sulphate thus formed is soluble, and may be tested for by the method described in Experiment 26.

On roasting copper sulphide it becomes oxidised, and converted into soluble sulphate, but on increasing the temperature the whole of the sulphur may be driven off as SO_2. Zinc sulphide may also be converted into soluble sulphate by roasting.

By partially roasting the metallic sulphides, and then heating to the melting point, the whole of the metal is liberated. This process, when applied to lead smelting, is known as the air-reduction process, and is especially applicable to rich ores containing little silica. The silicious ores are best treated by the iron-reduction process.

Experiment 23.—Take 300 grs. of galena (PbS) and sufficient iron to form ferrous sulphide and metallic lead, thus :—

$$PbS + Fe = FeS + Pb.$$

The galena should be finely crushed, and passed through 40 sieve. The iron should be cut into small pieces. Hoop iron or iron nails may be conveniently used. Heat in crucible until all action ceases, pour into mould, and when cold, fracture, and notice that the upper portion is FeS and the lower portion is metallic lead. Compare the FeS produced with the result of Experiment 19. Detach the iron sulphide with a hammer, being careful to remove the whole of it, and at the same time to lose none of the lead. Weigh, and estimate the percentage of lead in the galena. Reserve the button of lead for the separation of any silver it may contain, by the process of cupellation, to be subsequently described. Artificial PbS, the product of Experiment 17, may be used, in which case, however, the lead obtained need not be reserved for cupellation.

Calculation for quantity of iron required :—

$$\begin{array}{ccccccc} \mathrm{Pb\,S} & & \mathrm{Fe} & & \mathrm{Pb\,S} & & \mathrm{Fe} \\ 239 & : & 56 & :: & 300 & : & x = 70 \text{ grs. Fe.} \end{array}$$

Quantity of lead produced :—

$$\begin{array}{ccccccc} \mathrm{Pb\,S} & & \mathrm{Pb} & & \mathrm{Pb\,S} & & \mathrm{Pb} \\ 239 & : & 207 & :: & 300 & : & x = 259 \text{ grs. Pb.} \end{array}$$

$$\therefore \frac{259}{3} = \text{per cent.}$$

Experiment 24.—Take 300 grs. of galena and mix with 150 grs. of nitre ($K\,NO_3$), heat the mixture in crucible for 10 minutes at a moderate temperature. Stir the contents with a piece of wood, and heat at high temperature for 5 minutes more. The nitre is in excess, and oxidises the sulphur and lead, forming SO_2 and $Pb\,O$, the former escaping as a gas. The C of the wood reduces the $Pb\,O$, producing metallic lead and CO_2. Weigh the lead, and compare with calculated quantity.

Experiment 25.—Take 100 grs. of sulphide of antimony ($Sb_2\,S_3$) and sufficient iron to reduce it according to the equation :—

$$Sb_2\,S_3 + 3\ Fe = 3\ Fe\,S + Sb_2.$$

Crush the sulphide to a fine powder in an iron mortar, and use iron filings or iron wire cut up small. Mix, and heat in crucible at a moderate temperature, until all action ceases. Pour into mould, and when cold, fracture, and notice that the upper portion is Fe S and the lower portion is metallic antimony.

Calculation of quantity of iron required :—

$$\begin{array}{ccccccc} \mathrm{Sb_2\,S_3} & & \mathrm{3\ Fe} & & \mathrm{Sb_2\,S_3} & & \mathrm{Fe} \\ 340 & : & 168 & :: & 100 & : & x = 49 \text{ grs. Fe.} \end{array}$$

The quantity of antimony obtained :—

$$\begin{array}{ccccccc} \mathrm{Sb_2\,S_3} & & \mathrm{2\ Sb} & & \mathrm{Sb_2\,S_3} & & \mathrm{Sb} \\ 340 & : & 244 & :: & 100 & : & x = 72 \text{ grs. Sb.} \end{array}$$

Experiment 26.—Break in small pieces 400 grs. of Pb S. Roast in roasting dish in muffle with frequent stirring for 1 hour. The temperature should not exceed a dull red heat. Part of the lead is converted into sulphate, while SO_2 is given off, which changes may be shown by the equation :—

$$2\ Pb\,S + 7\ O = Pb\,SO_4 + Pb\,O + SO_2.$$

The presence of lead sulphate may be proved by the following test:—Take 30 grs. of the roasted product, place in a test-tube, and add dilute hydrochloric acid ($H\,Cl$), boil for a few minutes, pour off the clear solution into another test-tube, and allow to cool, when crystals of plumbic chloride ($Pb\,Cl_2$) will separate out. To the clear solution add a small quantity of hot solution of baric chloride ($Ba\,Cl_2$), when a white insoluble precipitate of baric sulphate ($Ba\,SO_4$) will be formed. The changes may be thus shown:—

$$(a)\quad Pb\,SO_4 + 2\ H\,Cl = Pb\,Cl_2 + H_2\,SO_4.$$
$$(b)\quad H_2\ SO_4 + Ba\,Cl_2 = 2\ H\,Cl + Ba\,SO_4.$$

Baric nitrate ($Ba\ 2\ NO_3$) may be used instead of baric chloride, when the change may be thus expressed:—

$$H_2\,SO_4 + Ba\ 2\ NO_3 = 2\ H\,NO_3 + Ba\,SO_4.$$

The presence of $Ba\,SO_4$ proves the presence of $H_2\,SO_4$, which depends upon, and, therefore, proves the successful roasting of the sulphide to sulphate.

Experiment 27.—Heat 300 grs. of the roasted lead sulphide (see Experiment 26) for 5 minutes in a crucible, using a good temperature. When the contents of the crucible are tranquil, pour, and weigh the lead. In the preceding roasting operation it has been shown that only part of the lead sulphide has been oxidised to sulphate, and when the mixture is heated at a higher temperature a reaction takes place between the lead sulphate and oxide and the unaltered sulphide, producing lead and liberating SO_2. This may be shown thus:—

$$Pb\,S + Pb\,SO_4 = 2\ Pb + 2\ SO_2.$$
$$Pb\,S + 2\ Pb\,O = 3\ Pb + SO_2.$$

Experiment 28.—Roast 200 grs. of powdered cuprous sulphide ($Cu_2\,S$), as in Experiment 26, test for copper sulphate by boiling a little in water in a test-tube, when its presence will be indicated by a blue colouration, copper sulphate ($Cu\,SO_4$) being soluble in water, while copper sulphide is insoluble. Roast the main portion for 1 hour longer at a higher temperature (full red heat), when the $Cu_2\,S$ will, on testing, be found to be converted into copper oxide ($Cu\,O$). Boil a little in water as before, when, if all is converted into oxide, there will be no colouration; if, however, this stage has not been reached, the roasting should be continued for half an hour longer. The following are the changes that take place—the first at a low temperature without any liberation of sulphur, the second at a higher temperature, the sulphur being oxidised and escaping as SO_2:—

$$\begin{array}{llcll}
(a) & 2\,Cu_2S + 5\,O_2 & = & 2\,CuSO_4 + 2\,CuO. & \\
(b) & Cu_2S + 2\,O_2 & = & 2\,CuO & + \; SO_2. \\
(c) & CuSO_4 & = & CuO & + \; SO_3.
\end{array}$$

Experiment 29.—Roast 200 grs. of powdered zinc blende until SO_2 ceases to be given off. The residue is zinc oxide, which should be weighed and compared with the former weighing. If the blende is pure, every 97 parts will lose 16, because ZnS becomes ZnO, therefore the 200 grs. will become 165 grs.

$$2\,ZnS + 3\,O_2 = 2\,ZnO + 2\,SO_2.$$

Experiment 30.—Take 200 grs. of crushed galena (PbS) and sufficient PbO to give reaction :—

$$PbS + 2\,PbO = 3\,Pb + SO_2.$$

Mix and heat in crucible for 5 or 7 minutes, taking care to prevent the formation of silicate. Pour and weigh the lead obtained.

The calculation for the quantity of litharge required :—

$$\begin{array}{ccccccc}
PbS & & 2\,PbO & & PbS & & PbO \\
239 & : & 446 & :: & 200 & : & x = 373 \text{ grs. } PbO.
\end{array}$$

The calculation for the lead obtained :—

$$\underbrace{\overset{PbS}{239}\quad\overset{2\,PbO}{446}}_{685} \; : \; \overset{3\,Pb}{621} \; :: \; \underbrace{\overset{PbS}{200}\quad\overset{PbO}{373}}_{573} \; : \; \overset{Pb}{x} = 519 \text{ grs. } Pb.$$

Compare the result with the weight of the button obtained.

Experiment 31.—Take 200 grs. of copper sulphide and sufficient cupric oxide (CuO) to give reaction :—

$$Cu_2S + 2\,CuO = 4\,Cu + SO_2.$$

The copper sulphide should be finely crushed, and intimately mixed with the cupric oxide. Have a hot fire and heat mixture in crucible for about 10 minutes, pour the copper, and weigh carefully.

The calculation for the copper oxide required :—

$$\begin{array}{cccccccc}
 & Cu_2S & & 2\,CuO & & Cu_2S & & CuO \\
\text{As} & 158 & : & 158 & :: & 200 & : & x = 200 \text{ grs. } CuO.
\end{array}$$

The calculation for the quantity of copper produced :—

$$\begin{array}{llllll}
 & \mathrm{Cu_2S} \quad \mathrm{2\,Cu\,O} & \mathrm{4\,Cu} & \mathrm{Cu_2S} \quad \mathrm{2\,Cu\,O} & \mathrm{Cu} & \\
 & \underbrace{158 \qquad 158} & \vdots & \underbrace{200 \qquad 200} & & \\
\text{As} & \quad 316 \quad : & 252 & :: \quad 400 \quad : & & x = 319 \text{ grs. nearly of Cu.}
\end{array}$$

Experiment 32.—Take 200 grs. of lead sulphide (PbS) and sufficient lead sulphate ($PbSO_4$) to give the reaction as seen in equation below. Reduce the sulphide to a fine state of division, and mix with the sulphate. Place the mixture in a crucible, and heat in a hot fire for about 5 minutes, or until the contents of the crucible are tranquil. Pour and weigh the button of lead, and compare with the theoretical quantity.

$$PbS + PbSO_4 = 2\,Pb + 2\,SO_2.$$

The calculation for sulphate required :—

$$\begin{array}{llllllll}
 & \mathrm{PbS} & & \mathrm{PbSO_4} & & \mathrm{PbS} & & \mathrm{PbSO_4} \\
\text{As} & 239 & : & 303 & :: & 200 & : & x = 253 \text{ grs. } \mathrm{PbSO_4}.
\end{array}$$

The calculation for the lead produced :—

$$\begin{array}{llllll}
 & \mathrm{PbS} \quad \mathrm{PbSO_4} & \mathrm{2\,Pb} & \mathrm{PbS} \quad \mathrm{PbSO_4} & \mathrm{2\,Pb} & \\
 & \underbrace{239 \qquad 303} & \vdots & \underbrace{200 \qquad 253} & \vdots & \\
\text{As} & \quad 542 \quad : & 414 & :: \quad 453 \quad : & & x = 346 \text{ grs. of Pb.}
\end{array}$$

LIQUATION.

The operation of liquation depends upon the fact that if an alloy of two or more metals is heated to the melting point of the more fusible constituent, it will melt and flow out, leaving the more infusible portion behind. If argentiferous copper be fused with lead, and cast into cakes, and subsequently heated to a temperature above the melting point of lead, but below that of copper, the lead will flow from the copper, accompanied by the greater portion of the silver. The lead may then be cupelled for the separation of the silver, and the copper may be fused with more lead, and treated in a like manner for the separation of the remaining silver. The argentiferous copper should be alloyed with lead in the proportion of 1 to 4 for liquation, and after the operation will retain about 15 per cent or 20 per cent of lead, and from ·005 per cent to ·0005 per cent of silver, depending upon the amount originally present.

Liquation is also resorted to in the metallurgy of tin, bismuth, antimony, &c. Tin is liquated out of a mass of crude metal containing besides tin, iron, arsenic, copper, and tungsten. The liquated tin is afterwards subjected to a process of refining. Bismuth is separated from its gangue by liquation, and antimony sulphide, by virtue of its fusibility, is also separated in this way from the extraneous matter occurring with it.

Experiment 33.—Make an alloy of lead, silver, and copper in the following proportions:—600 grs. of lead, 150 grs. of copper, and 10 grs. of silver; melt together in a crucible under a little charcoal, cast into a round mould, and flatten out into a cake by hammering. Place the alloy on an inverted crucible lid, and so arrange the lid that when the alloy melts the metal will run off the lid into the crucible, on which the lid may be made to rest (Fig. 6). Heat the alloy in the furnace at a low temperature, when the lead, having a lower melting point than the copper, will become liquid, and flow away from the copper, which will remain behind as a porous mass. The silver for the most part will accompany the lead, and may be separated in the operation of cupellation, to be described in the next section.

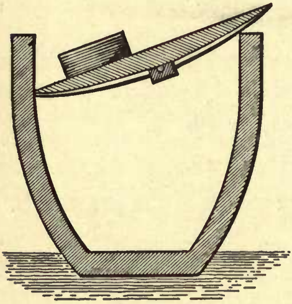


Fig. 6.

Experiment 34.—Melt 350 grs. of tin at a low temperature, add 20 grs. of iron filings, and keep the tin melted for some time, until all the iron is dissolved in the molten bath of tin. When this is accomplished, add 40 grs. of arsenic (As), 10 grs. at a time. When all is melted and mixed, pour into an ingot mould. When cold, fracture, and note the crystalline arrangement. Liquate the alloy as in the last experiment, and cast the tin into an ingot mould. Fracture the ingot of liquated tin, and compare with the appearance of the original alloy. Repeat the liquation for the further separation of the impurities. The residue upon the lid consists of iron, together with some tin and arsenic, and corresponds somewhat to the '*hardhead*' of the Cornish tin-smelting process.

Experiment 35.—Take 200 grs. of the mineral stibnite ($Sb_2 S_3$) and liquate as in Experiment 33. The antimony sulphide ($Sb_2 S_3$) will melt out and separate from the infusible gangue or matrix with which it is associated.

CUPELLATION AND SCORIFICATION.

Cupellation has for its object the removal of base metals from noble ones by oxidation, and the oxides thus formed are either absorbed by the substance of the cupel or are removed in some other way as oxides. The operation is performed on some porous bed which does not contain silica or any body that combines with metallic oxides to form fusible compounds, *e.g.*, either bone ash or marl. In the laboratory bone ash is always used, and is moulded and hammered into the form of a shallow vessel having a thick bottom. Such a vessel is called a test or cupel. (L. Cupella, a little cup.) A bone ash cupel will absorb about its own weight of litharge, so that if the quantity of lead in the alloy to be treated is known, a cupel of the proper size may be chosen. The oxides of lead and bismuth are the only ones that are absorbed by the substance of the cupel, but either of these oxides is capable of dissolving a certain quantity of other oxides, notably copper, and carrying them into the cupel. For example, if it is required to separate by cupellation gold and silver from an alloy of those metals with copper, either lead or bismuth must be added; so that the copper as it oxidises may be dissolved in the oxide of lead or bismuth and so be absorbed by the cupel, leaving the gold and silver in a pure state. Lead is used in preference to bismuth on account of its cheapness.

Cupels should be carefully and slowly dried before being used. They must be free from cracks, and capable of being handled and taken hold of with the cupel tongs without crumbling to pieces. When one of the proper size has been selected it should be placed in a hot muffle, the bottom of which is covered over with sand or bone ash to preserve it from injury in case any lead is spilt, and when the cupel has attained the same temperature as the muffle, the button or alloy to be cupelled is placed in it. The front of the muffle should then be closed until the alloy is melted, when air should be admitted and the operation allowed to proceed until finished.

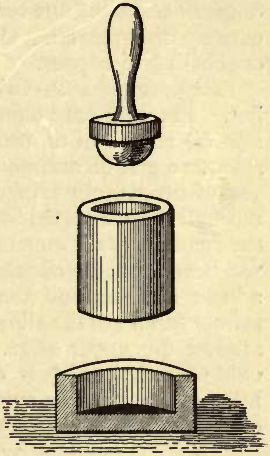
As silver is somewhat volatile the operation of cupellation should be carried on at as low a temperature as possible, but at the same time the temperature must be sufficient to keep the litharge formed during the process, in a well fused state. If the temperature is too low the extra time required for the cupellation would cause the loss due to volatilisation to be greater than when a higher temperature with shorter time was employed. When the cupels appear white, and the fumes, scarcely visible, ascend straight to the top of the muffle rapidly, the heat is too great. When the fumes are thick and very slow in movement, and the litharge is not readily absorbed by the cupel, the heat is insufficient.

It has been shown that when copper is cupelled it is necessary to add lead in order that the oxide of copper formed may be dissolved in the molten oxide of lead, and by that means be removed, and in Experiment 39 the student may determine the quantity of lead required for 1 part of copper. In Experiment 40, where antimony and tin are heated on cupels, they are not absorbed by the cupels but remain behind in the form of oxides. If silver is present the oxides act mechanically in preventing the particles of silver from running together to form one button, and thus tend to a loss of silver. An alloy containing silver with these metals, or a large proportion of copper, should first be treated by scorification for their removal as silicates, and finally cupelled with lead for the separation of the silver.

In the process of scorification the metals oxidise and form fusible silicates by the combination of the metallic oxides with the silica of the scorifier. The operation is allowed to proceed until the surface of the molten metal is covered with the silicate, when the contents of the scorifier are poured and the slag broken away from the metallic portion.

Care should be taken not to carry the operations of cupellation and scorification too far; for in the one case the cupel would become saturated and the oxides pass through the bottom and corrode the muffle, and in the other case the scorifier would be perforated and the contents lost in the muffle.

Experiment 36.—*To Make Cupels.*—Pass a quantity of bone ash through a 60 sieve, and mix it with sufficient water to enable it to clot together when squeezed in the hand (Figs. 7, 8, 9). Fill the cupel mould with the moistened bone ash, and force in the plug with two or three blows of the hammer. Remove cupel (Fig. 10), and put in a warm place to dry. Cupels should be kept for some time before using.



Figs. 7, 8, 9.

Experiment 37.—Take three small cupels; place in muffle until red-hot. Introduce into one 50 grs. of lead, into another 50 grs. of copper, and into the third 20 grs. of silver. Keep at a bright red heat for half an hour, remove cupels, allow to cool, and note the contents and appearance of each. The first will be found empty, the lead having all been oxidised and absorbed, leaving a straw-coloured stain.* In the second the copper will not have been melted, but will be covered with a black scale of cupric oxide (Cu O), under which may be noticed a thin layer of red cuprous oxide (Cu_2O). In the third the silver will have been melted, but will have suffered no other change. The weight of each should be noted, when it will be found that the lead, although apparently lost, has increased in weight due to oxidation. The copper may be removed from the cupel, and will also be found to have increased in weight. The silver should be of the same weight as before.

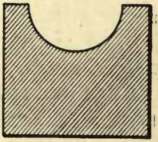


Fig. 10.

Experiment 38.—Take the button of argentiferous lead, the result of Experiment 33, and place in a previously heated cupel in a hot muffle. Heat until the whole of the lead is absorbed, and the button of silver remains bright and globular. If the silver is not bright, more lead must be added, and the cupellation continued. The weight of the silver obtained should correspond with the amount of silver introduced into the alloy.

Experiment 39.—Take three cupels, heat in muffle, and put into each 20 grs. of copper. Into the first put also 20 grs. of lead

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* See Appendix A, note 6.

to assist the copper to melt. Into the second put 150 grs. of lead, and into the third put 300 grs. of lead. Heat them in a muffle until the third cupel is empty, when they should be removed and allowed to cool. Notice that the copper in the first has not sensibly diminished in quantity, that the copper in the second has diminished about one-half, and that the copper in the third has entirely disappeared. Observe the dark coloured stains on the cupels due to copper.

Experiment 40.—Take four cupels, heat in muffle until red-hot. Put into (*a*) 20 grs. of antimony (Sb) and 280 grs. of lead; into (*b*) 20 grs. of tin (Sn) and 280 grs. of lead; into (*c*) 10 grs. of silver, 10 grs. of antimony, and 260 grs. of lead; and into (*d*) 10 grs. of silver, 10 grs. of tin, and 260 grs. of lead. Heat in muffle until all the lead is oxidised and absorbed. Allow to cool, and note the contents of the cupel in each case. The antimony in (*a*) and (*c*) will have formed a closely-adhering ring of oxide $Sb_2 O_3$, mixed with a little $Pb O$ around the inside of the cupel, at the level of the former surface of the alloy, and the cupels will be found to be cracked around the upper edge. In (*b*) and (*d*) the tin is converted into oxide ($Sn O_2$), which is of a light yellow colour (due to traces of litharge), and is in a spongy form, and not closely adhering to the cupel. The silver in (*c*) is isolated on the bottom of the cupel, but in (*d*) is covered by the oxide of tin. The antimony, being the most oxidisable of the four metals, is removed first before the alloy has been much diminished by the oxidation of the lead, and only when the bulk of lead has been absorbed is the tin oxidised. The infusibility of tin oxide prevents its absorption by the cupel.

Experiment 41.—Make four alloys by melting in crucible under a little charcoal, (*a*) 950 grs. of lead and 50 grs. of silver; (*b*) 800 grs. of lead and 200 grs. of copper; (*c*) 850 grs. of lead, 50 grs. of copper, 50 grs. of silver, and 50 grs. of antimony; and (*d*) 850 grs. of lead, 50 grs. of copper, 50 grs. of silver, and 50 grs. of tin. When thoroughly mixed, pour into hemispherical mould, flatten under a hammer, and divide each alloy, by means of chisel, into two parts. Fuse one half of each alloy in a scorifier, with the addition of 10 grs. of borax, for half an hour, at a good red heat. Pour into mould, and when cold remove slag with a hammer. Introduce the button of alloy into a hot cupel, and heat again in muffle until cupellation is finished. Place the other halves of the alloys on cupels in a muffle at a good red heat, and allow the operation to proceed until finished. Compare the cupels used for the portion of the alloys that have been scorified, with those used for the portions that have not been so treated. Weigh accurately the silver from both methods, and also notice the colour of the cupels and scorifiers used.

EFFECTS OF IMPURITIES.

MINUTE quantities of one metal when alloyed with another frequently alter its physical properties; *e.g.*, Professor Roberts-Austen noticed that gold alloyed with $\frac{1}{4000}$ per cent of lead has its tenacity diminished from 18 tons per square inch to 7·7 tons per square inch, and when alloyed with $\frac{1}{2000}$ per cent of lead broke with a strain of 5·4 tons per square inch, which figure remained constant for any addition of lead. The gold bars on which the experiments were carried out, when pure, showed 20 per cent of elongation; but when alloyed with the lead showed practically no elongation. The same experimenter observed that the presence of ·2 per cent of silicon greatly diminished the melting point of gold.

The presence of a small quantity of cuprous oxide in copper very materially influences its tenacity and malleability, which properties are also impaired by the presence of traces of antimony, arsenic, sulphur, &c., but when the latter elements are present (as they always are in commercial copper) a small quantity of cuprous oxide acts as an antidote, and the malleability and tenacity are restored to the copper. If commercial copper is melted under charcoal and cast, it is found to be less tenacious and less malleable than before; but if remelted and allowed to absorb oxygen from the air, it will be found to possess the same physical properties as before. Antimony, arsenic, sulphur, &c., in small quantities, also act on lead, and cause it to be less tough and malleable, and to show a distinctive fracture. A small quantity of iron in zinc causes the fracture to be much less crystalline.

If zinc and lead are melted together and allowed to cool slowly they separate almost completely, the lead, owing to its superior specific gravity, being at the bottom. If any silver is present originally in the lead it will pass into the zinc, and this property is utilised by Parkes for separating silver from argentiferous lead. For this separation he adds about 2 per cent of zinc to the argentiferous lead and obtains a crust of zinc on the molten lead which is rich in silver and contains also a little of the lead. This crust is then subjected to a process of liquation, when the lead flows out, carrying the greater portion of the silver with it. The liquated lead is then cupelled for the separation of the silver, and the zinc crusts are subjected to a distillation whereby the zinc is volatilised, and the silver which it contains is left behind as a spongy mass.

A small quantity of impurity in tin will cause the surface of an ingot to become dull through oxidation while cooling down from the molten state, at the same time, the surface of an ingot of pure tin will remain bright and smooth. By this simple means the relative purity of commercial tin may be ascertained.

If silver is kept in a state of fusion for some time in contact with oxygen or air, it will absorb about 20 times its own volume of oxygen, which it again liberates at the moment of solidification, the evolution being attended with the projection of the metal into a number of protuberances on the surface of the silver. This is known as the *spitting* or *vegetating* of silver, and may be prevented by cooling the metal slowly, so that the occluded gas may escape through the still fluid metal and not have to burst through the solidified crust. The presence of a small quantity of copper prevents the absorption of oxygen and the subsequent spitting.

Other metals have the power of absorbing gases, and the property of selecting particular ones from a mixture of gases; *e.g.*, platinum and palladium selecting and absorbing hydrogen, and iron taking up hydrogen and carbonic oxide.

The presence of a small quantity (·5 per cent) of phosphorus in iron makes it unworkable in the cold state, and iron possessing this amount or more, is said to be '*cold short*.' The presence of a very small quantity of sulphur in iron (·15 per cent) will render it unworkable at a red heat, when it is said to be '*red short*.'

Iron will not alloy with silicon by simply heating iron and silica together, but in the presence of a reducing agent, at a sufficiently high temperature, the silica is reduced, the silicon combining with the iron to form silicon-iron. Iron may be made to combine with the necessary amount of carbon to form steel by fusing wrought iron, which contains practically no carbon, with cast iron, which contains a comparatively large amount, when the product is cast steel.

Experiment 42.—Cast 600 grs. of lead into ingot mould

(Fig. 11), and when cool place the ingot across two supports about 1 inch apart, and strike with a hammer. Being a soft metal it will not fracture, but simply bend. If the ingot be heated nearly to its melting point and again struck with a hammer, it will break, exhibiting a transversely fibrous fracture, showing that lead at a few degrees below its melting point is brittle. Advantage is taken of this fact (see Experiment 17, p. 18) for obtaining lead in a fine state of division.

Fig. 11.

Experiment 43.—Remelt the last ingot and add 15 grs. of antimony. Cast into mould and fracture while hot. Remelt, cast, and fracture cold. Compare the appearance of the fracture with that of pure lead.

Experiment 44.—Take 600 grs. of lead, melt and add 30 grs. of lead sulphide. Pour into mould, fracture as before both hot and cold. Compare the appearance of the fracture with that of the lead, and also with the lead made impure with antimony.

Experiment 45.—Melt 1000 grs. of copper under 20 grs. of charcoal; when melted, stir with a piece of wood and pour into ingot mould. The longitudinal ridge and the appearance of the fracture characteristic of *over-poled* copper should be noted (Fig. 12). Remelt without charcoal and add 10 grs. of cuprous oxide (Cu_2O), pour as before, and notice the depression of the ingot along its surface, and that the fracture is granular and of a brick-red colour. This is *under-poled* copper (Fig. 13). Remelt the last ingot, and while melted, stir with a stick of green wood. Cast into ingot mould, when the surface of the ingot should be flat and the fracture silky and of a salmon-red colour, characteristic of *tough-pitch* copper (Fig. 14).

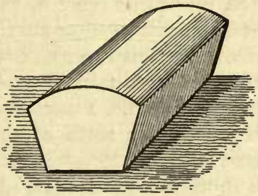

Fig. 12.

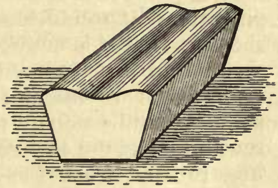

Fig. 13.

Experiment 46.—Melt 500 grs. of zinc at a low temperature, pour into mould, and when cold fracture and note appearance.

Remelt and add 20 grs. of iron filings. Keep the zinc at a low temperature for 15 minutes, when the iron will gradually dissolve and form an alloy. Cast, fracture, and compare with the appearance of that of zinc alone. Melt 500 grs. of zinc at a low temperature and pour into ingot mould; heat the ingot to a temperature of 100° to 150° C.; place between two supports 1 inch apart, and strike with a hammer, when the ingot will bend. Heat to a temperature of about 300° C., when a blow with a hammer will cause it to break.

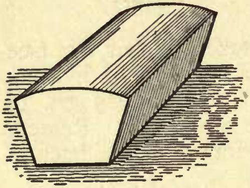

Fig. 14.

Experiment 47.—Melt together 250 grs. of lead and 250 grs. of zinc at a low temperature. Pour into upright mould, remove when cold, and notice that the lead and zinc have separated, and that the zinc forms the upper portion and the lead the lower. The separation is, however, not complete, as a small amount of zinc remains with the lead, and a small amount of lead remains with the zinc.

Experiment 48.—Take 500 grs. of tin and melt at a low temperature. Remove crucible from the fire, and pour the tin, when showing signs of solidifying, into ingot mould. Notice that the surface of the ingot is bright and smooth. Remelt the ingot with 20 grs. of lead and 10 grs. of iron, keeping the tin in a molten state for about 10 minutes to dissolve the iron. Pour at low temperature, and compare the appearance of the surface of the ingot with that of the surface of the pure tin.

The product from Experiment 34 may be used instead of the last for showing the effect of impurities on the surface of tin. It is very important that the tin should be poured at a low temperature, for if it is poured hot, the surface of the pure tin will have somewhat the same appearance as that of the impure ingot.

Experiment 49.—Take 50 grs. of standard silver, roll out into a thin strip, clean and dissolve in about 2 ozs. of dilute nitric acid ($H NO_3$) in the proportion of 1 of acid to 2 of water. Dissolve 50 grs. of common salt ($Na Cl$) in 5 ozs. of distilled water. The silver and salt should be dissolved in separate beakers, aided by the application of heat. When the silver is quite dissolved, dilute with distilled water to a pint. Heat both solutions to the boiling point, and add the solution of salt to the solution of silver, when a heavy flocculent precipitate of silver chloride ($Ag Cl$) will be produced. Allow to settle for some time, at least twelve hours, decant the supernatant liquid through a filter paper, and finally wash the precipitate on to the filter paper. Wash with boiling water so that any traces of lead chloride that may be present may be dissolved out. (See Experiment 26, p. 23.) Dry the paper and precipitate, and transfer both to a large clay crucible, add 100 grs. of carbonate of soda (Na_2CO_3), and heat in furnace at a good temperature for 10 minutes. Pour into a round mould, break away slag, which should be examined for shots of metal, and clean the button with hot water. Weigh the silver carefully, and compare the silver with former weighing.

As standard silver contains 92·5 per cent of fine silver, the weight of the silver should be :—

$$\begin{array}{ccccccccc} \text{Stand. silver} & & \text{Ag} & & \text{Stand. silver} & & \text{Ag} & & \\ 100 & : & 92{\cdot}5 & :: & 50 & : & x & = & 46{\cdot}25 \text{ grs. Ag.} \end{array}$$

The chemical changes taking place are, the conversion of silver, copper, and lead into nitrates, which are soluble, thus :—

$$3\,Cu + 8\,HNO_3 = 3\,(Cu\,2\,NO_3) + 2\,NO + 4\,H_2O.$$
$$3\,Pb + 8\,HNO_3 = 3\,(Pb\,2\,NO_3) + 2\,NO + 4\,H_2O.$$
$$3\,Ag + 4\,HNO_3 = 3\,AgNO_3 + NO + 2\,H_2O.$$

Then, upon the addition of the salt solution, the lead and silver are converted into insoluble chlorides, thus :—

$$Pb\,2\,NO_3 + 2\,NaCl = 2\,NaNO_3 + PbCl_2.$$
$$AgNO_3 + NaCl = NaNO_3 + AgCl.$$

We have now the lead and silver in a solid form, and may separate them from the copper by filtration. Lead chloride, of which only a trace will be present, although insoluble in cold water, is soluble in hot water, and this forms a ready means of separating these metals. By fusing the silver chloride with carbonate of soda, the following reaction takes place :—

$$4\,AgCl + 2\,Na_2CO_3 = 4\,NaCl + 2\,Ag_2 + 2\,CO_2 + 2\,O.$$

The copper solution may now be treated for that metal by placing a strip of clean iron in the liquid, when the copper will be precipitated, and the iron will go into solution :—

$$Cu\,2\,NO_3 + Fe = Fe\,2\,NO_3 + Cu.$$

The copper should be collected, dried, and weighed.

Experiment 50.—Heat two small cupels in muffle, and when red-hot place in each 10 grs. of silver, wrapped in 50 grs. of sheet lead. When cupellation is finished, take out of muffle, cover one with an inverted hot cupel in order that it may cool slowly, while the other is allowed to cool quickly. The one cooled slowly will have a smooth surface, and the other will have '*vegetated*' or '*spit*.'

Experiment 51.—Cut into small pieces 600 grs. of hoop iron, place in crucible, and heat until white-hot. Drop into the crucible one or two pieces of dry phosphorus about the size of a bean. The addition of the phosphorus will cause the iron to melt. Cast into ingot mould, and when cold, fracture. Notice the appearance of the fracture, and the different effects of hammering when hot and when cold. It is white iron and '*cold short*.'

Experiment 52.—Heat 600 grs. of hoop iron as before. Drop in 30 grs. of sulphur, and increase the heat until the iron is melted. Pour into ingot mould, and when cold, fracture. Notice that the iron is white, and that the effect of hammering is different from that of the phosphoric iron, for it may be hammered while cold, but if hammered hot it will break, being '*red short*.'

Experiment 53.—Heat 600 grs. of iron filings with 50 grs. of sand for half an hour. The mass will be found to be somewhat agglutinated, but it may easily be reduced to powder in a mortar, and will have undergone no chemical change. Mix the powdered mass with 50 grs. of charcoal, and increase the heat until melted. Allow to cool in the crucible, and when cold, break the crucible and extract the button of iron. Fracture, and notice that the appearance is grey and highly crystalline, and that the iron is brittle and hard, containing both carbon and silicon.

Experiment 54.—Take 600 grs. of iron filings and 50 grs. of powdered charcoal. Place in crucible and lute on the lid. Heat in very hot fire for 40 minutes. Remove crucible, and allow to cool in upright position, and when cool, break crucible, and extract the button of iron. Weigh carefully, and determine the quantity of carbon combined, from the increase in weight. Fracture, and notice the crystalline character, and the hardness and brittleness of the iron. This is *cast iron.*

Experiment 55.—Heat, at highest temperature obtainable, 135 grs. of cast iron with 265 grs. of wrought iron in a crucible having its lid luted on. After heating for about an hour, remove crucible and allow to cool. Break the crucible, and examine the button of *cast steel* produced.

FORMATION OF SILICATES.

If silica is heated with cupric oxide ($Cu\,O$), oxygen is liberated and a silicate of cuprous oxide ($Cu_2\,O$). No silicate of the black or cupric oxide is known. Silica will combine with metallic oxides at a temperature lower than the melting point of the silicate produced, and this combination of two solid bodies without melting is called '*fritting*.' Silicates of lead and iron may be produced in the same way.

If iron sulphide is heated with copper silicate or with cuprous oxide and silica, silicate of iron and sulphide of copper are formed, owing to the superior affinity of copper for sulphur and of oxide of iron for silica.

Experiment 56.—Take 200 grs. of black copper oxide ($Cu\,O$) and sufficient sand ($Si\,O_2$) to give reaction :—

$$4\,Cu\,O + Si\,O_2 = 2\,Cu_2\,O,\ Si\,O_2 + O_2.$$

The sand should be the fine white variety, and intimately mixed with the $Cu\,O$. Heat for 40 minutes in muffle at full red heat. When cold, note the appearance of the product, which is silicate of copper, having the composition as shown above, and it should have been produced without melting. It will be seen from the equation that cuprous oxide is in combination with the silica, and not the cupric oxide that was taken, oxygen having been liberated.

The calculation for the quantity of sand required :—

$$\begin{array}{r} 4\,Cu = 252 \\ 4\,O\ =\ \ 64 \\ \hline 4\,Cu\,O = 316 \end{array} \qquad \begin{array}{ccccccc} 4\,Cu\,O & & Si\,O_2 & & Cu\,O & & Si\,O_2 \\ 316 & : & 60 & :: & 200 & : & x \end{array} = 38 \text{ grs. } Si\,O_2.$$

$$\begin{array}{r} Si = 28 \\ 2\ O = 32 \\ \hline Si\,O_2 = 60 \end{array}$$

The calculation for the quantity of cuprous silicate produced :—

$$\begin{array}{r} 2\,Cu_2\,O = 284 \\ Si\,O_2 =\ \ 60 \\ \hline 2\,Cu_2O,\,Si\,O_2 = 344 \end{array} \qquad \begin{array}{ccccccc} 4\,Cu\,O & & 2\,Cu_2O,\,Si\,O_2 & & Cu\,O & & 2\,Cu_2O,\,Si\,O_2 \\ 316 & : & 344 & :: & 200 & : & x \end{array}$$

$$= 217 \text{ grs. of } 2\,Cu_2\,O,\ Si\,O_2.$$

Experiment 57.—Take 400 grs. of oxide of lead ($Pb\,O$) and sufficient sand to give reaction :—

$$2\,Pb\,O + Si\,O_2 = 2\,Pb\,O,\ Si\,O_2.$$

Place in scorifier as in the preceding experiment. Heat at low temperature, and when cold note the appearance. The product is silicate of lead, with composition as shown above, and should have been produced without melting.

The calculation for quantity of sand required :—

$$\begin{array}{r} 2\ Pb = 414 \\ 2\ O = 32 \\ \hline 2\ PbO = 446 \end{array} \qquad \begin{array}{ccccccc} 2\ PbO & & SiO_2 & & PbO & & SiO_2 \\ 446 & : & 60 & :: & 400 & : & x \end{array} = 53 \text{ grs. } SiO_2.$$

Experiment 58.—Take 200 grs. of finely powdered hematite and sufficient sand to form ferrous silicate.

$$Fe_2O_3 + SiO_2 = 2\ FeO,\ SiO_2 + O.$$

Heat in scorifier as before, and when cold note the appearance. It will be seen that the ferric oxide is decomposed with the formation of ferrous silicate and the liberation of oxygen. No silicate of the red oxide, Fe_2O_3, or the black oxide, Fe_3O_4, is known.

The calculation for the sand required :—

$$\begin{array}{r} 2\ Fe = 112 \\ 3\ O = 48 \\ \hline Fe_2O_3 = 160 \end{array} \qquad \begin{array}{ccccccc} Fe_2O_3 & & SiO_2 & & Fe_2O_3 & & SiO_2 \\ 160 & : & 60 & :: & 200 & : & x \end{array} = 75 \text{ grs. } SiO_2.$$

The calculation for the quantity of silicate produced :—

$$\begin{array}{r} 2\ FeO = 144 \\ SiO_2 = 60 \\ \hline 2\ FeO,\ SiO_2 = 204 \end{array} \qquad \begin{array}{ccccccc} Fe_2O_3 & & 2\ FeO,\ SiO_2 & & Fe_2O_3 & & 2\ FeO,\ SiO_2 \\ 160 & : & 204 & :: & 200 & : & x \end{array}$$

$$= 255 \text{ grs. } 2\ FeO,\ SiO_2.$$

Experiment 59.—Take 200 grs. of silicate of copper, the product of Experiment 56, and sufficient ferrous sulphide (FeS) to give reaction :—

$$2\ Cu_2O,\ SiO_2 + 2\ FeS = 2\ Cu_2S + 2\ FeO,\ SiO_2.$$

Crush finely, mix and place in crucible, lute on lid, and heat strongly for half an hour. Allow to cool in an upright position; break crucible and notice the contents. Break away from the copper sulphide the ferrous silicate which forms the upper portion. The weight of the copper sulphide should be noted and compared with the theoretical weight.

The calculation for the ferrous sulphide required :—

$$\begin{array}{r} 2\ Cu_2O = 284 \\ SiO_2 = 60 \\ \hline 2\ Cu_2O,\ SiO_2 = 344 \end{array} \qquad \begin{array}{ccccccc} 2\ Cu_2O,\ SiO_2 & & 2\ FeS & & 2\ Cu_2O,\ SiO_2 & & FeS \\ 344 & : & 176 & :: & 200 & : & x \end{array}$$

$$= 102 \text{ grs. } FeS.$$

The calculation for the quantity of copper sulphide produced:—

$$\begin{array}{r} 2\,Cu_2 = 252 \\ 2\,S \;=\; 64 \\ \hline 2\,Cu_2S = 316 \end{array}$$

$$\begin{array}{cccc} 2\,Cu_2O, SiO_2 & 2\,Cu_2S & 2\,Cu_2O, SiO_2 & Cu_2S \\ 344 & : 316 :: & 200 & : x \end{array}$$

= 186 grs. Cu_2S.

Experiment 60.—Take 200 grs. of silicate of lead and sufficient iron to reduce it.

$$2\,PbO, SiO_2 + 2\,Fe = 2\,FeO, SiO_2 + 2\,Pb.$$

Heat in crucible in a hot fire, and when all action has ceased pour into mould. Break away the ferrous silicate and weigh the lead.

The calculation for the quantity of iron required:—

$$\begin{array}{r} 2\,Pb = 414 \\ 4\,O = 64 \\ Si = 28 \\ \hline 2\,PbO, SiO_2 = 506 \end{array}$$

$$\begin{array}{cccc} 2\,PbO, SiO_2 & 2\,Fe & 2\,PbO, SiO_2 & Fe \\ 506 & : 112 :: & 200 & : x \end{array}$$

= 44 grs. of iron.

Calculation for lead produced:—

$$\begin{array}{cccc} 2\,PbO, SiO_2 & 2\,Pb & 2\,PbO, SiO_2 & Pb \\ 506 & : 414 :: & 200 & : x = \end{array}$$ 163 grs. of lead.

Experiment 61.—Take 200 grs. of silicate of lead and sufficient lime (CaO) and charcoal (C) to reduce it according to the equation—

$$2\,PbO, SiO_2 + 2\,CaO + 2\,C = 2\,CaO, SiO_2 + 2\,CO + 2\,Pb.$$

Heat together in a hot fire for 15 minutes. Pour, remove slag, and weigh the lead. The reduction in this case is imperfect, the whole of the silicate not being reduced.

The calculation for the lime required:—

$$\begin{array}{cccc} 2\,PbO, SiO_2 & 2\,CaO & 2\,PbO, SiO_2 & CaO \\ 506 & : 112 :: & 200 & : x = 44 \end{array}$$ grs. of lime.

The calculation for the carbon required:—

$$\begin{array}{cccc} 2\,PbO, SiO_2 & 2\,C & 2\,PbO, SiO_2 & C \\ 506 & : 24 :: & 200 & : x = 9{\cdot}5 \end{array}$$ grs. charcoal.

The calculation for the quantity of lead reduced:—

$$\begin{array}{cccc} 2\,PbO, SiO_2 & 2\,Pb & 2\,PbO, SiO_2 & Pb \\ 506 & : 414 :: & 200 & : x = 163 \end{array}$$ grs. lead produced.

FUEL.

The term fuel is applied to all material that is capable of being burnt for the generation of heat. Fuels used in metallurgical operations are divisible into two classes—natural and artificial. To the natural class belong coal, wood, peat, &c., and to the artificial class, coke, charcoal, &c. Only carbon and hydrogen in coal are capable of producing heat, and in the case of charcoal and coke, only carbon. Carbon may be burned to CO or CO_2, but hydrogen always forms H_2O. Coal may be subdivided into three varieties—lignite, bituminous coal, and anthracites. The lignites are brown or black in colour, with a dull shining lustre, and often having a wood-like appearance. The bituminous coals burn with a more or less smoky flame, and those varieties which occur in the middle of the series, and farthest removed from the lignites and anthracites, have the property of becoming converted into a hard, vesicular mass called *coke*, when heated for some time without access of air. These particular kinds of coal are called *caking coal.* The anthracites have a bright, shining appearance, and do not soil the fingers when touched. They contain a larger percentage of carbon, and much less volatilisable substances, and they are much denser than either of the foregoing, and, as a consequence, require a stronger draught to burn them, producing a short flame and an intense local heat. Neither the anthracites nor the lignites can be converted into coherent coke by the ordinary means, and are therefore called *non-caking* coals.

Coke, as we have seen, is the residue left on the destructive distillation of coal, and consists essentially of carbon with a certain amount of earthy matter or ash.

Coke varies in colour from silver-grey to black, and also varies very much in density and porosity. The length of time, and the temperature employed in coking, considerably affect the coke produced, it being harder and denser in quality, and greater in quantity, the higher the temperature employed.

Wood contains a large amount of water, and for this reason cannot be used as the fuel where high temperatures are required. If, however, it is subjected to a process of distillation, the volatile compounds are driven off, and there remains a carbonaceous residue called *charcoal*, containing earthy impurities, which, on combustion of the charcoal, remain as ash. The charcoal is more or less compact and dense according to the temperature at which the operation has been carried on.

Peat like wood cannot be used where high temperatures are required, but its usefulness may be increased by submitting it to a distillation to drive off the volatile matters, and for the production of a residue of carbon which is called *peat charcoal.*

In the formation of coke it is necessary that the air should be excluded, or the fixed carbon would be burnt off, whereas the result desired is to expel the whole of the volatile hydro-carbons and leave the fixed carbon behind. If, however, coal or wood is heated in contact with air, the whole of the carbon is burnt off, and a residue is left which is called the *ash.* This ash consists of the inorganic or earthy matter, as potash, soda, lime, silica, and metallic sulphides, and chlorides. The ash of coal and peat also contains oxide of iron and alumina. These materials sometimes fuse together when the coal is burned, and form *clinkers* on the fire bars, blocking up the air passages, and interfering with the regular burning of the fuel.

The ash of wood varies from 1 per cent to 4 per cent. Peat frequently yields 10 per cent to 20 per cent of ash, and coal from 1 per cent to 15 per cent. Good coal, however, should not yield more than 10 per cent of ash.

Experiment 62.—*Estimation of the Amount of Coke.*—Take 600 grs. of anthracite, crush in mortar, and pass through 10 sieve. Weigh out 500 grs. and place in small copper assay crucible. Well cover with a lid and heat in hot fire for 20 minutes. Allow to cool without removing the lid. When cold turn out of the crucible and weigh. Notice decrease in weight, and that the coal is not caked, it having the same appearance as before the experiment.

Experiment 63.—*Method of Determining the Ash.*—Pass the remainder of the 600 grs. of the anthracite through 60 sieve, and weigh out 30 grs. Heat in an open porcelain crucible* in muffle (Fig. 15) for 1 hour, or until the whole of the carbon is burnt off, allowing free access of air. When cool, weigh and carefully note the appearance of the ash.

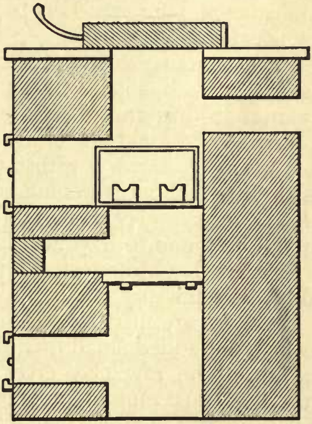

Fig. 15.

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* See Appendix A, note 2.

Experiment 64.—Pass a quantity of steam coal through 10 sieve. Weigh out 500 grs. and place in small fireclay crucible, taking care to have it covered with a well-fitting lid. Heat for 20 minutes; allow to cool while still covered. Examine and weigh the coke. Note the quality of the coke, whether hard or soft, firm or friable, dense or porous.

Experiment 65.—Pass the remainder of the steam coal through 60 sieve. Weigh out 30 grs. and heat in porcelain crucible for the estimation of the ash, proceeding as with the anthracite. When cool, weigh and note the appearance of the residue. Repeat the above experiments with any other kind of coal obtainable.

FIRECLAY AND CRUCIBLES.

THE term clay is given to certain plastic earths which contain large amounts of silica and alumina, and also water in a state of chemical combination. It is to this combined water that they owe their plasticity.

Clays contain, as impurities, varying amounts of lime, iron, magnesia, potash, soda, sulphur, &c. These bodies tend to make clay more fusible, and, therefore, prevent its being used for building furnaces or making crucibles. Clays which do not contain much impurity, and will withstand a lengthened exposure to a high temperature without softening, are called *fireclays*. By the application of heat to clay the combined water is driven off, when the clay will be found to have lost its plastic character.

Fireclay should be tested for its power of resisting corrosion, and for its refractory power.

Crucibles are made of various mixtures of raw and burnt clay, to which are added small quantities of sand, graphite, coke, dust, or ashes. The raw clay gives the necessary plasticity, and the burnt clay is useful in preventing the cracking of the crucibles while drying. Crucibles may either be used plain, or they may be lined with charcoal, when they are said to be *brasqued.*

The advantages of lined crucibles over plain ones, are that the lining gives greater solidity, and prevents loss of shape through the softening of the crucible whilst hot; particles of metals do not adhere to the sides as in clay crucibles; and when metallic bodies are fused in them, contact with silica is prevented. The lining also effects the reduction of certain metallic oxides by cementation, and does away with the necessity of adding powdered charcoal. This last property is very valuable, because when an oxide is reduced by charcoal, an excess must always be employed, and this excess remains with the metal, and prevents its exact weight from being ascertained.

Experiment 66.—Take a quantity of burnt clay, the clean pieces of old crucibles or muffles, or broken firebricks, and pass through 60 sieve. Pass also a quantity of raw clay through 40 sieve; measure out one volume of burnt, and two volumes of raw clay. Mix well together with sufficient water to give it the consistency of putty, kneading it until it does not stick to the fingers.

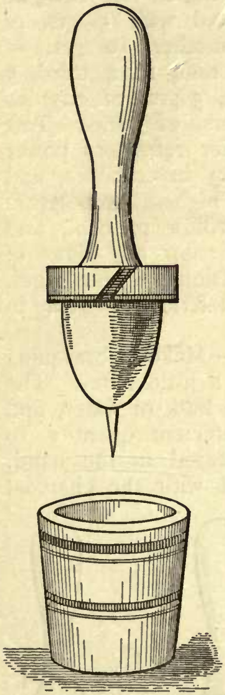

Fig. 16.

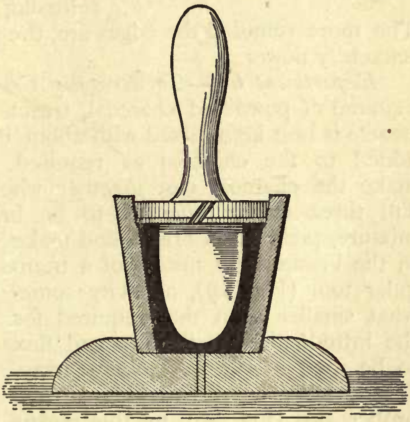

Fig. 17.

By means of crucible mould (Figs. 16 and 17), make 6 small crucibles and lids and two pyramids about 2 ins. high (Fig. 18). Put in warm place, and allow to dry for a week. Put the crucibles into a cold muffle, and gradually raise the temperature until red-hot. Bake, at a good red heat, for half an hour, and cool slowly. The crucibles should be white, or nearly so, and should be strong enough to bear handling without breaking.

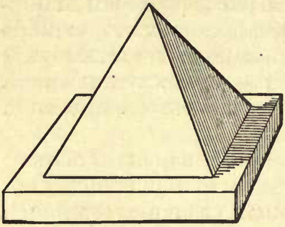

Fig. 18.

Experiment 67.—Test the crucibles for their power of resisting corrosion by fusing in one 100 grs. of litharge mixed with 5 grs. of charcoal, in another 10 grs. of cuprous oxide, and, in a third, 5 grs. of litharge, 5 grs. of cuprous oxide, and 5 grs. of borax. Test the pyramids for refractory power by placing them in crucibles, and heating at the highest temperature for 1 hour. Allow to cool, and notice if they show any signs of softening or fusion on the edges. The more rounded the edges are, the more inferior is the clay in refractory power.

Experiment 68.—*To Brasque Crucibles.*—Make a brasquing material of powdered charcoal, treacle, and a little water. The treacle is best kept mixed with about its own bulk of water, and added to the charcoal as required, in sufficient quantity to make the charcoal clot together when squeezed in the hand. Fill three of the crucibles to be brasqued with the charcoal mixture, press down firmly, and make in the brasque, by means of a triangular tool (Fig. 19), a cavity somewhat smaller than that required for the introduction of the ore and flux to be used in the subsequent assay. Insert, now, a polished plug of the proper size (Fig. 20), by this means making the cavity larger, and the brasque firmer and smoother. For ordinary purposes the brasque may be $\frac{3}{8}$ in. thick at the bottom, and $\frac{1}{8}$ in. or so at the sides. The crucibles should now be put in a warm place, in order to drive off the water from the brasque, and when dried should be heated in a muffle to a dull red heat, care being taken to keep the crucibles covered with the lids, to prevent the burning of the charcoal.

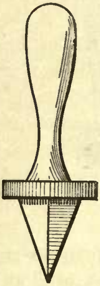

Fig. 19.

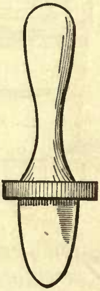

Fig. 20.

Experiment 69.—Take 10 grs. of finely powdered hematite, and mix with lime, 3 grs.; china-clay, 2 grs. Place the mixture in a brasqued crucible, and fit into the top of the lining a charcoal plug, cut from a piece of wood charcoal. Mix, also, 10 grs. of the same sample of hematite with charcoal, 5 grs.; lime, 3 grs.; and china-clay, 2 grs. Place this mixture in an unlined crucible, also fitted with a charcoal plug. Lute a lid on to each crucible, and lute both crucibles to a portion of firebrick, so that they may be heated in a furnace without fear of them turning over. When the lute is dry, heat in a furnace at a high temperature for 40 minutes. Break crucibles when cold and weigh the buttons of iron. Compare the weights of the results from the two methods.

FORMATION OF ALLOYS.

ALLOYS are not, as far as is known, definite chemical compounds; they have, generally speaking, the same physical properties as the metals, they are solid at the ordinary temperature, they have metallic lustre and high specific gravity, and are conductors of heat and electricity.

When mercury is made to alloy with any other metal the result is called an amalgam, and may be either solid or liquid.

Alloys have not, as a rule, a density which is the mean of their constituents, showing that at the moment of their union an increase or diminution of volume has taken place.

The melting point of alloys is also not the mean of the melting points of its components, but is generally below. This property is of great use in the arts.

Alloys containing a volatile metal are decomposed, either wholly or partially, when exposed to a strong heat. This is the case with alloys of zinc, mercury, and arsenic.

When an alloy consists of two metals whose fusibilities differ widely, it may be partly decomposed by heating it to the temperature at which the most fusible melts (see Experiments 33 and 34, p. 26).

Some alloys may be separated by submitting them to fusion and gradually cooling, when one of the constituents crystallises out and becomes solid, and may be removed, as in the Pattinson process, by means of a perforated ladle.

The tenacity of alloys is frequently inferior to the mean tenacity of the separate metals, as, for instance, traces of lead very greatly diminish the tenacity of gold. The ductility and malleability is affected in the same way. In some cases, however, the effect of a small quantity of impurity is to increase to a very large degree the tenacity and ductility of the metal, as, for instance, 1 per cent of carbon in iron increases its tenacity from 25 tons per square inch to 50 tons per square inch.

The following alloys may be made by melting and mixing the constituents together under a little charcoal:—

ALLOYS OF LEAD.

Experiment 70.—*Pewter.*—Melt together 320 grs. of tin and 80 grs. of lead, with the addition of 10 grs. of charcoal, in a crucible, using a low temperature, stir with a piece of wood when melted, and pour the mixed metals into an ingot mould. Weigh the pewter obtained, break the ingot, and note the appearance of the fracture and of the surface.

Experiment 71.—*Soft Solder.*—Melt together 200 grs. of tin and 200 grs. of lead, with the addition of 10 grs. of charcoal. Stir as before when melted and pour into ingot mould. When cold, weigh, fracture, and note the appearance of the fracture and surface.

Experiment 72.—*Type Metal.*—Melt 200 grs. of lead with 150 grs. of antimony and 50 grs. of tin, with charcoal as before. Mix and pour into mould. Weigh, fracture, and note the appearance.

Experiment 73.—*Shot Metal.*—Take 320 grs. of lead and 20 grs. of charcoal. Melt the lead in a crucible under the charcoal and add 100 grs. of arsenic (As), or 150 grs. of white arsenic (As_2O_3), in small quantities. Mix and cast as before; weigh, and note the appearance of the surface and fracture. Remelt a portion at a low temperature and pour the molten alloy on to a board placed at an angle of 25° to 30°. Compare the result with that obtained when ordinary lead is melted and poured in a similar way.

ALLOYS OF COPPER.

Experiment 74.—*Bronze.*—Take 350 grs. of copper and melt with 50 grs. of tin under charcoal. Mix and cast into ingot mould; weigh the ingot; fracture, and note the appearance. Notice that if the alloy is cooled slowly it is brittle, but that if it is cooled quickly, by plunging it in water, it is comparatively soft and workable. In this respect it behaves in an exactly opposite manner to steel under the same treatment.

Experiment 75.—*Bell Metal.*—Melt together 320 grs. of copper and 80 grs. of tin. Mix and cast as before. Weigh, fracture, and note appearance. Antimony is sometimes added in small quantities to this alloy, when it displaces some of the copper.

Experiment 76.—*Speculum Metal.*—Melt together 260 grs. of copper, 130 grs. of tin, and 10 grs. arsenic. The copper and tin should be melted together under charcoal, and the arsenic added in two lots of 5 grs. each. Mix well, pour into mould, weigh when cold, and note the appearance of the surface and of the fracture. This alloy is capable of receiving a high polish, which may be shown by first filing the surface to free it from oxide, then rubbing with sandpaper, and lastly polishing with putty powder ($Sn\,O_2$).

Experiment 77.—*Britannia Metal.*—Take 340 grs. of tin, 40 grs. of antimony, and 20 grs. of copper. Melt under charcoal, stir with a piece of wood, and cast into ingot mould. Weigh when cold, fracture, and note appearance.

Experiment 78.—*Tinning Copper.*—Polish a piece of sheet copper with moistened pumice-stone until quite smooth. Heat the plate, and smear it over with sal-ammoniac ($NH_4\,Cl$) to remove any oxide of copper from its surface. Sprinkle on the plate a little powdered resin and some finely divided tin, and again heat up until the tin melts. Spread the tin over the plate by means of a piece of tow, and when uniform allow to cool. The resin is used to prevent the formation of oxide of copper.

Experiment 79.—*Muntz's Metal.*—Melt under a little charcoal 240 grs. of copper, and add in small quantities 160 grs. of zinc, stirring with a piece of wood after each addition. Pour into ingot mould. Weigh, fracture, and observe the appearance, which will not be homogeneous unless special care is taken that the metals are thoroughly mixed. Notice that this alloy is malleable when hot.

Experiment 80.—*Brass.*—Melt 266 grs. of copper under charcoal, and add cautiously, in small portions, 134 grs. of zinc, mix well, and pour into mould, weigh, fracture, and note appearance. Notice that the brass is not so malleable while hot as Muntz's metal.

Experiment 81.—*White Brass.*—Melt 134 grs. of copper under charcoal, and add, in small portions, 266 grs. of zinc. Stir, after each addition of zinc, with a piece of wood. Pour into mould, weigh, fracture, and note the appearance of the surface and fracture.

Experiment 82.—*Aich Metal.*—Melt together 240 grs. of copper and 8 grs. of iron under charcoal. Add, in small quantities, 152 grs. of zinc. Stir after each addition of zinc, and when well melted pour into ingot mould. Weigh, fracture, and note the appearance. *Sterro metal* is similar to the last, but contains 58 per cent of copper, 38 per cent of zinc, 2·5 per cent of iron, and 1·5 per cent of tin.

Experiment 83.—*Nickel Bronze* (*Coinage*).—Take 320 grs. of granulated copper and 82 grs. of grain nickel (Ni). Place in crucible with 10 grs. of charcoal. The 2 grs. excess of nickel is added to make good any slight loss occasioned during melting. Heat at high temperature for 30 minutes. Allow to cool in crucible without pouring. When cold, break crucible, and examine the button. Weigh, fracture, and note the appearance.

Experiment 84.—*German Silver.*—Make an alloy of 100 grs. of copper and 100 grs. of zinc, and a second alloy of 100 grs. of copper and 100 grs. of nickel. Melt the copper first in each case, and add the zinc or nickel in small portions at a time. Weigh each alloy, fracture, and note the appearance. The nickel alloy will require the highest obtainable temperature for its production. Melt together, under a little charcoal, 30 grs. of the copper-zinc alloy, 40 grs. of the copper-nickel alloy, and 30 grs. of copper. Pour into ingot mould; weigh the German silver obtained, and calculate its composition from the weights of the constituents taken. Fracture, and notice the appearance of the fracture and surface, and also that it is capable of taking a high polish.

Experiment 85.—*Regulus of Venus.*—Melt together 100 grs. of copper and 100 grs. of antimony (Sb) under charcoal. Pour, weigh, and note the appearance of the fracture.

Experiment 86.—*Standard Silver.*—Melt together, in small crucible, 92·5 grs. of pure silver (Ag) and 7·5 grs. of electrotype copper. *Standard Gold.*—91·6 grs. of pure gold (Au) and 8·3 grs. of electrotype copper.

ALLOYS OF IRON AND NICKEL.

Experiment 87.—*Arsenide of Iron.*—Take 100 grs. of iron wire, cut up into small pieces, and 100 grs. of arsenic. Heat in crucible at moderate temperature for 10 minutes. Take out of the fire and add a mixture of 50 grs. of carbonate of soda (Na_2CO_3), 20 grs. of arsenic, 20 grs. of tartar, and 20 grs. of borax. Cover the crucible with a lid, return to fire, and heat for 10 minutes at a high temperature. Pour, weigh, and note the appearance of the fracture. Remelt with slag formed during the previous melting, and add 50 grs. of arsenic. Pour and reweigh. Deduce the formula and the percentage composition of the alloy, from the increase in the weight of the iron, due to arsenic. *Example*:—An alloy weighing 137 grs. was obtained from 100 grs. of iron, find its percentage composition and formula.

$$\begin{array}{ccccccc} \text{Alloy} & & \text{Fe} & & \text{Alloy} & & \text{Fe} \\ 137 & : & 100 & :: & 100 & : & x = 73 \text{ per cent of iron.} \\ \text{Alloy} & & \text{As} & & \text{Alloy} & & \text{As} \\ 137 & : & 37 & :: & 100 & : & x = 27 \text{ per cent of arsenic.} \end{array}$$

Divide the percentage of each constituent by its atomic weight:—

Iron = 56. $\frac{73}{56} = 1{\cdot}3.$ $\frac{27}{75} = {\cdot}36.$
Arsenic = 75.

Divide the greater by the less:—

$$\frac{1{\cdot}3}{{\cdot}36} = 3{\cdot}6,$$

which gives a relation of 1 of arsenic to 3·6 of iron, or 5 to 18; the formula, therefore, is $As_5\,Fe_{15}$.

Experiment 88.—*Nickel Speiss.*—Take 100 grs. of nickel and 100 grs. of arsenic. Heat in crucible, at low temperature, for 10 minutes. Add a mixture of 50 grs. of sodic carbonate (Na_2CO_3), 20 grs. of arsenic, 20 grs. of tartar, and 20 grs. of borax, cover with lid, and heat at a high temperature for 15 minutes. Pour into mould, weigh when cold, and fracture the ingot. Remelt with the slag from the first melting. Pour, weigh, and fracture. Deduce the percentage composition and formula from the increase in weight.

PART II.

THE experiments described in the preceding pages are capable of being effected by the aid of a good pair of scales, but now we have to deal with smaller quantities of material, and therefore some more delicate method for weighing must be adopted, and in order to perform the experiments described in the following pages, it is necessary that the student should be familiar with the manipulation of a chemical balance.

SPECIFIC GRAVITY.*

By specific gravity is meant the ratio which exists between the weight of a given bulk of pure water and the weight of an equal bulk of any solid or liquid body, compared at a temperature of 4° C. Thus, for example, lead is said to have a specific gravity of 11·3, which means that a given quantity of lead would weigh 11·3 times heavier than an equal bulk of water; so that, as a cubic centimetre of water at 4° C. weighs 1 gram, a cubic centimetre of lead would weigh 11·3 grams, at the same temperature. The specific gravity of the metals is increased by rolling or hammering, and the specific gravity of *native* metals is, as a rule, greater than when the same metals have been melted and poured.

When estimating the specific gravity of gases, hydrogen is taken as unity, and the specific gravity of the elementary gases is found to be identical with their atomic weights. They are, however, sometimes referred to air as unity, when the specific gravity of oxygen, for instance, becomes 1·10563.

Experiment 1.—*Estimation of Specific Gravity.*—Suspend a piece of lead by means of horsehair, weigh carefully on balances and note the weight. Now take a beaker of water at 20° C. and allow the lead to hang from the beam, below the surface of the water, and take the exact weight. Divide the weight in air by the difference between the weight of the lead in air and in water, and the result will be the specific gravity for lead.

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* For table of specific gravity of elements, see Appendix C.

The specific gravity of liquids may be determined by filling a glass weighing bottle, fitted with a drilled stopper, with distilled water, and suspending it in a constant temperature bath at 20° C. for some time, until no more water exudes from the hole in the stopper. Care must be taken that the bottle is absolutely full, and that there are no air bubbles. Remove from bath and cool, when the liquid will contract and there will be no danger of losing any of the water. Weigh carefully the bottle of water, which should then be emptied, dried, and filled quite full with the liquid under examination. Suspend in constant temperature bath until exudation ceases; cool, dry, and weigh. Subtract the weight of the bottle, and divide by the weight of the water, and the result is the specific gravity of the liquid, referred to water as unity.

FUEL.

Experiment 2.—*Coking of Coals.*—Crush a piece of ordinary house coal and pass through 10 sieve. Pass a quantity through a 60 sieve, taking care to have an average sample, and put into a well corked bottle. Weigh a dried porcelain crucible carefully on the balance, and introduce into it about 30 grs. of the finely powdered coal, taking the exact weight. Place the crucible in a hot muffle and heat strongly for half an hour, keeping the crucible covered with a closely-fitting lid.* Allow to cool without removing the lid, and when cold, weigh. Deduct the weight of the crucible and calculate the percentage of coke produced from the coal. Note also the appearance and character of the coke.

Experiment 3.—*Estimation of the Amount of Ash in Coal.*—Weigh out 20 grs. of the finely powdered coal and transfer to weighed porcelain crucible. Heat in muffle without the lid, until the whole of the carbon is burnt away, stirring occasionally with a platinum wire. The residue will be of a reddish brown to grey colour, but must not be black, as that would indicate the presence of carbon. Cool, weigh, and calculate the percentage of ash.

Experiment 4.—*To Determine the Moisture.*—Dry a pair of watch glasses and a clip in a water-oven (Fig. 21), cool in desiccator, and weigh carefully; introduce into one of the glasses about 20 grs. of the finely powdered coal and take the exact weight. Put the glasses, clip, and coal, back into the water-oven, and maintain at a temperature of 100° C. for 1 hour, leaving the

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* See note 2, Appendix A.

coal uncovered so that the moisture may escape. Remove from oven, and cover the coal with the other watch glass, and put on the clip. Cool in desiccator and reweigh. Compare with former weighing and calculate percentage of moisture. Return the whole to the water-oven, and continue the drying for half an hour longer, or until the weight is constant. If left too long, however, the weight may increase, due to the oxidation of $Fe\,S_2$ to $Fe\,SO_4$.

Experiment 5.—*Estimation of Sulphur in Coal.*—Weigh out accurately 20 grs. of the finely powdered coal, 260 grs. of pure sodium chloride ($Na\,Cl$), 135 grs. of pure potassic nitrate ($K\,NO_3$), and 5 grs. of sodium carbonate ($Na_2\,CO_3$). Dry these substances in a water-oven for half an hour, before weighing, mix well together, and half fill a porcelain crucible with the mixture. Heat over a Bunsen burner until the contents have deflagrated and become white, then add more of the mixture and ignite until the whole is deflagrated. Care must be taken during this part of the experiment that none of the contents of the crucible get on to the upper edge, or creep down the outside of the crucible, or a considerable amount of sulphur may be absorbed from the flame. When all is deflagrated and white, wash out and dissolve in hot water. Acidulate with pure hydrochloric acid ($H\,Cl$), heat to boiling, and add a hot solution of barium chloride ($Ba\,Cl_2$) or barium nitrate ($Ba\,(NO_3)_2$) as long as a precipitate is formed. Stir well for 5 minutes, allow to stand for 10 minutes more, and decant through filter paper of known ash. Collect ppt. on to the filter, wash well with water until the washings give no ppt. with sulphuric acid. Dry, brush off ppt. into porcelain crucible. Burn filter and add the ash to the ppt. and ignite in muffle for 15 minutes. Cool in desiccator, weigh, deduct the weight of the

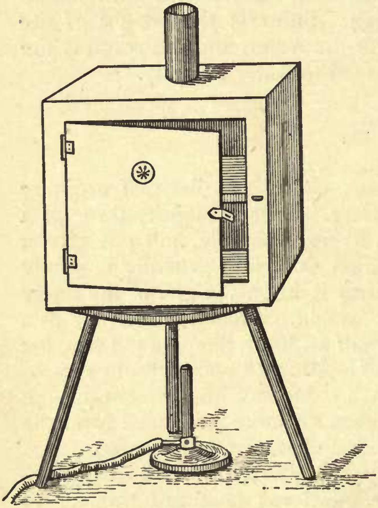

Fig. 21.

filter-ash and the crucible, and multiply the remainder by the co-efficient of sulphur in barium sulphate ($Ba\,SO_4$), viz., ·137.[*]

If the salt, nitre, and sodic carbonate used are not pure, it will be necessary first to estimate the amount of sulphur in them, proceeding in the manner above described, only it will not be necessary to deflagrate the mixed substances, as they are soluble, and may be dissolved in water at once, a little $H\,Cl$ being added, and then the $Ba\,2\,NO_3$ or $Ba\,Cl_2$. If, however, the impurity present is an insoluble sulphide, the deflagration will be necessary. Deduct the weight of the precipitated $Ba\,SO_4$ obtained from the same quantity of material as was used to deflagrate the coal, from the weight of the precipitate, before multiplying by the co-efficient.

Sulphur exists in coal in the form of iron pyrites ($Fe\,S_2$), and occasionally as calcium sulphate ($Ca\,SO_4$), and in rare cases as barium sulphate ($Ba\,SO_4$). These substances are practically insoluble in water, and it is necessary to render them soluble, so that the sulphur may be precipitated and weighed. By fusion with $K\,NO_3$, &c., the sulphur is converted into soluble sulphates of potassium and sodium, which, on the addition of $H\,Cl$ and barium salt, are precipitated as $Ba\,SO_4$. The changes may be thus expressed :—

$$Na\,K\,SO_4 + 2\ H\,Cl = Na\,Cl + K\,Cl + H_2\,SO_4.$$
$$H_2\,SO_4 + Ba\,Cl_2 = 2\,H\,Cl + Ba\,SO_4.$$

Or, if the nitrate is used,

$$H_2\,SO_4 + Ba\,(NO_3)_2 = 2\ H\,NO_3 + Ba\,SO_4.$$

It is preferable to use the baric chloride however, because the nitrate is somewhat insoluble in acid solution.

Experiment 6.—*Estimation of the Calorific or Heating Power.*—The calorific power of a body is ascertained by burning a given weight, and causing the heated products of combustion to pass through water, which thereby becomes warmed. The instrument known as Thompson's calorimeter[†] is used. Weigh out 30 grs. of the finely divided coal, 225 grs. of potassium chlorate ($K\,Cl\,O_3$), and 75 grs. of $K\,NO_3$. Dry all three separately for half an hour in a water-oven. Make a small quantity of saturated solution of $K\,NO_3$, into which dip a piece of cotton wick and set it aside to dry. When dry, try how a small portion will serve as a fuse. Intimately mix the dried coal with the oxidising material, and transfer to the copper cylinder (A) of the

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[*] See Appendix F for table of co-efficients.

[†] Sometimes known as Wright's.

calorimeter, and insert a small piece of the prepared cotton wick, leaving one end projecting above the top of the tube. (Figs. 22, 23, and 24.) The temperature of a measured quantity of water in the vessel (E) is taken and noted. The thermometer used gives readings of $\frac{1}{10}$ degree, and is usually enclosed in a brass sheath for protection. The copper cylinder is now placed in the stand (C), and the fuse ignited, and the bell-like cover (B) is placed over, and the whole lowered into the water. When the deflagration has taken place, open the stopcock (D) at the top of the cover, so that the water may enter and take up the heat of the tube. Move up and down through the water once or twice, then take temperature of the water, and notice the increase due to the combustion of the fuel. About a tenth of the increase of temperature is added for loss incidental to the use of the instrument. This loss of heat is due to radiation, imperfect cooling of the products of combustion, heat taken up by apparatus, &c., and its precise amount for each instrument is ascertained by the manufacturer.

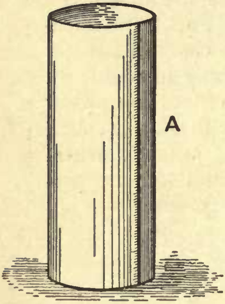

Fig. 22.

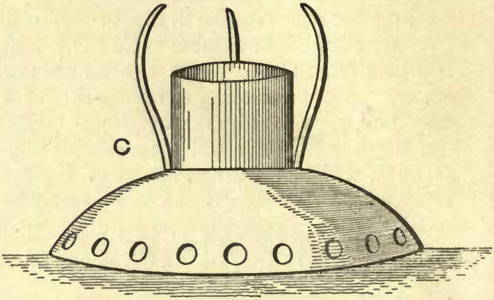

Fig. 23.

The method of obtaining the calorific power and the evaporative power from this instrument will be best shown by an example :—

Initial temperature of water	48·5° Fahr.
Final temperature of water	60·0°
Increase of temperature	11·5
10 per cent added ...	1·15
	12·65

$$\frac{\text{Weight of water} \times \text{rise of temperature}}{\text{Weight of fuel}} = \text{Calorific power.}$$

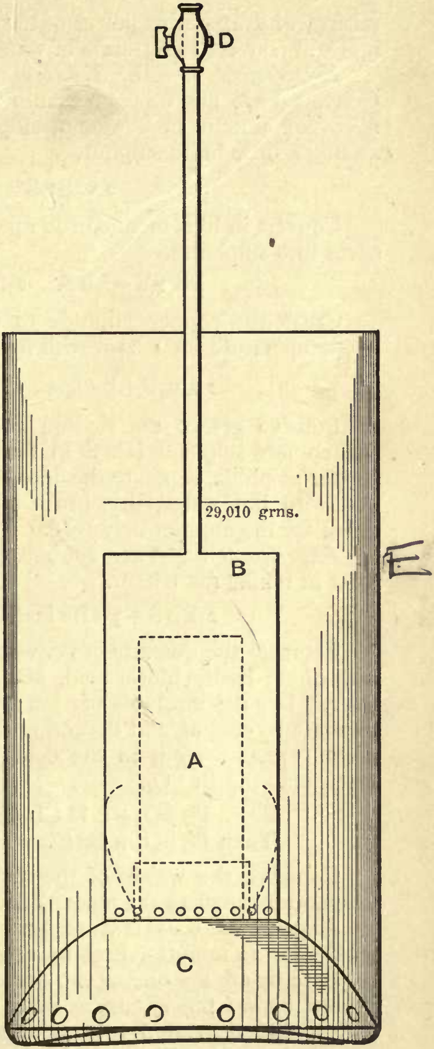

Fig. 24.

The weight of water in grains multiplied by the corrected increase of temperature, and divided by weight in grains of fuel used, gives the calorific power. As calculated from the above figures, it will be

$$\frac{12{\cdot}65 \times 29{\cdot}010}{30} = 12{,}232{\cdot}55,$$

which is the calorific power in Fahr. degrees, or in Centigrade 6796°.

It is obvious that in the foregoing there is no particular reason for taking 29,010 grs. of water; any convenient quantity would do—say, four pints; but for the evaporative power it is convenient to take this particular quantity, because it is the weight of the fuel taken, multiplied by the amount of heat required to convert a unit of water at 212° Fahr. into steam, namely, 967. The heat required to convert a unit of water into steam is 967 times the amount required to raise the same weight of water 1° Fahr. As 30 grs. of fuel are used, and there are 967 grs. of water to each grain of fuel, the rise of temperature due to the combustion, at once expresses the number of units of water which the unit of fuel would convert into steam, assuming the water to be at 212° Fahr. In the above case 12·65 is the steamraising, or evaporative power of the fuel, and means that 1 unit of fuel will convert 12·65 units of water at 212° into steam.

Experiment 7.—*The Effect of Roasting on Sulphides, &c.*—Convert 1000 grs. of copper into sulphide, by mixing with the necessary amount of flowers of sulphur, fusing in a crucible and adding a little more sulphur.

$$2\ Cu + S = Cu_2\ S.$$

Convert in like manner 1000 grs. of lead and 30 grs. of pure silver into sulphides.

$$Pb + S = Pb\,S. \quad 2\ Ag + S = Ag_2 S.$$

Crush the copper sulphide to powder, and heat in muffle at low temperature for 1 hour with frequent stirring.

$$2\ Cu_2 S + 5\ O_2 = 2\ Cu\,SO_4 + 2\ Cu\,O.$$

Boil 50 grs. of the roasted material in water to dissolve out the copper sulphate ($Cu\,SO_4$) formed by the oxidation of the copper sulphide, separate the insoluble portion by filtration, wash well with hot water, dry, brush off the filter paper, and weigh. Calculate the amount dissolved.

Experiment 8.—Take 200 grs. of crushed lead sulphide, and roast in muffle for 1 hour.

$$2\ Pb\,S + 7\ O = Pb\,SO_4 + Pb\,O + SO_2.$$

Estimate the quantity of converted $Pb\,SO_4$ by digesting 50 grs. with dilute hydrochloric acid, and washing with hot water on a filter. Dry the insoluble portion and weigh. Test the filtrate for sulphate by cooling and decanting the clear liquid from the $Pb\,Cl_2$, which crystallises out in the cold, and adding $Ba\,Cl_2$ solution to precipitate the $Ba\,SO_4$.

$$Pb\,SO_4 + 2\ H\,Cl = Pb\,Cl_2 + H_2\,SO_4\,;$$
$$\text{Then } H_2\,SO_4 + Ba\,Cl_2 = Ba\,SO_4 + 2\ H\,Cl.$$

Compare the weight of the insoluble portion with the weight taken, and calculate the amount dissolved.

Experiment 9.—Heat 10 grs. of silver sulphide ($Ag_2\,S$) in muffle for 20 minutes, boil in water, and test for soluble silver sulphate by adding one or two drops of hydrochloric acid. There should be no precipitate, as silver sulphide is insoluble in water, and is not converted into sulphate by roasting, as other metals are—*e.g.*, copper and lead. If the silver from which the sulphide was made had any copper alloyed with it, as standard silver has, it would then partly be converted into sulphate, and the water would give a precipitate with hydrochloric acid.

Experiment 10.—Roast 5 grs. of silver sulphide with 50 grs. of copper sulphide for 40 minutes, at a moderate temperature. Both sulphides should have been finely powdered and intimately mixed together. Boil a portion when roasted and cooled, in water, and test for the presence of silver sulphate by $H\,Cl$. If any silver has become soluble, a white precipitate of silver sulphide ($Ag\,Cl$) will be produced. The above is the basis of the extraction of silver from ores where the metal exists as sulphide, by the method known as Ziervogel's, in which process the silver is thrown down from solution by means of metallic copper. In the process for the extraction of silver by Augustin's method the argentiferous ore is roasted with common salt, which decomposes the sulphates formed by the roasting, and converts them into chlorides, which are then dissolved out by means of a strong brine solution, and the silver finally precipitated by means of metallic copper.

$$Ag_2S + 2\,O_2 = Ag_2SO_4.$$
$$Ag_2SO_4 + 2\,Na\,Cl = 2\,Ag\,Cl + Na_2SO_4.$$

In the Percy-Patera process, sodium thiosulphate ($Na_2S_2O_3$) is used to dissolve out the silver chloride after roasting, thus :—

$$Na_2S_2O_3 + Ag\,Cl = Ag\,Na\,S_2O_3 + Na\,Cl,$$

from which solution the silver is precipitated by means of sodium sulphide (Na_2S).

Experiment 11.—Roast 100 grs. of finely powdered blende ($Zn\,S$) at low temperature for half an hour. Digest 10 grs. in hot water, and test for zinc sulphate by adding a few drops of hydrochloric acid and baric chloride. Wash well with hot water, filter, and weigh the residue. Estimate the percentage of soluble matter. Further roast at a higher temperature for an hour. Prove the absence of sulphate of zinc by digesting with water and testing with $H\,Cl$ and $Ba\,Cl_2$, when there should be no precipitate.

The reactions at the lower temperature may be shown thus :—

$$2\,Zn\,S + 7\,O = Zn\,SO_4 + Zn\,O + SO_2.$$
$$Zn\,SO_4 + 2\,H\,Cl + Ba\,Cl_2 = Ba\,SO_4 + Zn\,Cl_2 + 2\,H\,Cl.$$

At the higher temperature the zinc sulphide reacts on the sulphate, forming zinc oxide ($Zn\,O$) and sulphurous anhydride.

$$Zn\,SO_4 + Zn\,S + O_2 = 2\,Zn\,O + 2\,SO_2.$$

Experiment 12.—Prove that in the following equations neither the cuprous sulphide (Cu_2S) or cupric oxide (CuO) or cuprous oxide (Cu_2O) are in excess.

(*a*) $Cu_2S + 2\ CuO = 4\ Cu + SO_2$.
(*b*) $Cu_2S + 2\ Cu_2O = 6\ Cu + SO_2$.

Prove also that in the next two equations the excess of copper sulphide added is not reduced.

(*c*) $2\ Cu_2S + 2\ CuO = 4\ Cu + Cu_2S + SO_2$.
(*d*) $2\ Cu_2S + 2\ Cu_2O = 6\ Cu + Cu_2S + SO_2$.

These reactions are the basis of the separation of metallic copper in the Welsh process for smelting copper, in the latter stages of which process, copper oxide and sulphide are heated together, both of which by a mutual reaction become reduced to the metallic state, and the sulphur passes off as sulphurous anhydride. If an excess of either is present it will remain over unacted upon, except in so far as a considerable quantity of the oxide would, if that were in excess, be dissolved in the melted copper.

Experiment 13.—*Assay of Galena.*—Make two assays of galena (PbS), taking for each 300 grs. of finely powdered galena, 300 grs. of sodic carbonate (Na_2CO_3), and 30 grs. of potassic bitartrate (tartar). Mix together the above reagents, saving about 50 grs. of Na_2CO_3 to cover the remainder when in the crucible. Put also into the crucible a piece of hoop iron about 3 ins. long, and heat until all action ceases. If any iron is left, take hold of it with a pair of tongs, and strike smartly while holding it over the crucible. By this means any adhering lead is liberated and falls into the crucible. Pour into mould, and when cold hammer into the form of a cube, then by hammering the cube on the corners, the slag and iron sulphide that have been produced during the reduction are broken away, and a mass of lead is left. Brush the lead in hot water with a hard tooth-brush until quite clean. Dry and weigh carefully, and calculate the percentage of metal in the ore, and also the amount per ton. Preserve the lead for the estimation of silver by cupellation.

Experiment 14.—Make two assays, taking for each 300 grs. of galena (PbS), 250 grs. of sodic carbonate, 30 grs. of tartar, and 50 grs. of borax ($B_4O_7Na_2$). The ore and fluxes, except the borax, should be intimately mixed. Place the mixture in a crucible, and the borax on the top, and insert a piece of iron as before. When all action has ceased pour into mould, cool, and detach slag and sulphide by hammering and washing. Weigh the button of lead and compare the percentage obtained with that from the first method. Preserve the lead for cupellation.

Experiment 15.—Make two assays of galena (PbS), using 300 grs. each of the ore, and reducing by means of iron alone, without the addition of any flux.

$$PbS + Fe = FeS + Pb.$$

Weigh the buttons of lead after cleaning them, and compare with the weight of those from the preceding experiments. Reserve the lead for cupellation.

Experiment 16.—*To Cupel the Buttons of Lead for the Estimation of the Silver.*—Galena almost invariably contains traces of silver, present in the form of sulphide. The quantity of silver in galena is very variable, some samples assaying upwards of 300 oz. to the ton, others only a few grains. When argentiferous galena is smelted, the whole of the silver passes into the lead, from which it is readily extracted. The silver can be profitably extracted if the galena contains not more than ·002 per cent.

Select 6 cupels, each weighing considerably more than the button of lead that is to be placed in it, and having a capacity sufficient for holding the lead when melted. Place the empty cupels into a muffle, and when red-hot introduce into each a button of the lead from the galena, and heat in muffle until all the lead has been oxidised and absorbed by the cupel. Remove cupels and allow to cool slowly; when cold, carefully weigh the button of silver.

To calculate the quantity of lead and silver per ton of ore, multiply the weight of lead from the sample of ore by the number of grains in a ton, and divide by the weight taken, reduced to grains, and the result gives the lead per ton in grains.

For the silver, multiply the weight of silver from the sample by the number of grains in a ton, and divide by the grains in the weight taken.

Example:—Calculate the amount of lead and silver from a ton of ore, where 300 grs. gave 250 grs. of lead, and which on cupellation gave ·8 gr. of silver.* (See Appendix G.)

$$\text{To find the lead, } \frac{250 \times 7000 \times 2240}{300} = 13{,}066{,}666 \text{ grs.}$$

$$= 16 \text{ cwt. } 2 \text{ qrs. } 13{\cdot}6 \text{ lbs. of lead per ton.}$$

$$\text{To find the silver, } \frac{{\cdot}8 \times 7000 \times 2240}{300} = 41{,}813{\cdot}\dot{3} \text{ grs.}$$

$$= 87 \text{ oz. } 2 \text{ dwt. } 4{\cdot}3 \text{ grs. troy of silver per ton.}$$

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* See note 7, Appendix A.

Experiment 17.—*Assay of Hæmatite.*—Crush and pass through 80 sieve 100 grs. of hematite. Make four assays, two of each of the following mixtures, in brasqued crucibles (Fig. 25) (see p. 44).

First—Ore ...	10·0 grs.	Second—Ore	10·0 grs.
Sand ...	0·5 „	Glass	2·5 „
Lime ...	2·5 „	Lime	3·0 „
China-clay	2·0 „		

Mix the ore and the fluxes thoroughly on glazed paper, and transfer the mixtures into the respective crucibles, and fit into the top of each a charcoal plug. The plugs should be marked in some way by means of which the assays may be distinguished when the operation is complete. Lute on the lids,* and also lute all the crucibles to a portion of firebrick. When the lute is dry, place the whole in a furnace, allowing the brick to rest upon the bars, light the fire, and heat at a high temperature for 2 hours. If the ores contain much titanium they will require 3½ to 4 hours. When the fire has burnt low, remove the crucibles and allow to cool. Break open the crucibles and separate the slag from the iron buttons, taking care to keep the assays separate. Grind the slag in a clean iron mortar, and extract by means of a magnet any small shots of iron, and add them to the main portion. Weigh the iron carefully from each assay, and calculate the percentage of iron in the ore. The results of the assays should not differ more than ·3 or ·4 per cent. The slag should be globular and well fused, opaque, and somewhat vitreous in appearance.† Each button of iron should be wrapped in a stout piece of paper, and struck with a hammer on an anvil, and should flatten slightly before breaking. The fracture of the iron should be grey and granular. If the buttons and slags do not answer to this description the assay should be repeated, and a higher temperature, if possible, obtained.

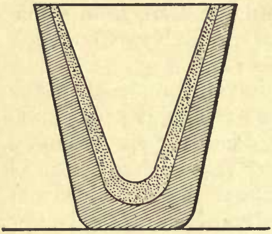

Fig. 25.

Experiment 18.—Assay in unlined crucible. Take 1000 grs. of hematite and pass through 60 sieve. Weigh out 500 grs. and mix with 200 grs. of china-clay, 250 grs. of lime, 50 grs. of sand, and 100 grs. of powdered anthracite. Introduce into crucible,

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* Note 1, Appendix A.

† Note 3, Appendix A.

and lute on the lid. Place in furnace with a low fire, and build up the fire around it, and heat at high temperature for 2½ hours. Remove in an upright position, and when cool break crucible, remove button of iron, and grind the slag and all parts of the crucible which have any slag adhering, in an iron mortar, to fine powder. Separate any small shots of iron by means of a magnet, and from the weight of the iron obtained calculate the percentage of iron in the ore, comparing the result of the assay with that made in the lined crucible. Fracture and note the appearance of the iron, and also of the slag. A good button of iron will separate completely from the slag, and if of good quality will slightly flatten before breaking, and when broken will show a finely granular fracture. The slag should be well fused, of a light grey colour, and somewhat vitreous. A transparent green slag indicates an excess of silica, while a dull, stony slag indicates an excess of bases. If the ore contains lime and magnesia the product will probably be only fritted, and will require an additional amount of silica.*

Experiment 19.—Crush and pass through 60 sieve, 1000 grs. of clay ironstone, and make two assays of each of the following mixtures: (1), 10 grs. of ore, 2·5 grs. of powdered glass, and 2·5 grs. of lime; (2), 10 grs. of ore, 2 grs. of china-clay, 1 gr. of sand, and 2 grs. of lime. Intimately mix the constituents of each assay and introduce into brasqued crucible. Lute the four crucibles employed to a brick, and treat as described in Experiment 17. Separate carefully any stray shots of metal, and calculate from the weight of iron obtained, the percentage in the ore.

Experiment 20.—Make two assays of the clay ironstone in unlined crucible, taking 500 grs. of the ore, 250 grs. of glass, 250 grs. of lime, and 125 grs. of anthracite, in each case. Treat as described in Experiment 18, and weigh the iron obtained. Note the appearance of the fracture of the iron and of the slag, and calculate the percentage of iron, comparing it with the result of Experiment 19.

Experiment 21.—Mercury compounds are readily reduced to the metallic state by heating with some substance that will combine with the body, in combination with the mercury, to form a fixed compound; and the mercury, by virtue of its volatility, may be made to pass off, and condense in the cooler parts of the apparatus. Quicklime is the substance used, and the reaction between that body and sulphide of mercury (cinnabar) may be thus shown:—

$$4\,\mathrm{Hg\,S} + 4\,\mathrm{Ca\,O} = 4\,\mathrm{Hg} + 3\,\mathrm{Ca\,S} + \mathrm{Ca\,SO_4}.$$

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* Note 3, Appendix A.

The iodide of mercury is, however, not completely decomposed by this means, but by the addition of copper turnings or filings to the lime, this compound is readily split up and the mercury liberated.

Assay of Mercury.—Take a piece of combustion tubing from 1 ft. to 1½ ft. long, hermetically seal one end, and carefully anneal the closed end to prevent its cracking in the subsequent heating. Introduce into the cooled tube 100 grs. of the mineral magnesite ($Mg\,CO_3$), finely powdered and dried at 100°, on the top of that 50 grs. of dried quicklime, and then a mixture of 100 grs. of finely powdered cinnabar, 30 grs. of dried quicklime, and 10 grs. of powdered charcoal, and, lastly, about 100 grs. of dried quicklime. Draw out before the blowpipe the glass tubing about 1½ in. from its open end, and bend the part which has thinned by being drawn out to a right angle. Place the tube in a small combustion furnace (Turner's), so arranged that the tube is supported its entire length, and that the bent end just dips below the surface of water contained in a small beaker (Fig. 26). Heat at good temperature for half an hour the portion of the tube containing the cinnabar, and lastly the magnesite, which, on the application of heat, is split up into $Mg\,O$ and CO_2. The CO_2 passing over the material in the tube sweeps out all traces of mercury vapour. When cold, cut off the end of the tube, and remove the mercury from it with a camel-hair brush. Decant the water, dry carefully by means of filter paper as far as possible, pour the mercury on to a watch glass, and place in a desiccator for an hour. Weigh, and deduct the weight of the glass.

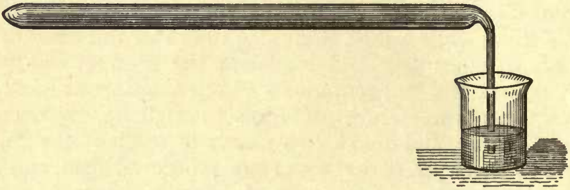

Fig. 26.

Experiment 22.—Take 50 grs. of finely powdered cinnabar, 15 grs. of quicklime, and 5 grs. of charcoal; mix well together and intoduce into weighed porcelain crucible. All the materials should have been well dried for half an hour in water-oven. Cover with 10 grs. of dried quicklime, and heat in fume closet by means of a Bunsen burner for half an hour. Cool in desiccator and weigh. The loss of weight is due to the volatilisation of the mercury. Compare the result with that of the preceding experiment.

Experiment 23.—The amount of zinc in an ore may be approximately estimated by the following means:—Pass a sample of zinc blende (ZnS) through 60 sieve, weigh out 100 grs., and roast in roasting dish at a low temperature in muffle for half an hour, with constant stirring. Increase the temperature and roast further, with occasional stirring, for 2 hours, or until sweet. Heat a blacklead crucible in a furnace until white-hot and project into it the roasted mass, which should have been cooled and weighed, mixed with 10 grs. of powdered charcoal. Heat at high temperature for 10 minutes, remove from fire and allow to cool. Turn out any residue and reroast for 20 minutes, stirring occasionally, and reweigh. By the first roasting all the sulphides will be converted into oxides, and the zinc oxide thus formed is reduced and the zinc volatilised when heated in the blacklead crucible with charcoal. The difference between the weight after the first roasting and the weight of the residue gives the quantity of ZnO in 100 grs. of ore. The object of roasting the residue after ignition in the crucible is to convert any lead or iron that may be present in the ore, and which would be reduced to the metallic state in the crucible, back to the state of oxide, and to drive off any excess of charcoal in the form of CO_2.

Example.—If the assay after roasting sweet weighs 81·7 grs., and after ignition in the crucible and reroasting weighs 2·34 grs., then the weight of zinc oxide from 100 grs. of ore is 79·36 grs.

First weighing 81·70 grs.
Second ,, 2·34 ,,
79·36 grs.

$$\begin{array}{rcl} Zn & = & 65 \\ O & = & 16 \\ \hline ZnO & = & 81 \end{array}$$

$$\begin{array}{ccccccc} ZnO & & Zn & & ZnO & & Zn \\ 81 & : & 65 & :: & 79{\cdot}36 & : & x \end{array}$$

$$\frac{65 \times 79{\cdot}36}{81} = 63{\cdot}684 \text{ per cent Zn.}$$

Experiment 24.—The method known as Von Patera's for extracting silver from argentiferous copper pyrites depends upon the solubility of silver chloride ($AgCl$) in a solution of thiosulphate of soda (hyposulphite of soda). The method is briefly shown in the following experiment. Pass a sample of argentiferous copper pyrites* through 60 sieve, weigh out 100 grs., and mix with 100 grs. of common salt. The salt should have been previously ignited to prevent it decrepitating. Roast the mixture at a low temperature in roasting dish in muffle for 1 hour, with occasional stirring. Cool and digest the roasted mass with a *cold* solution of thiosulphate of soda ($Na_2 S_2 O_3$) which dissolves out the silver chloride ($Ag Cl$). Allow to stand for 12 hours, filter and wash residue with water containing a little $Na_2 S_2 O_3$ until the washings do not give a precipitate, when a solution of $H_2 S$ is added. Mix the filtrate and the washings, and pass $H_2 S$ gas until all the silver is precipitated as sulphide ($Ag_2 S$). Filter, wash with hot water, dry, and weigh. Estimate the quantity of silver. The silver sulphide may be reduced by fusing with sodium carbonate, and a small quantity of nitre.

Experiment 25.—The silver may be precipitated, after roasting and dissolving out with water, by means of a soluble iodide, as in the method proposed by Claudet. Mix 100 grs. of finely divided argentiferous copper pyrites with an equal weight of ignited common salt, and roast at low temperature for 2 hours, with occasional stirring. Allow to cool, and dissolve out the chlorides with hot water to which a little $H Cl$ has been added, by digesting for some time at a gentle heat. Decant solution through filter paper, and wash the residue two or three times, decanting each time. Collect the residue on the filter paper and give it a final washing, each time adding the washings to the main portion. Heat the solution to boiling, and add 10 grs. of potassium iodide ($K I$) or zinc iodide ($Zn I_2$), and allow to stand for some time in a warm place. A precipitate of silver iodide ($Ag I$) will be formed. Filter, wash well with water, and add the first washings to the filtrate. The precipitate of $Ag I$ may be dried, brushed from the paper by means of a camel-hair brush, and weighed on a watch-glass, and from the weight the amount of silver per ton may be readily calculated. To the solution containing the copper, &c., add $H Cl$, and boil for some time to expel the iodine, dilute largely with water, and pass $H_2 S$ for some time. Filter, wash, and dissolve the precipitate in dilute $H NO_3$, add excess of sodic hydrate, when the whole of the copper is thrown down as hydrate. Filter, wash well, and dry the paper and precipitate. Transfer the precipitate as far as possible, with the aid of a camel-hair brush, to a weighed

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* See note 4, Appendix A.

porcelain crucible; burn the paper separately. Ignite the precipitate, and allow to cool in a desiccator. From the weight deduct the crucible and ash, and calculate the percentage of copper and the amount per ton of ore.

Equations. $Ag_2S + 2\ NaCl + 2\ O_2 = 2\ AgCl + Na_2SO_4.$
$AgCl + KI = KCl + AgI.$

Experiment 26.—The action which is performed by the metal mercury, in the extraction of silver from its ores, may be studied to a limited extent by causing mercury to be brought into contact with silver sulphide. Convert 20 grs. of silver into silver sulphide (Ag_2S) by heating the silver in a crucible, and dropping into the crucible while at a red heat a lump of roll sulphur. Pour, weigh, fracture, and notice the appearance of the sulphide, and that it flattens out a little before breaking, being somewhat malleable.

Experiment 27.—Triturate for some time 10 grs. of finely divided silver sulphide, with excess of mercury, at a moderately warm temperature. When all the silver sulphide is decomposed pour off the mercury, and weigh the residue of mercury sulphide (HgS). Squeeze the excess of mercury through washleather until the remaining portion is pasty. Transfer the pasty mass to a porcelain crucible of known weight, and heat in fume chamber to volatilise the mercury. The weight of the silver, if the whole of the sulphide was decomposed, should be 8·7 grs.

$$Ag_2S + 4\ Hg = HgS + Ag_2Hg + 2\ Hg.$$
$$Ag_2Hg = Hg + 2\ Ag.$$

The formula Ag_2Hg is only approximate.

Experiment 28.—Take 20 grs. of standard silver and dissolve in dilute nitric acid, heat gently, make up the solution to half a pint, and add a warm solution of 20 grs. of common salt. Heat to boiling, and allow to stand for some hours. Decant solution through filter paper, and wash precipitate of silver chloride ($AgCl$) on to the filter. Wash well with hot water until the washings give no colouration, when a solution of H_2S is added. Add the washings to the main portion of solution, add a few drops of HCl, and evaporate nearly to dryness to expel the nitric acid. Dilute largely, and pass a current of H_2S gas for some time. Boil, filter, and test the filtrate for copper by again passing H_2S for some time. If a precipitate is formed, filter through the same paper. Wash precipitate on the filter with warm water, dry, and weigh as CuS. Dry also the silver chloride, and weigh. Calculate the percentage of silver and copper in the alloy of silver taken.

Experiment 29.—Triturate 10 grs. of dry silver chloride with mercury until all the Ag Cl is decomposed, pour off the amalgam, and weigh the residue of mercuric chloride ($HgCl_2$). Squeeze the excess of mercury through washleather, and heat the pasty mass in a porcelain crucible in muffle to volatilise the mercury. Weigh the silver obtained.

Experiment 30.—Dissolve 10 grs. of silver chloride in brine. Heat to boiling, and place in the solution a strip of copper. Allow to stand for 24 hours for the precipitation of the silver, which should be collected, dried, and weighed. The importance of cautiousness when adding Na Cl to a silver solution so as to avoid a large excess, is shown by this experiment, for it shows the solubility of silver chloride in an excess of a soluble chloride. The property of one metal to replace another in solution is also shown. This change is an example of the action of an electro-positive metal upon a solution of a less electro-positive one. The following metals would also precipitate metallic silver from a solution:—Zn, Pb, Sn, Sb, Fe, Cd, and Hg. The quantity of metal deposited, and the quantity of metal taken into solution, may be calculated by dividing the atomic weights of the metals by their atomicity, thus:—$\frac{63}{2}$ parts of copper will deposit $\frac{108}{1}$ parts of silver, and the same quantity of silver will be deposited by 32·5 parts of zinc, 51·4 parts of lead, 29·4 parts of tin, 22 parts of antimony, 14 of iron, 59·5 of cadmium, and 100 of mercury.

Experiment 31.—Make cupels of bone ash, finely powdered and passed through 60 sieve, and moistened with water in such proportion that a little squeezed in the hand resists to a sensible degree an attempt to pull it apart. Fill the cupel mould with the moistened bone ash, and force in the plug with one or two blows of a mallet. (See Figs. 7, 8, and 9, page 29.) Remove the cupel from the mould, and proceed as before, making 2 dozen of various sizes and with varying quantities of bone ash. Put aside in a warm place to dry.

Experiment 32.—Make an alloy of 200 grs. of copper, 600 grs. of lead, and 20 grs. of silver, cast into round mould, and flatten out into a cake. Liquate the lead and silver from the copper after the manner described in Experiment 33, Part I. Cupel the lead, and carefully weigh the silver obtained. A small quantity of bone ash is generally found adhering to the button of silver, and should be removed by a gentle tap with a hammer before weighing. Calculate the loss of silver per cent, and, if considerable, remelt the copper remaining from the liquation with 500 grs. of lead, and again liquate and cupel the lead. Add the weight of the second button of silver to the first, and, if necessary, repeat the liquation with another 500 grs. of lead.

Experiment 33.—Take two large cupels, heat in muffle, and introduce into each 500 grs. of commercial lead. Cupel the lead until the whole has been converted into oxide and absorbed. Weigh very carefully the small button of silver obtained. Compare the two results, and if they do not agree, repeat with two other cupels with the same quantity of lead.

Experiment 34.—Make two alloys, (*a*) 500 grs. of lead and 10 grs. of silver, (*b*) 500 grs. of lead, 10 grs. of silver, and 10 grs. of copper, by melting in crucible under a little charcoal. Pour into ingot mould, and flatten out with a hammer. Roll out, by means of a rolling mill, into thin strips. Take 4 pieces of 50 grs. each of (*a*), and introduce into a previously heated small cupel. Heat in muffle until cupellation is completed. Remove the buttons of silver, free them from adhering bone ash, and weigh carefully. Repeat with four other assays, and if the alloy is homogeneous the results will vary very little. Take also 4 pieces of 50 grs. each of (*b*), and treat in the same way, weighing the silver buttons. Observe that those cupels in which lead only has been oxidised and absorbed, are of a light yellow or straw colour, while those to which copper has been added have a dark brown or black stain. The examination of a cupel will frequently enable a person to state with accuracy what metals have been present during the cupellation.*

Experiment 35.—It frequently happens that alloys contain metals that are not readily cupelled, and these alloys should be subjected to the process of scorification before being cupelled. The presence of much copper, of antimony, tin, sulphur, nickel, arsenic, or zinc, will necessitate the operation of scorification. In cases where the composition is doubtful, it is better to scorify. If the button of lead is too large, it should be reduced by means of a scorification before being introduced into the cupel. A cupel will absorb about its own weight of litharge, but a cupel should be chosen that weighs at least 15 per cent or 20 per cent more than the button of lead that it is to receive. Make an alloy of 300 grs. of copper, 50 grs. of tin, 20 grs. of antimony, and 20 grs. of silver, by melting the constituents together under a little charcoal. Place

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* See Appendix A, note 6.

a piece of the alloy of about 10 grs. weight on a cupel in muffle, and heat for 10 minutes. Observe the effect on the alloy and on the cupel. Cut off a piece of the alloy, weighing about 100 grs., and introduce it, with 100 grs. of lead, 10 grs. of sand, and 10 grs. of borax, into a scorifier, previously heated to redness. Continue the heating till the surface of the liquid metal is covered with slag, when the slag should be poured off and 50 grs. of lead added. Heat further until the surface is again covered with slag, pour the whole into a round mould, and when cold break away the slag with a hammer. Weigh the button and introduce it, together with more lead, into a hot cupel; heat, and add more lead if necessary, until the whole of the base metals have been removed, and the button of silver in the cupel is bright and clear. Notice the colour and appearance of the scorifier, of the slag, and of the cupel.

Experiment 36.—In the assay proper of silver bullion, it is necessary, in consequence of the loss of silver due to volatilisation and absorption by the cupel, to make a check assay of silver of known standard at the same time, and under the same conditions, as the assay of the bullion. By simple comparison of the weights of the final buttons, the purity and value of the bullion can be ascertained. If the buttons obtained from an equal quantity of the alloy and of the standard are of the same weight, then the alloy and standard are of the same purity and value (assuming that no gold is present). The check may be of the ordinary coinage, or the constituents of ordinary silver may be weighed out.

Weigh out four assays of standard silver of 10 grs. each, wrap each in 100 grs. of sheet lead free from silver. For the check weigh out 9·25 grs. of pure silver and ·75 grs. of electrotype copper, and wrap them also together in 100 grs. of sheet lead. Heat 5 cupels of convenient size to redness in muffle, and place in each, one of the weighed assays. Heat until cupelled, and cool down carefully, to prevent loss of silver through 'spitting' or 'vegetating.' (See page 32.) The silver lost during the assay may be ascertained by the difference between the weight of the silver obtained from the check and 9·25. If, now, this loss is added to the weights of the results of each of the four assays, the true weight of silver present in 10 grs. of the standard silver taken will be obtained.

The loss of silver during cupellation varies from ·1 per cent to ·45 per cent.

Experiment 37.—Obtain a French silver coin, and make an assay by weighing out 10 grs. into each of four cupels. Weigh out also for a check 9 grs. of pure silver and 1 gr. of pure copper. Wrap each in 100 grs. of pure lead and treat as in last experiment. Weigh the buttons carefully and calculate the percentage of silver. Repeat the above with any other silver alloy, *e.g.*, French or English jewellery.

Experiment 38.—When an alloy containing gold or platinum is subjected to cupellation, the whole of the noble metal is retained on the cupel alloyed with any silver that may be present, and the alloy must be treated by a wet method for its separation. Melt on a cupel 100 grs. of lead, 25 grs. of silver, and 5 grs. of platinum (Pt). When all the lead is absorbed, remove cupel, allow to cool, and weigh the button. Flatten the silver and platinum alloy, and roll out thin and treat will nitric acid ($H NO_3$) in conical flask. Heat to boiling, and when dissolved transfer to porcelain dish and evaporate nearly to dryness. Take up with water and add H Cl (dilute) until all the silver is precipitated as silver chloride (Ag Cl). Heat nearly to boiling, allow precipitate to settle and filter through a good filter paper. Wash well with hot water, dry, and fuse with $Na_2 CO_3$ for the reduction of the silver. Allow filtrate to cool, filter off any precipitate, add an excess of a solution of ammonium chloride (Am Cl). Transfer to porcelain dish and evaporate to dryness. Cool, and treat with water to which has been added an equal bulk of alcohol. Decant through a filter paper of known ash, and collect the insoluble residue on the filter. The residue is the double chloride of platinum and ammonium, and has the formula 2 Am Cl, $Pt Cl_4$. It contains 43·9 per cent of platinum. Wash the residue with alcohol, dry, and heat gently in porcelain crucible until the ammonium chloride has been expelled, when the crucible should be raised to a full red heat. Allow to cool in desiccator and weigh the residue of metallic platinum.

The weight of the platinum may be obtained by weighing the double chloride after drying at 100° and calculating the amount of platinum from the formula, or simply by multiplying by the factor ·439.*

Experiment 39.—Weigh out 10 grs. of standard gold and fuse with 100 grs. of pure lead on a cupel. The gold is not subject to loss as the silver is, and so a check need not be taken. It is, however, advisable to take two assays of 10 grs. each for comparison. Calculate the percentage of gold present in the standard from the weights of the buttons of fine gold remaining after

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* See Appendix F for table of factors.

cupellation.* A light, or greenish yellow colour indicates the presence of silver in the alloy. Australian coinage contains silver, and a button from such an assay would require to be treated by the process known as *parting* for the separation of the silver, since both gold and silver remain alloyed together on the cupel.

Fig. 27.

Fig. 28.

Experiment 40.—*Parting.*—Make an alloy of 30 grs. of silver and 10 grs. of gold, cast into ingot, and cut into two equal parts. Flatten out under the hammer, clean with hot water, and roll out thin (Fig. 27). Coil each piece round a lead pencil, to from a 'cornet' (Fig. 28), take the exact weight of each, and proceed to 'part' (*a*) with dilute nitric acid, and (*b*) with strong sulphuric. Place (*a*) in a parting flask (Fig. 29), and add about 10 c.c. of dilute nitric acid (1 acid to 2 water), boil for 10 minutes, or until all action ceases. Pour oft the acid solution into a large beaker, and pour over the cornet 5 c.c. of strong nitric acid; boil again for 5 minutes to ensure that the whole of the silver is dissolved out. Pour off the strong acid and wash the cornet in the flask several times with hot water, adding all the washings to the nitric solution. The washing must be continued until the filtrate gives no trace of a precipitate with hydrochloric acid. Fill the parting flask with water, cover with the thumb, and invert it into a small smooth crucible (cornet crucible) (Fig. 30). After allowing any small particles of gold that may have been detached to descend

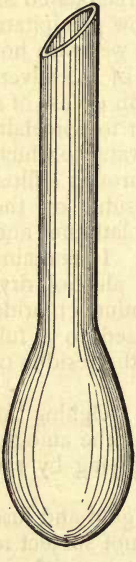

Fig. 29.

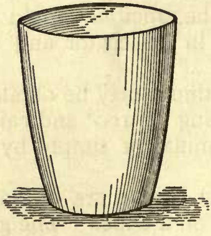

Fig. 30.

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* See Appendix G for table.

into the crucible, together with the cornet, the flask is removed and the water poured carefully away from the gold. The crucible should now be dried carefully, and gradually heated to redness in a muffle, when the cornet will change from a brown to a bright yellow colour, and when cold may be weighed. To the solution containing the silver add common salt or hydrochloric acid for the precipitation of the silver as chloride, in which state it may be weighed after drying, or it may be fused with sodic carbonate for reduction to the metallic state.

$$4\ Ag + 6\ HNO_3 = 4\ AgNO_3 + NO_2 + NO + 3\ H_2O, \text{ or}$$
$$6\ Ag + 8\ HNO_3 = 6\ AgNO_3 + N_2O_2 + 4\ H_2O.$$

$$AgNO_3 + NaCl = AgCl + NaNO_3, \text{ or}$$
$$AgNO_3 + HCl = AgCl + HNO_3.$$

Place (*b*) in parting flask, add 10 c.c. of strong sulphuric acid, boil for 15 minutes, pour off the acid, and repeat the boiling twice with concentrated sulphuric acid. Pour off the acid and wash repeatedly with hot water, until the washings give no precipitate with hydrochloric acid. Fill the parting flask with water, invert into crucible, pour off the water, dry carefully, and ignite in muffle as before. Weigh the gold cornet, and compare with the weight of the cornet from the nitric acid parting. Mix the washings and the acid solutions containing the silver, and add $NaCl$ or HCl for its precipitation as chloride. Weigh either as chloride or as metallic silver after reduction, and compare with the weight of the silver from the nitric acid parting.

$$2\ Ag + 2\ H_2SO_4 = Ag_2SO_4 + SO_2 + 2\ H_2O.$$
$$Ag_2SO_4 + 2\ NaCl = 2\ AgCl + Na_2SO_4.$$
$$Ag_2SO_4 + 2\ HCl = 2\ AgCl + H_2SO_4.$$

Experiment 41.—Make an alloy of 50 grs. of lead, 20 of copper, 10 of tin, 10 of antimony, 10 of zinc, 10 of silver, and 5 of gold. Treat this alloy by the methods described in the preceding experiments, embracing the operations of scorification, cupellation, and parting, weigh accurately the silver and gold obtained, and note the appearance of each scorifier and cupel used.

ALLOYS.

Experiment 42.—Make the following alloys by melting the constituents under a little charcoal, and deduce the percentage composition from the weight of the ingot, and the formula from the percentage composition :—

COPPER-ZINC SERIES.

	FORMULA.	PERCENTAGE COMPOSITION.	
1.	$Cu_{10}Zn$	Cu 90·66	Zn 9·34
2.	Cu_5Zn	Cu 82·90	Zn 17·10
3.	Cu_2Zn	Cu 65·97	Zn 34·03
4.	$CuZn$	Cu 49·43	Zn 50·57
5.	$CuZn_2$	Cu 32·64	Zn 67·36
6.	$CuZn_3$	Cu 24·42	Zn 75·58

COPPER-TIN SERIES.

1.	$SnCu_{15}$	Cu 88·92	Sn 11·08
2.	$SnCu_{10}$	Cu 84·24	Sn 15·76
3.	$SnCu_7$	Cu 78·91	Sn 21·09
4.	$SnCu_5$	Cu 72·77	Sn 27·23
5.	$SnCu_4$	Cu 67·86	Sn 32·14
6.	$SnCu_3$	Cu 61·58	Sn 38·42
7.	$SnCu_2$	Cu 51·66	Sn 48·34
8.	$SnCu$	Cu 34·82	Sn 65·18
9.	Sn_2Cu	Cu 21·08	Sn 78·92
10.	Sn_3Cu	Cu 15·11	Sn 84·89
11.	Sn_4Cu	Cu 13·35	Sn 86·65
12.	Sn_5Cu	Cu 10·67	Sn 89·33

TIN-LEAD SERIES.

1.	Sn_4Pb	Sn 69·60	Pb 30·40
2.	Sn_2Pb	Sn 53·37	Pb 46·63
3.	$SnPb$	Sn 36·39	Pb 63·61
4.	$SnPb_2$	Sn 22·22	Pb 77·78
5.	$SnPb_4$	Sn 12·51	Pb 87·49
6.	$SnPb_6$	Sn 8·62	Pb 91·38

Dry Assay of Copper Ore.—The ores of copper may be conveniently divided into three classes—1st, oxidised ores, including the blue and green carbonates of copper, the red and black oxides, &c. ; 2nd, yellow or pyritic ores, comprising the sulphury ores of copper, otherwise than the fahlerz, &c. ; 3rd, the grey ores, including fahlerz, &c.

Experiment 43.—*Assay of Ores of the First Class : Oxidised*

Ores.—Pass a sample of the ore through 60 sieve, weigh out 100 grs., and mix with 100 grs. of sodic carbonate, 80 grs. of argol, 30 grs. of fused borax, and 30 grs. of lime. Introduce the mixture into a small copper assay (Cornish) crucible, and heat in sharp fire for 10 to 15 minutes. When all action has ceased, pour into round mould, cool, and break away slag. The slag may be conveniently separated by plunging into water while still hot, or by throwing water on it immediately after solidification. Separate any shots of copper from the slag by crushing it to powder, and add the shots to the main portion. The product corresponds to the coarse copper of the Welsh copper-smelting process. The slag contains a notable amount of copper, which it may be made to yield by fusing with 50 grs. of tartar, 20 grs. of sodic carbonate, and 5 grs. of charcoal, and which fusion should be performed in the same crucible that was used for the production of the coarse copper. Add the small button obtained from cleaning the slag to the main portion, and weigh. Refine the coarse copper by dropping it into a white-hot crucible, and allowing it to remain molten for some time. Introduce into the crucible containing the molten copper 100 grs. of *refining flux*, and after two minutes pour the copper into a round mould. (For the method of preparing the refining flux see note 5, Appendix A.) Cool, detach slag, and grind the latter to powder in an iron mortar. Mix the powdered slag with 50 grs. of tartar, 20 grs. of calcium carbonate (limestone) ($Ca\,CO_3$), and 5 grs. of charcoal, and fuse in the same crucible as used for the refining, in order to clean the slag. Add the small button from the refinery slag to the main portion, weigh, and estimate the percentage of copper and the amount per ton of ore.

Experiment 44.—*Assay of Ores of the Second Class: Pyritic Ores.*—Crush a sample of the ore and pass through 80 sieve, weigh out 200 grs. after careful mixing, and add 200 grs. lime, 200 grs. fluor-spar ($Ca\,F_2$), 150 grs. powdered glass, 150 grs. borax, and 50 grs. nitre. Heat in large copper assay crucible for 15 minutes, using a low temperature at first, and gradually increasing the heat so as to melt the charge thoroughly, and form a liquid slag. Pour into round mould, and when cold detach the slag, and weigh the regulus. This slag contains no copper, and therefore may be neglected. Grind the regulus in an iron mortar, very finely, and afterwards clean out the mortar, and thereby recover any regulus that may have been left adhering to its sides by pulverising in it 5 grs. of anthracite. Mix intimately the anthracite and the finely powdered regulus, and introduce into a small copper assay crucible. Fill up a wind furnace with small coke, and fix the crucible on the top in a slanting position, so that the air may have free access. The fire must be kept low, and the crucible must not be allowed to become visibly heated. The contents of the crucible must now be stirred constantly with an iron stirring rod from 50 to 60 minutes, and the regulus must not be allowed to clot or become pasty. Towards the end of the operation the temperature may be raised to a dull red heat. The object of this treatment is to oxidise and remove, as far as possible, the sulphur that is present. It is necessary to regulate the fire so that the clotting of the regulus may be prevented, for if clots are formed the oxidation is rendered impossible. This tendency to clot is greater when the slags produced by the first fusion are not thoroughly removed. The odour of sulphurous anhydride should have ceased when the operation is completed, and the regulus is then said to be roasted 'sweet.' When this is accomplished, remove the crucible from the fire and allow to cool. Grind the calcined regulus in the mortar, cleaning it out afterwards with 20 grs. of anthracite; mix the anthracite and regulus, and heat again in crucible for 10 minutes for the decomposition of any $Cu\ SO_4$ that may have been formed during the roasting. Again allow to cool, and turn out the contents upon a sheet of glazed paper. Weigh out 80 grs. tartar, 50 grs. sodic carbonate, and 30 grs. borax, mix with the roasted product, transfer to same crucible, and heat at good temperature, to fuse the mass, for the production of coarse copper and a liquid slag. The time required will be about 10 or 15 minutes, and when the surface of the fused mass appears tranquil, remove from fire and pour into mould. Allow to cool, detach slag, which should be crushed and cleaned, as in the former case, by fusion with argol, 50 grs.; carbonate of soda, 20 grs.; and charcoal, 5 grs. Add the small button from the cleaning of the slag to the larger button, and weigh. Refine the copper in the same way as before, using a clean crucible, and the same amount of refinery flux. Clean the refinery slag by grinding, and mixing with 50 grs. argol, 20 grs. limestone, and 5 grs. charcoal, and fusing in the crucible used for refining. Add the small button from the refinery slag to the larger button, weigh, and calculate the percentage of copper in the ore and also the amount per ton.

Experiment 45.—*Assay of Ores of the Third Class: Grey Ores.*—Weigh out 100 grs. of finely powdered ore, 20 grs. of hematite, 30 grs. of sulphur, 20 grs. of argol, 200 grs. of limestone, 200 grs. of fluor-spar, 150 grs. of glass, and 150 grs. of borax. Fuse this mixture in a large copper assay crucible for the formation of a regulus and a slag. Separate and neglect the slag, and calcine the regulus after pounding in a mortar, and observe the same precautions as to temperature as in the last experiment, finishing by roasting with 20 grs. of anthracite. Refine the copper obtained, using a fresh crucible and 100 grs. of refining flux, and clean the slag as before. Weigh the copper obtained, and calculate percentage of copper and amount per ton.

The dry assay of copper almost invariably gives a result which is lower than the copper contained in the ore assayed, and greater accuracy is obtained by a wet assay, to be described in the next experiment. The results obtained by a dry assay determine, however, the amount of copper that may be *extracted from* an ore by commercial processes, perhaps more exactly, than an assay by the wet method. The loss of copper is due to traces remaining in the various slags, and to some metal being carried away in the vapours given off by the various fluxes. As a rule the loss of copper in the assay is greater when the ores are poorer, and with very poor ores the yield of metal is considerably greater than indicated by the assay.

Alloys of copper cannot be assayed by a dry method, and are invariably treated by a wet method. In cases where the ores contain, in addition to copper, gold and silver, these metals are reduced, and pass into the copper button, and are estimated as copper.

Experiment 46. — *Wet Copper Assay* (*Potassium Cyanide Method*). — Dissolve 1000 grs. of potassium cyanide (K Cy) in 3 pints of water. Weigh out roughly four pieces of electrotype copper of about 4, 5, 6, and 7 grs. respectively, and take accurate weight of each piece on balance. Dissolve each separately in a conical flask in about 20 c.c. dilute nitric acid ($H\,NO_3$), heat to expel fumes, and transfer the solution to 30 oz. flask, well washing out the conical flask with distilled water. Add strong ammonia ($N\,H_3$) in excess, when the solution will assume a dark blue colour, and allow to cool. Fill a 50 c.c. burette (Fig. 31) with the solution of potassium cyanide, and run a few c.c. into the cooled solution of copper. Well shake the flask and add more cyanide solution at intervals, until the blue colour begins to disappear. As the solution loses colour, proceed cautiously, shake well and allow to stand for a moment or two after each addition. When the solution is decolourised, or has only a very faint blue colour, note the quantity of cyanide solution used, by reading off the level of the liquid in the burette. The time required for each decolourisation should be about 15 minutes. In practice a slight colour is left in the solution, which serves to show that an excess of the K Cy solution has not been added. Care must, however, be taken that the same depth of colour is left in when standardising as when estimating the copper in an ore or in an alloy. Calculate the number of c.c. of cyanide solution that would be required for 10 grs. of copper. Treat each of the four copper solutions in a similar manner, and take the average number of c.c. required for 10 grs. as the strength of the standard. Having now prepared and standardised the potassium cyanide solution, proceed to estimate the copper in a carbonate or silicate of copper by selecting an average sample, reduce it to powder, and pass it through 80 sieve. Weigh out two assays, one of 12 grs. and the other of 15 grs., and boil with 12 or 15 c.c. of strong hydrochloric acid until dissolved, and then add 5 c.c. of strong nitric acid, and continue boiling 10 minutes longer. Dilute with water, transfer to 30 oz. flask, and add strong ammonia in excess. Allow to cool and proceed as before, preserving as far as possible the same conditions as when standardising, and occupying about the same time. The results calculated from the reading of the burette for the 12 and 15 grs. should not vary more than ·1 per cent. In treating ores of this class, sulphur is occasionally met with, and may be found floating on the surface of the solution after the ore has been dissolved. This separated sulphur should be removed and ignited in a porcelain crucible, the residue dissolved out with strong H Cl, and the solution added to the main portion.

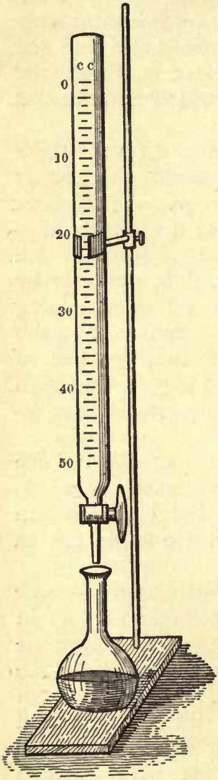

Fig. 31.

The method of standardising from the readings of the burette is shown by the following example:—

	Grains.	C.C. required.	C.C. that 10 grs. require.
(1)	4·20	29·05	69·52
(2)	4·90	34·07	69·52
(3)	6·14	42·68	69·51
(4)	6·94	48·26	69·53
			278·08

$$\frac{278{\cdot}08}{4} = 69{\cdot}52.$$

Thus the average of four determinations shows that a solution of 10 grs. of copper require 69·52 c.c. of potassium cyanide solution to decolourise it. These figures are now used to obtain the percentage of copper in the ore thus:—

Suppose 12 grs. of ore required 24·3 c.c. of K Cy solution, and 15 grs. of ore required 30·4 c.c. of K Cy solution, we have seen that—

C.C.		Grains.		C.C.		Grains.
69·52	:	10	::	24·3	:	3·495, then
Ore.		Copper.		Ore.		Copper.
12	:	3·495	::	100	:	29·12 per cent.
C.C.		Grains.		C.C.		Grains.
69·52	:	10	::	30·4	:	4·373,
Ore.		Copper.		Ore.		Copper.
15	:	4·373	::	100	:	29·15 per cent.

29·15 − 29·12 = ·03 variation per cent.

This method of estimating copper depends upon the decolourisation of an ammoniacal solution of copper by potassium cyanide, which produces a double cyanide of copper and ammonia which is colourless, together with various organic bodies. The quantity of ammonia present influences in some degree the amount of cyanide solution required, and therefore the quantity of ammonia added, after the neutral point has been reached, should, as far as practicable, be the same when the ore is under treatment as when the cyanide solution was standardised. The action of heat also affects the quantity of cyanide solution required, a warm solution not requiring so much to decolourise it as a cold one does, hence the necessity of cooling the ammoniacal solution before adding the potassium cyanide. It is found that 10° increase in temperature causes a difference of about ·4 c.c. The presence of silver, zinc, nickel, and cobalt, is found to interfere with this method, giving results that are too high, while the presence of iron (usually present in copper ores) does not affect the accuracy of the estimation. The silver is precipitated as chloride by the hydrochloric acid and may be filtered off, well washed with hot water, the washings being added to the copper solution, which is then neutralised and the ammonia added in excess. The method described in Experiment 48 may be employed to remove the zinc from the copper when it is present. If, however, the amount of zinc present does not exceed 5 per cent of the copper present, it need not be removed; if that amount is exceeded there will be a difference of about 5 per cent between the amount of copper present and the estimation. Occasionally the copper is filtered off from the silicate, &c., left on boiling the ore with nitric acid, and to the solution a rod of zinc is added and kept in contact with a strip of platinum foil, which induces voltaic action, and the zinc goes into solution and the copper is precipitated. The rod of zinc is then withdrawn and the copper washed well with hot water to dissolve out every trace of zinc. The precipitated copper is then dissolved in dilute nitric acid, and ammonia is added to the solution, which is then cooled, and the potassium cyanide solution run in. As the solution of potassium cyanide undergoes slow decomposition, it becomes necessary to restandardise it after an interval of a few days.

Experiment 47.—Sulphury or pyritic ores must be treated for the oxidation of the sulphur by calcining at a low red heat, with occasional stirring. Weigh out 20 grs. and 25 grs. of powdered copper pyrites, and roast until sweet in a muffle. Carefully crush all lumps, and transfer when cold to a conical flask. Add 12 c.c. of strong nitric acid and heat for 30 minutes; add more acid if necessary, and when all is dissolved, transfer to 30-ounce flask, add ammonia in excess, cool, and run in the K Cy solution from the burette, shaking occasionally until decolourised. Calculate the percentage of copper in the ore, and also the amount per ton. Any iron that may be present in the ore will be precipitated as hydrated oxide ($Fe_2 O_6 H_6$), when the ammonia is added in the form of a flocculent, red-brown precipitate. This may be left in the solution, and will in no way interfere with the result; but if it is desirable to estimate the iron as well as the copper, it should be filtered off, well washed with dilute ammonia, redissolved in dilute sulphuric acid, boiled with zinc for the reduction to the ferrous state, and finally estimated by the potassium bichromate method (See Experiment 54.)

Experiment 48.—*Illustrating the Action of Zinc in influencing the Result obtained by this Method.*—Weigh out 20 grs. of oxidised copper ore, dissolve in strong HCl, and add 5 grs. of zinc; add also 5 c.c. of strong nitric acid; boil for 10 minutes, dilute with water, and transfer to large beaker. Make a solution of 60 grs. of sodium thiosulphate ($Na_2S_2O_3$), heat to boiling, and add half of the solution to the hot solution of copper and zinc, when the copper will be thrown down as a black precipitate. Heat gently, and stir occasionally for 10 or 15 minutes, when, if the solution is not colourless (above the precipitate), add more $Na_2S_2O_3$ solution. Allow to settle, and decant clear solution through filter, leaving the precipitate in the beaker. Wash two or three times with boiling water, and decant the water after each washing. Transfer the precipitate to the filter, wash with hot water, dry, ignite filter paper, and precipitate in porcelain crucible. After ignition, wash out into a 30-ounce flask, heat, and add dilute sulphuric acid and nitric acid. When dissolved, dilute, add ammonia in excess, cool, and proceed as before.

It may be advisable to simultaneously carry out an experiment with the same quantity of ore and zinc, and treat in the ordinary way, leaving the zinc in solution, and noting the difference between the results obtained.

Experiment 49.—*Estimation of Copper, Zinc, and Lead, in Brass.*—Make an alloy of 200 grs. of copper, 100 grs. of zinc, and 5 grs. of lead. File the surface, flatten out under the hammer, and roll out thin. Dissolve 50 grs. of the alloy in dilute hydrochloric acid, and dilute the solution to half a pint. Pass sulphuretted hydrogen (H_2S) through the cooled solution for some time, when both copper and lead will be precipitated as sulphide. Heat and allow to settle, and add H_2S solution to see if all is precipitated. If, on this addition, a black colour is produced, pass H_2S gas for some time longer. Allow precipitate to settle, decant clear solution through filter paper, and wash the precipitate with water, to which a little HCl has been added. Transfer the precipitate to filter paper, and wash with acidulated water, to which H_2S has been added, until the washings give no residue on evaporation. Dissolve precipitate in smallest quantity of dilute nitric acid, add a few drops of strong sulphuric acid, evaporate to dryness, and redissolve in moderately strong H_2SO_4. Dilute with water, filter quickly through a small filter paper, wash with water acidulated with H_2SO_4. The copper is now removed, and the precipitate of lead should be washed carefully with water mixed with an equal bulk of methylated spirits, until the washings give no precipitate with a solution of baric chloride ($BaCl_2$). Dry, brush off the precipitate as far as possible, and burn the filter on the lid of a porcelain crucible. Moisten the ash with a drop of nitric acid, heat, and add one drop of sulphuric acid, and ignite the precipitate of lead sulphate in the crucible, and also that contained by the lid. Weigh, deduct the weight of the crucible and ash, and calculate as $PbSO_4$. The filtrate which contains the zinc should now be boiled to expel the H_2S, and a crystal of potassium chlorate added. Prepare a hot solution of sodic carbonate, and add it to the zinc solution as long as a precipitate forms. Heat to boiling, and allow to stand for 10 minutes; test if all the zinc is precipitated by adding more of the Na_2CO_3 solution. Filter through tarred filter paper, wash well, dry, ignite, and weigh as zinc oxide (ZnO). The filtrate from the lead sulphate contains the copper, which may be estimated by one of the methods given in Experiments 28, 46, or 50.

Experiment 50.—*Analysis of Bronze.*—Flatten out thin a bronze coin, cut off a piece each of about 10 and 12 grs. Weigh accurately, and dissolve each piece in an 8-ounce beaker with dilute nitric acid (one of acid to one of water). Boil for 10 minutes, dilute with water to three times its bulk, and further heat for 20 minutes, stirring occasionally. Allow precipitate to settle, filter through tarred paper, and wash well with water containing a little nitric acid. Dry in water-oven, brush off and burn paper, ignite in porcelain crucible, and weigh as tin oxide (SnO_2). Evaporate the solution to dryness, with a little hydrochloric acid, in order to remove the nitric acid. Redissolve in water, add a little HCl, and pass H_2S gas until all the copper is precipitated. Wash precipitate in beaker with water containing HCl, and collect on filter, wash well, dry, ignite, and weigh as CuS. If great accuracy is desired the copper precipitate should be redissolved and again precipitated and filtered off, the filtrate being tested for zinc. Boil filtrate to expel the H_2S, evaporate nearly to dryness, add water and a saturated solution of sodic carbonate. Boil the solution, and filter off any $ZnCO_3$, wash well, dry, ignite, and weigh as ZnO.

Compare the results obtained from both the estimations.

Experiment 51.—*The Gravimetric Estimation of Iron.*—Weigh out 10 grs. of finely powdered hematite, place in beaker, add 10 c.c.

of hydrochloric acid, boil for 15 minutes, wash down the sides of the beaker, and evaporate to dryness on a sand-bath, using a gentle heat. Allow to cool, and redissolve in dilute hydrochloric acid, assisting the solution by boiling. Dilute largely, filter off insoluble portion (silica, &c.), and make the solution alkaline by adding ammonia, and then a solution of ammonium acetate $\left(\left\{\begin{matrix}CH_3\\ CO\,NH_4\,O\end{matrix}\right.\right)$. Boil the solution, when a red-brown precipitate of $Fe_2\,(CH_3\,CO_2)_6$ will be produced. Allow to settle, filter, wash well with hot water containing ammonia, dry, brush the precipitate as far as possible from the paper, burn the paper, and ignite the precipitate, and weigh as $Fe_2\,O_3$. Calculate the percentage of iron and the amount per ton. The filtrate from the acetate of iron should be quite clear and colourless. The insoluble portion should be well washed with hot water containing $H\,Cl$, dried, ignited, and weighed as $Si\,O_2$.

Experiment 52.—*Assay of Silver Ore by Fusion Method.*—Weigh out 1000 grs. of the ore, and dry in porcelain dish, with occasional stirring, for 30 minutes. Allow to cool, and reweigh. Reduce to fine powder in iron mortar, and pass through 60 sieve, collect the metallic portions that will not pass through the sieve, and cupel them with twice their weight of assay lead. Thoroughly mix the powdered portion, and weigh out 100 grs., and mix with 500 grs. of red lead, 300 grs. of sodic carbonate, 200 grains of borax, and 25 grs. of charcoal. Transfer to crucible, and heat for 20 minutes at high temperature. Pour into round mould, and when cold detach slag, and clean the button by washing in warm water and brushing with hard tooth-brush. Crush the slag to powder, and mix with red lead 300 grs., sodic carbonate 25 grs., and charcoal 15 grs., and fuse in the same crucible as before to clean the slag. Pour after about 15 minutes, and when cold detach slag from the button, clean it with hot water, and cupel it, and also the larger button, in separate cupels, for the isolation of the silver. Red lead frequently contains small quantities of silver, and this must be estimated by reducing 400 grs. with charcoal, and then cupelling. As 800 grs. of red lead have been used in the assay, the weight of the minute button must be doubled, and the weight deducted from the quantity of silver obtained in the reduction of the ore.

To find the percentage of silver :—

$$\frac{m \times 7000 \times 2240}{100} = x.$$

Where m is the weight of silver from 100 grs. of the ore, and x is the silver per ton. The silver from the metallic portions is calculated separately, and the result added to the other.

Experiment 53.—*Assay of Silver Ore by Scorification Method.*—Take 50 grs. of ore, 500 grs. of granulated lead, and 5 grs. of borax. Weigh out two quantities for assay, and treat them simultaneously. Mix the ore with half the lead, introduce into a previously heated scorifier, and place in hot muffle. After 15 minutes add the remainder of the lead and the 5 grs. of borax. Allow free access of air for oxidation, and when the surface of the metal is covered with slag, add 3 grs. of powdered anthracite, wrapped in paper, by which means the slag is cleaned. Heat for 10 minutes longer, and then pour into a round mould. Detach slag when cold, and cupel the lead. Weigh the silver obtained, and calculate as before. Compare the result with that of the fusion method. Cupel 500 grs. of lead for the estimation of the silver in it, the weight of which must be deducted from the weight of silver obtained from the ore.

Experiment 54.—*Volumetric Assay of Iron, by means of Potassium Bichromate.*—This determination is based upon the oxidation of a solution of ferrous to the ferric state by means of a solution of potassium bichromate of known strength. A solution of potassium ferricyanide, free from ferrocyanide, is used to indicate when sufficient bichromate solution has been added to convert the whole of the ferrous iron into the ferric state, a drop of the iron solution, to which the bichromate is being added, is brought in contact with a drop of a weak solution of the potassium ferricyanide, upon a white tile. As long as any ferrous iron remains, the two drops on mixing will form a rich blue precipitate (Turnbull's blue), which, however, becomes fainter as more of the bichromate solution is added, and when the two drops do not give a precipitate or a colouration the process is finished.

Dissolve 300 grains of potassium bichromate ($K_2 Cr_2 O_7$) in 4 pints of distilled water, and also 5 grs. of potassium ferricyanide ($K_4 Fe_2 Cy_{12}$) in 4 ounces of water. Weigh out 4 pieces of clean, pure, iron wire, of about 4, 5, 6, and 7 grs. each, and weigh each piece accurately on balance. Pour into 4 conical flasks, about 10 c.c. of dilute hydrochloric acid (1 acid to 1 water), boil, and keep the mouth of each flask closed by a bulb or small funnel. Introduce into each, about 5 grs. of sodic carbonate to expel the air; drop into each one of the pieces of weighed iron wire, numbering the flasks, so that the quantity of iron in each may be noted.

Boil until the iron is dissolved, and keep simmering until required for use; this solution must be colourless. Dilute one of the iron solutions, and transfer to a large dish, well wash out the flask into the dish, and run in a few c.c. of the bichromate solution from a burette (Fig. 32), stir well with a glass rod, and add more solution from the burette from time to time, until a drop taken on the glass rod, and added to a drop of potassic ferricyanide solution on a white tile, does not give a blue colour. At first a deep blue results, but as more of the bichromatic solution is added, and fresh trials made, the colour becomes fainter, changes to a green, and finally to a greyish hue; and as these indications appear the $K_2 Cr_2 O_7$ solution must be added cautiously. When the whole of the $Fe Cl_2$ has been thus converted into the $Fe_2 Cl_6$ condition, the number of c.c. of the bichromate solution used is read off and noted. Fill up the burette, and rinse out the dish, and proceed in the same manner with another iron solution. The number of c.c. required for 10 grs. of iron should be calculated from each trial made, and the results should not vary more than ·03 per cent. The mean of the four results should be taken as the standard of the strength of the potassium bichromate solution. The iron solution must contain an excess of free acid during the titrating.

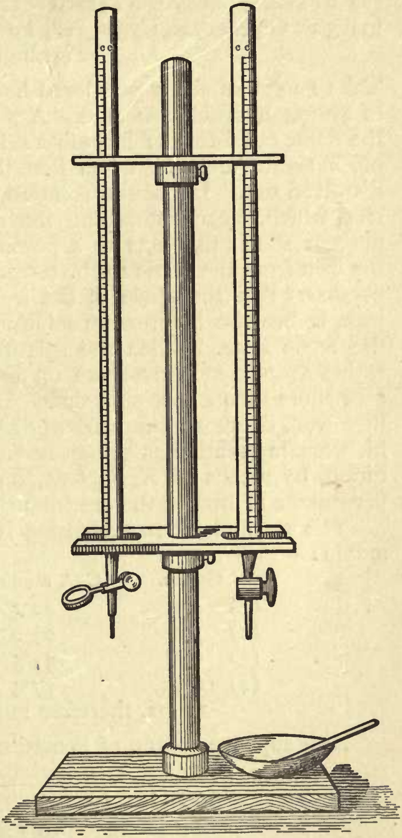

Fig. 32.

The reactions which take place may be represented by the following equations :—

(1) $Fe + 2\,HCl = Fe\,Cl_2 + H_2$.
(2) $6\,FeCl_2 + K_2Cr_2O_7 + 14\,HCl = 3\,Fe_2Cl_6 + 2KCl + Cr_2Cl_6 + 7\,H_2O$.
(3) $3\,Fe\,Cl_2 + Fe_2\,K_6\,Cy_{12} = Fe^{II}_3\,Fe^{IV}_2\,Cy_{12} + 6\,KCl$.
(Turnbull's blue.)

Take 10 grs. of finely powdered hematite, and dissolve by boiling in strong hydrochloric acid. A residue will probably remain in the flask, consisting of insoluble silica, which need not be filtered off, but care must be taken that the whole of the iron has been dissolved out. Dilute the solution, and add a few pieces of pure zinc, which, by decomposing the acid, liberates hydrogen in a nascent state; this acts as a powerful reducing agent to reduce the iron from the ferric to the ferrous condition, as it is obviously necessary that the whole of the iron must be present as ferrous iron, before the bichromate solution is added for its oxidation to the ferric state. When the solution is perfectly colourless, test with a drop of sulphocyanate on a white tile, when it should not give more than a rose-pink tint. After the whole of the zinc is dissolved, dilute and transfer to dish, and run in from burette the bichromate solution as before, testing the solution after each addition, by means of $K_6\,Fe_2\,Cy_{12}$, on a white tile. Calculate the percentage of iron in the ore from the number of c.c. required.

The method of standardising is shown by the following example :—

	Grains.	C.C. required.	C.C. that 10 grs. require.
(1)	4·1	22·1	53·9
(2)	5·0	27·0	54·0
(3)	6·2	33·5	54·0
(4)	6·9	37·4	54·1

10 grs. therefore require 54·0 c.c.

Now suppose 10 grs. of hematite required 36·7 c.c., then :—

C.C.		Grs.		C.C.		Grs.
54	:	10	::	36·7	:	x

$$\frac{36{\cdot}7 \times 10}{54} = 67{\cdot}96 \text{ per cent Fe.}$$

The iron and ores may be dissolved in dilute $H_2\,SO_4$ instead of H Cl, in which case the solution of the ore, after adding the zinc to reduce the ferric iron by the hydrogen liberated, must be tested with potassium sulphocyanate (K Cy S), to ascertain if all the iron is in the ferrous state. Ferric salts give a blood-red colouration with K Cy S, while ferrous salts give no colour.

Equations:—

(1) $Fe + H_2SO_4 = FeSO_4 + H_2$.

(2) $6\,FeSO_4 + 7\,H_2SO_4 + K_2Cr_2O_7 = 3\,Fe_2(SO_4)_3 + Cr_2(SO_4)_3 + K_2SO_4 + 7\,H_2O$.

(3) $3\,FeSO_4 + K_6Fe_2Cy_{12} = Fe^{II}_3 Fe^{IV}_2 Cy_{12} + 3\,K_2SO_4$.

It is sometimes preferred to make deci-normal solution of potassium bichromate, that is a solution of such a strength that 1 litre would be equivalent to 5·59 grams of iron, or 1 c.c. equivalent to ·00559 gram of iron. It will be seen from equation (2) that one equivalent, or 294·14 parts of bichromate, will convert six equivalents, or 335·4 parts of iron to the ferric state, therefore by dissolving $\frac{294{\cdot}14}{6}$ grams of pure potassium bichromate in a litre of water, a normal solution would be made, and by taking $\frac{1}{10}$ of this quantity, namely, 4·9023 grams, and dissolving in 1 litre, a deci-normal solution is formed, of which 1 c.c. is equivalent to ·00559 gram of iron.

With this solution it is only necessary to multiply the number of c.c. required by ·00559 and by 100, and to divide by the weight taken, to get the percentage.

$$\frac{\text{Number of c.c.} \times {\cdot}00559 \times 100}{\text{Weight of ore}} = \text{per cent.}$$

Experiment 55.—*Estimation of Iron by Potassium Permanganate.*—Weigh out four pieces of iron wire of about 5, 6, 7, and 8 grs. each, take the accurate weight of each on balance, and dissolve separately in dilute sulphuric acid (one to three water) in a 16-ounce flask, assisting the solution by heating. When dissolved, cool the solution, which should be quite colourless and free from iron in the ferric state. It is advisable to add a little sodic carbonate to the acid in the flask to expel the air before introducing the iron. Run into the cooled solution of iron, contained in the flask, a solution of potassium permanganate ($K_2Mn_2O_8$) from a burette, until it has a permanent pink colour, when the level of the liquid in the burette should be read off.

The permanganate solution may be made by dissolving 100 grs. of the $K_2Mn_2O_8$ in 3 pints of water.

The principle is the same as in the preceding experiment, the permanganate oxidising the ferrous iron to the ferric condition, only that no external indicator is necessary, for the iron in the solution decolourises the permanganate as fast as it is run in, by abstracting its oxygen until the whole of the iron is satisfied, when the colour becomes permanent. From the four trials, the results of which should not vary more than ·02 per cent, calculate the quantity of iron that 100 c.c. equals, taking the mean as the true standard.

	Grs.	C.C. required.	Grs. per 100 c.c.
(1)	4·855	30·1	16·136
(2)	5·920	36·7	16·131
(3)	7·100	44·0	16·136
(4)	7·940	49·2	16·138
			64·541

$$\frac{64{\cdot}541}{4} = 16{\cdot}135 \text{ grs. per 100 c.c.}$$

Take 5 grs. of hematite, dissolve in smallest quantity of dilute HCl (1–1), and, when dissolved, add a few drops of strong sulphuric acid, and evaporate to complete dryness in fume closet. Redissolve in dilute sulphuric acid, boil, and add zinc free from iron, to reduce the ferric iron to the ferrous state. Allow the action to go on for some time, keeping the flask closed with a small funnel or bulb, and test solution from time to time, by adding a drop to a drop of potassium sulphocyanate ($K\,Cy\,S$) on a white tile. If any red or pink colouration is shown, add more zinc, which, however, must all be dissolved before adding the permanganate solution. When the reduction is complete, and the zinc dissolved, cool, dilute, and run in from burette the standardised solution, until a permanent pink colour is established. Read off the number of c.c., and calculate the amount of iron in the ore.

If 5 grs. require 21 c.c., then

$$\begin{array}{ccccccc} \text{C.C.} & & \text{Grs.} & & \text{C.C.} & & \text{Grs.} \\ 100 & : & 16{\cdot}135 & :: & 21 & : & x \end{array}$$

$$\frac{16{\cdot}135 \times 21}{100} = 3{\cdot}388 \text{ grs. Fe from 5 grs. ore.}$$

$$\begin{array}{cccccccc} & \text{Grs. ore.} & & \text{Grs. iron.} & & \text{Ore.} & & \text{Iron.} \\ \text{Then,} & 5 & : & 3{\cdot}388 & :: & 100 & : & x \end{array}$$

$$\frac{3{\cdot}388 \times 100}{5} = 67{\cdot}76 \text{ per cent Fe in the ore.}$$

Cementation of Iron.—Cementation is the process of carburisation, or introducing carbon into wrought iron, in order to give it the properties of steel, by heating it in the presence of charcoal, or other carbonaceous matter, for a more or less prolonged period, at a temperature far below the point of fusion. The same term is applied to the operations which have an opposite, or decarburising effect, *i.e.*, taking carbon out of cast iron and so rendering the material malleable.

Experiment 56.—Take a piece of combustion tubing 12 inches long, and draw out one end to a fine tube. Place in the tube several pieces of soft iron wire. Draw out the other end, and connect up to a supply of coal gas. Ignite the gas at the other end and turn down low. Heat the tube in a small tube furnace (Turner's) as in Experiment 21, Part II., for one hour. Shake out one piece of wire, and test it by hardening it in the usual way, and by bending and filing it. Continue heating the remainder for one hour more and shake out other pieces. Notice the effect of the carbon which the wire will have taken in. It has now the properties of steel.

Experiment 57.—Take three or four pieces of bar iron, preferably of various thicknesses, about 2 inches long, and embed vertically in roughly powdered charcoal, in a fairly large crucible. Shake well down, and fill up as full as possible with finely powdered charcoal, and again shake down. Lute on the lid, and place in furnace. Keep up a high temperature for three or four hours. Open crucible when cold, and examine the pieces of iron. Break across, and notice to what extent the action has proceeded. Examine fracture with a lens. Repeat experiment with same size pieces of iron, subjecting them to longer heating. Try the effect of hardening the pieces, by heating them to redness and plunging them into cold water. Fracture in vice, and notice the appearance of surface.

Experiment 58.—*Decarburisation.*—Take three or four flat pieces of cast iron, or cast iron rods of ¼ inch diameter, and 2 inches long. Embed in powdered hematite or red ochre, in crucible. Shake well down, and fill up with the hematite; lute on lid, and heat in furnace for three or four hours. When cold remove from crucible, fracture, and examine with lens. Replace the pieces, keeping one back for comparison, and heat for a longer period and examine. The effect of the decarburisation will be readily seen.

Further Experiments with Gold.—It is well known that gold is attacked by chlorine gas, with the formation of gold chloride.

$$2\,Au + 3\,Cl_2 = 2\,Au\,Cl_3.$$

This property is taken advantage of in extracting gold from auriferous pyrites. When the metal occurs with sand or quartz, it is best extracted by means of mercury, an amalgam being formed, which is afterwards distilled, or treated as the silver in Experiment 27.

Experiment 59.—Take six or eight gold leaves, weigh carefully on balance. Crumple up and mix with about 150 grains of fine white sand. Draw out a piece of glass tubing (not combustion tubing) about 1 inch diameter, sufficiently thin to attach a piece of ordinary ¼ inch rubber tubing, and bend the drawn-out end up. Fix in clamp in vertical position, and introduce into it the mixture of gold and sand. Connect a chlorine apparatus to the small end of the tube. Generate chlorine gas by the action of strong commercial hydrochloric acid on manganese-dioxide, and arrange the whole in a fume chamber. Allow a slow current of chlorine gas to pass for ten minutes. Disconnect and transfer to a beaker, add water and warm. Decant the solution and wash sand several times. Precipitate the gold, by means of sulphurous acid, or oxalic acid, or ferrous sulphate. Collect on filter paper, wash well, dry, and incinerate in tared porcelain crucible. Weigh and compare with original weight of gold leaves. Six and a half gold leaves weigh about one grain.

Experiment 60.—Half-pound of pyritic ore containing gold is broken up and passed through 10 sieve. This must then be roasted till sweet in roasting dish. A glass tube similar to the one used in the last experiment, but 1½ inches diameter, is taken, and the ore placed in the tube, the coarser pieces at the bottom and the fine on the top. Connect with the chlorine apparatus, and pass the gas in a slow stream for one hour in the fume chamber. Instead of a tube as above, a gas jar may be used, in which case a leading tube is placed in the centre, reaching to the bottom, and the roasted ore packed round it. The material is now treated with water, and allowed to stand for a quarter of an hour with frequent shaking. Decant through filter paper, and wash the residue many times with chlorine water. Add the washings to the main solution, and concentrate by evaporation to about half a pint. Acidulate with dilute hydrochloric acid, and filter off any precipitate. Add now 50 c.c. of ferrous sulphate solution and stir well. Filter the precipitated gold, and test the filtrate by boiling with a little more ferrous sulphate solution. Wash precipitate, dry, and incinerate in tared crucible as before. Find weight of gold in ton of ore by reference to Appendix G.

Quartzose ores should be treated as follows:—

Place finely powdered ore (60 sieve) in a stout flask with sufficient water to cover, and add 10 c.c. of bromine, in fume chamber with good draught. Pass chlorine gas with constant stirring till the deep colour of the bromine has nearly disappeared. Cork the flask, and allow to stand in a dark place with occasional shaking for twelve hours, when the residue may be decanted, washed several times, and the solutions treated as before.

In the absence of ores containing gold, artificial ore may be made by mixing filings or gold leaves with ordinary ore. Jewellers' "sweepings" may be used if obtainable.

Note.—The Thompson's calorimeter, as described in Experiment 6, page 53, is now superseded by an improved form which gives better results. In this apparatus, which can be supplied by any dealer, no oxidising mixture is used, but oxygen gas is forced down the tube of the bell cover and the coal is placed in a small platinum crucible which takes the place of the copper cylinder. The apparatus is not suitable for use with coke.

APPENDICES.

APPENDIX A.

1. To lute on the lids of crucibles, take some finely crushed raw fireclay and mix with about half its volume of powdered burnt clay, *i.e.*, the clean portion of used pots or broken muffles, add water, and knead together until a fairly stiff mass is formed. Moisten the under side of the lid and also the top of the crucible with water, make a ring of the clay on the lid near its edge, and press it down on to the crucible, making the lute smooth and even by pressing with the moistened fingers. The luting should be slowly dried before the pots are put into the fire.

2. Porcelain crucibles should not be allowed to come in contact with the bone ash in the muffles while hot, but should be placed on a thin piece of firebrick or piece of broken muffle, otherwise the bone ash will stick to the glaze of the porcelain, and thus alter the weight of the crucible.

3. An indication of the kind of flux required for the assay of iron ores may be observed in the slags, and in the iron produced in the preliminary assay. If the iron is not melted into one button, but is dispersed as minute shots throughout the slag, silica is deficient in the flux, and a greater heat is required. Manganese gives an amethyst colour to the slag, and the button of iron produced from manganiferous ores is smooth and hard, and has a white crystalline fracture. Phosphorus makes the iron brittle when cold (cold-short), and sulphur causes it to be brittle when red-hot (red-short).

4. A good substitute for argentiferous pyrites may be made by mixing 10 grs. of finely crushed silver sulphide with 90 grs. of copper pyrites.

5. Refining flux for copper assay is made by taking 3 parts by measure of nitre ($K\,NO_3$), $2\frac{1}{2}$ parts of tartar (argol), and 1 part of common salt ($Na\,Cl$), mixing well together, and deflagrating in a crucible. A large crucible must be used, and not filled more than

one-half or two-thirds, and the mixture is ignited by touching with a red-hot poker. This should be performed in an empty wind furnace, or in a well-ventilated fume closet. Instead of igniting the whole at once, the mixture may be projected into the previously heated crucible, a small portion at a time. When cold the flux, which has attached itself to the sides of the crucible, may be crushed to powder and stored in a well-corked bottle.

6. The presence of the different metals during cupellation is indicated in the following manner:—

Lead.—Straw-coloured stain, caused by molten litharge which permeates the cupel.

Bismuth.—Yellow to orange-coloured stain, which also permeates the cupel.

Copper.—Dark brown stain, permeating the cupel when lead or bismuth is present.

Zinc.—Blue flame, white fumes, and mass of white oxide (ZnO) on the cupel.

Tin.—Loose grey scoria in the centre of the cupel, and not closely adhering to the bone ash.

Antimony.—Yellow or dark red compact scoria, forming a ring round the cupel at the level of the original surface of the bath of metal, which adheres to the cupel. The cupel is also cracked.

Arsenic.—White or pale yellow scoria.

Chromium.—Dark red stain.

Cobalt.—Dark green stain and scoria.

Nickel.—Same as cobalt.

Iron.—Dark red-brown scoria and dark ring.

Manganese.—Bluish black stain and scoria.

Platinum.—Greenish stain and infusible residue.

Palladium.—Same as platinum.

7. To reduce lbs. troy to lbs. avoirdupois, multiply the lbs. troy by ·822857. To reduce avoirdupois lbs. to troy lbs., multiply the avoirdupois lbs. by 1·215.

1 lb. troy = 5760 grs. troy = 13 ozs. 2·65143 drs. avoirdupois.
1 lb. avoir. = 7000 grs. troy = 1 lb. 2 ozs. 1 dwt. 16 grs. troy.
1 gr. troy = 64·8 milligrams.
1 lb. troy = ·373 kilogram.
1 lb. avoir. = ·4536 kilogram.
1 gram = 15·432 grains.
1 litre = 35 ozs. = 1·76 pint.

APPENDIX B.

TABLE OF FUSIBILITIES.

	CENTIGRADE.	FAHRENHEIT.	WEDGEWOOD.
Tin	226°·5	439°	—
Bismuth ...	267°	512°	—
Cadmium ...	320°	608°	—
Lead	335°	635°	—
Zinc	411°·5	773°	—
Antimony ...	440°	824°	—
Silver	1023°	1873°	22°
Copper ...	1054°	1930°	28°
Gold	1250°	2282°	32°
Cobalt... ...	1500°	2730°	130°
Cast iron ...	1515°	2786°	132°
Steel	1800°	3254°	160°
Manganese ...	1845°	3380°	165°
Wrought iron	2000°	3630°	175°
Nickel... ...	2060° about	3730° about	180°
Platinum ...	2060° about	3730° about	180°
Iridium ...	2060° about	3730° about	180°
Rhodium ...	2060° about	3730° about	180°

APPENDIX C.

LIST OF ELEMENTS WITH ATOMIC WEIGHT, &c.

NAME.	SYMBOL.	ATOMICITY.	ATOMIC WEIGHT.	SP. GRAVITY.
Aluminium ...	Al	IV. II.	27·02	2·6
Antimony ...	Sb	V. III.	119·95	6·71
Arsenic	As	V. III.	74·91	5·73
Barium	Ba	II.	136·76	3·75
Bismuth ...	Bi	V. III.	208·0	9·8
Boron	B	III. I.	10·94	2·53
Bromine ...	Br	I.	79·77	3·15
Cadmium ...	Cd	II.	111·65	8·6
Cæsium... ...	Cs	I.	133·0	1·88
Calcium... ...	Ca	II.	39·9	1·5
Carbon	C	IV. II.	11·97	3·5
Cerium	Ce	IV. II.	140·42	6·72

NAME.	SYMBOL.	ATOMICITY.	ATOMIC WEIGHT.	SP. GRAVITY.
Chlorine ...	Cl	I.	35·37	35·37
Chromium ...	Cr	VI. IV. II.	52·06	6·5
Cobalt	Co	IV. II.	58·88	8·6
Columbium ... or Niobium ...	Nb	V.	93·78	7·06
Copper	Cu	II.	63·17	8·92
Didymium ...	Di	II.	144·5	6·54
Erbium	E	III. I.	165·89	—
Fluorine... ...	F	I.	18·98	—
Gallium... ...	Ga	III.	69·2	6·0
Glucinum ... or Beryllium ...	Be	II.	9·7	2·1
Gold	Au	III. I.	196·16	19·32
Hydrogen ...	H	I.	1·0	1·0
Indium	In	III.	113·39	7·42
Iodine	I	I.	126·56	4·95
Iridium	Ir	VI. IV. II.	192·65	21·0
Iron	Fe	VI. IV. II.	55·9	7·86
Lanthanum ...	La	II.	138·3	6·16
Lead	Pb	IV. II.	206·47	11·38
Lithium... ...	Li	I.	7·0	·59
Magnesium ...	Mg	II.	23·96	1·75
Manganese ...	Mn	VI. IV. II.	54·8	8·1
Mercury ...	Hg	II.	199·76	13·55
Molybdenum...	Mo	VI. IV. II.	95·53	8·6
Nickel	Ni	IV. II.	58·6	8·9
Nitrogen ...	N	V. III.	14·02	14·02
Osmium ...	Os	VI. IV. II.	198·5	21·0
Oxygen	O	II.	15·963	15·963
Palladium ...	Pd	IV. II.	105·9	11·8
Phosphorus ...	P	V. III. I.	30·958	1·8
Platinum ...	Pt	IV. II.	194·4	21·5
Potassium ...	K	I.	39·04	·87
Rhodium ...	Rh	VI. IV. II.	104·05	12·0
Rubidium ...	Rb	I.	85·3	1·5
Ruthenium ...	Ru	VI. IV. II.	103·8	11·4
Samarium ... or Terbium ...	Tr	VI.	149·3	—

NAME.	SYMBOL.	ATOMICITY.	ATOMIC WEIGHT.	SP. GRAVITY.
Scandium	Sc	III.	43·98	—
Selenion	Se	VI. IV. II.	78·8	4·5
Silicon	Si	IV.	28·3	2·3
Silver	Ag	I.	107·67	10·5
Sodium	Na	I.	22·99	·974
Strontium	Sr	II.	87·37	2·54
Sulphur	S	VI. IV. II.	31·98	2·07
Tantalum	Ta	V.	182·14	10·75
Tellurium	Te	VI. IV. II.	127·96	6·5
Thallium	Tl	III. I.	203·7	11·8
Thorium	Th	IV.	232·0	7·8
Tin	Sn	IV. II.	117·7	7·29
Titanium	Ti	IV. II.	47·98	5·3
Tungsten or Wolfram	T W	VI. IV.	183·6	19·12
Uranium	U	VI.	238·48	18·4
Vanadium	V	V. III.	51·25	5·5
Ytterbium	Yb	III.	172·7	—
Yttrium	Y	III.	89·2	—
Zinc	Zn	II.	64·9	7·15
Zirconium	Zr	IV.	89·37	4·1

Those printed in italics are non-metals. The specific gravity of the gases are referred to hydrogen as unity. The remainder to water.

APPENDIX D.

A TABLE OF THE EQUATIONS OF THE PRINCIPAL REACTIONS WHICH TAKE PLACE IN METALLURGICAL OPERATIONS.

REACTIONS OF LEAD (Pb).

$Pb + O = Pb\,O.$
$3\ Pb\,O + O = Pb_3\,O_4.$
$Pb_3\,O_4 = 3\ Pb\,O + O.$
$2\ Pb\,O + C = CO_2 + 2\ Pb.$

$Pb_3O_4 + 2\ C = 2\ CO_2 + 3\ Pb.$
$Pb\,CO_3 = Pb\,O + CO_2.$
$3\ Pb\,O_2 = Pb_3\,O_4 + O_2.$
$Pb + S = Pb\,S.$
$Pb\,S + Fe = Fe\,S + Pb.$
$Pb\,S + 2\ O_2 = Pb\,SO_4.$
$2\ Pb\,S + 3\ O_2 = 2\ Pb\,O + 2\ SO_2.$
$2\ Pb\,S + 7\ O = Pb\,O + Pb\,SO_4 + SO_2.$
$Pb\,SO_4 + Pb\,S = 2\ Pb + 2\ SO_2.$
$Pb\,S + 2\ Pb\,O = 3\ Pb + SO_2.$
$Pb\,SO_4 + Pb = 2\ Pb\,O + SO_2.$
$Pb\,SO_4 + H_2 = H_2\,SO_4 + Pb.$
$2\ Pb\,SO_4 + 7\ H_2 = 2\ Pb + SO_2 + SH_2 + 6\ H_2\,O.$
$2\ Pb\,S + 2\ K\,NO_3 = 2\ Pb + K_2\,SO_4 + SO_2 + N_2.$
$7\ Pb\,S + 4\ Na_2\,CO_3 = 4\ Pb + 3\ (Pb\,S, Na_2\,S) + Na_2\,SO_4 + 4\ CO_2.$
$2\ Pb\,O + Si\,O_2 = 2\ Pb\,O, Si\,O_2.$
$2\ Pb\,O, Si\,O_2 + 2\ Fe = 2\ Fe\,O, Si\,O_2 + 2\ Pb.$
$3\ Pb + 8\ H\,NO_3 = 3\ Pb\,(NO_3)_2 + 4\ H_2\,O + N_2\,O_2.$
$Pb\,O + 2\ H\,NO_3 = Pb\,(NO_3)_2 + H_2\,O.$
$Pb\,O + H_2\,SO_4 = Pb\,SO_4 + H_2\,O.$
$Pb\,O_2 + SO_2 = Pb\,SO_4.$
$Pb\,O_2 + 4\ H\,Cl = Pb\,Cl_2 + 2\ H_2\,O + Cl_2.$
$2\ Pb\,O_2 + 2\ H_2\,SO_4 = 2\ Pb\,SO_4 + 2\ H_2\,O + O_2.$
$Pb_3\,O_4 + 4\ H\,Cl = 2\ Pb\,Cl_2 + Pb\,O_2 + 2\ H_2\,O.$
$Pb_3\,O_4 + 8\ H\,Cl = 3\ Pb\,Cl_2 + Cl_2 + 4\ H_2\,O.$
$Pb_3\,O_4 + 2\ H_2\,SO_4 = Pb\,O_2 + 2\ Pb\,SO_4 + 2\ H_2\,O.$
$Pb_3\,O_4 + 4\ H\,NO_3 = 2\ Pb\,(NO_3)_2 + Pb\,O_2 + 2\ H_2\,O.$
$Pb\,(NO_3)_2 + 2\ H\,Cl = Pb\,Cl_2 + 2\ H\,NO_3.$
$Pb\,SO_4 + 2\ H\,Cl = Pb\,Cl_2 + H_2\,SO_4.$
$Pb\,Cl_2 + Zn = Zn\,Cl_2 + Pb.$

REACTIONS OF IRON (Fe).

$2\ Fe + 3\ O = Fe_2\,O_3.$
$3\ Fe + 2\ O_2 = Fe_3\,O_4.$
$2\ Fe\,O + O = Fe_2\,O_3.$
$3\ Fe_2\,O_3 = 2\ Fe_3\,O_4 + O.$
$Fe_2\,O_3 + C = 3\ CO + 2\ Fe.$
$Fe_3\,O_4 + 4\ C = 4\ CO + 3\ Fe.$
$Fe_2\,O_3 + 3\ CO = 3\ CO_2 + 2\ Fe.$
$3\ Fe + 4\ H_2\,O = Fe_3\,O_4 + 4\ H_2.$
$Fe_2\,O_3 + 3\ OH_2 = 3\ H_2 + 2\ Fe.$

$3\ Fe CO_3 = 2\ CO_2 + CO + Fe_3 O_4$.
$Fe + Si O_2 + C = CO_2 + Fe Si$.
$Fe + S = Fe S$.
$Fe S + 2\ O_2 = Fe SO_4$.
$2\ Fe S + 7\ O = Fe_2 O_3 + 2\ SO_2$.
$Fe S_2 + 3\ O_2 = Fe SO_4 + SO_2$.
$2\ Fe + 2\ Pb O, Si O_2 = 2\ Pb + 2\ Fe O, Si O_2$.
$Fe S + Cu_2 O + Si O_2 = Fe O, Si O_2 + Cu_2 S$.
$2\ Fe S + 2\ Cu O + Si O_2 = 2\ Fe O, Si O_2 + Cu\ S + S$.
$Fe_2 O_3 + Si O_2 = 2\ Fe O, Si O_2 + O$.
$Fe + Cl_2 = Fe Cl_2$.
$2\ Fe + 3\ Cl_2 = Fe_2 Cl_6$.
$Fe + 2\ H Cl = Fe Cl_2$.
$3\ Fe Cl_2 + 4\ H_2 O = Fe_3 O_4 + 6\ H Cl + H_2$.
$Fe + SO_4 H_2 = Fe SO_4 + H_2$.
$4\ Fe O, H_2 O + O_2 = 2\ Fe_2 O_3 + 4\ H_2 O$.
$Fe S + H_2 SO_4 = H_2 S + Fe SO_4$.
$Fe S + 2\ H Cl = H_2 S + Fe Cl_2$.
$Fe_2 O_3 + 6\ H Cl = Fe_2 Cl_6 + 3\ H_2 O$.
$Fe_2 Cl_6 + H_2 S = 2\ Fe Cl_2 + 2\ H Cl + S$.
$Fe_2 Cl_6 + 2\ KI = 2\ Fe Cl_2 + 2\ K Cl + I_2$.
$2\ Fe_2 Cl_6 + 3\ K_4 Fe Cy_6 = 3\ Fe Cy_2, 2\ Fe_2 Cy_6 + 12\ K Cl$.

$6\ Fe Cl_2 + 14\ H Cl + K_2 Cr_2 O_7 = 3\ Fe_2 Cl_6 + 2\ K Cl + Cr_2 Cl_6 + 7\ H_2 O$.

$10\ Fe Cl_2 + 16\ H Cl + K_2 Mn_2 O_8 = 5\ Fe_2 Cl_6 + 2\ K Cl + 2\ Mn Cl_2 + 8\ OH_2$.

$6\ Fe SO_4 + 7\ H_2 SO_4 + K_2 Cr_2 O_7 = 3\ Fe_2 (SO_4)_3 + Cr_2 (SO_4)_3 + K_2 SO_4 + 7\ OH_2$.

$10\ Fe SO_4 + 8\ H_2 SO_4 + K_2 Mn_2 O_8 = 5\ Fe_2 (SO_4)_3 + 2\ Mn SO_4 + K_2 SO_4 + 8\ OH_2$.

REACTIONS OF COPPER (Cu).

$2\ Cu + O = Cu_2 O$.
$Cu_2 O + O = 2\ Cu O$.
$Cu O + Cu = Cu_2 O$.
$Cu O + C = CO + Cu$.
$Cu O + CO = CO_2 + Cu$.
$Cu_2 O + C = CO + 2\ Cu$.
$2\ Cu O + C = CO + Cu_2 O$.
$Cu O + H_2 = Cu + OH_2$.
$2\ Cu + S = Cu_2 S$.

$Cu_2S + 5\ O = Cu\,SO_4 + Cu\,O$.
$Cu\,SO_4 + Cu_2S + O_2 = 2\ SO_2 + Cu\,O + Cu_2O$.
$Cu\,SO_4 + Fe = Fe\,SO_4 + Cu$.
$2\ Cu\,O + Cu_2S = 4\ Cu + SO_2$.
$Cu\,SO_4 + Cu_2S = 3\ Cu + 2\ SO_2$.
$2\ Cu_2O + 2\ Fe\,S + Si\,O_2 = 2\ Fe\,O,\ Si\,O_2 + 2\ Cu_2S$.
$4\ Cu\,O + Si\,O_2 = 2\ Cu_2O,\ Si\,O_2 + 2\ O$.
$Cu + Cl_2 = Cu\,Cl_2$.
$Cu + Fe_2Cl_6 = Cu\,Cl_2 + 2\ Fe\,Cl_2$.
$Cu\,Cl_2 + Cu = Cu_2Cl_2$.
$2\ Cu\,Cl_2 = Cu_2Cl_2 + Cl_2$.
$Cu\,O + 2\ H\,Cl = Cu\,Cl_2 + OH_2$.
$Cu\,O + SO_4H_2 = SO_4Cu + OH_2$.
$2\ Cu + 2\ H\,Cl = Cu_2Cl_2 + H_2$.
$3\ Cu + 8\ H\,NO_3 = 3\ (Cu\ 2\ NO_3) + 4\ H_2O + N_2O_2$.
$Cu + 2\ SO_4H_2 = Cu\,SO_4 + 2\ OH_2 + SO_2$.
$4\ Cu\,O + 2\ Sn\,Cl_2 = 2\ Cu_2O + Sn\,Cl_4 + Sn\,O_2$.
$Cu\,SO_4 + 2\ Na\,Cl = Cu\,Cl_2 + Na_2SO_4$.
$Cu\,SO_4 + Ba\,Cl_2 = Ba\,SO_4 + Cu\,Cl_2$.
$Cu_2O + Fe_2Cl_6 + 2\ H\,Cl = 2\ Cu\,Cl_2 + 2\ Fe\,Cl_2 + H_2O$.
$2\ Cu\,Cl_2 + Sn\,Cl_2 = Cu_2Cl_2 + Sn\,Cl_4$.
$2\ Cu\,SO_4 + 2\ Fe\,SO_4 = Cu_2SO_4 + Fe_2(SO_4)_3$.
$2\ Cu\,SO_4 + 4\ KI = Cu_2I_2 + 2\ K_2SO_4 + I_2$.

REACTIONS OF ZINC (Zn).

$Zn + O = Zn\,O$.
$Zn\,O + C = Zn + CO$.
$Zn + CO_2 = Zn\,O + CO$.
$Zn\,O + CO = Zn + CO_2$.
$Zn + S = Zn\,S$.
$Zn\,S + 2\ O_2 = Zn\,SO_4$.
$Zn\,S + 3\ O = Zn\,O + SO_2$.
$Zn + Hg\,S = Zn\,S + Hg$.
$Zn\,SO_4 + 2\ C = Zn\,S + 2\ CO_2$.
$Zn\,SO_4 + 2\ S = Zn\,S + 2\ SO_2$.
$Zn\,SO_4 + Ba\,Cl_2 = Ba\,SO_4 + Zn\,Cl_2$.
$Zn\,CO_3 = Zn\,O + CO_2$.
$Zn + Cl_2 = Zn\,Cl_2$.
$Zn + 2\ H\,Cl = Zn\,Cl_2 + H_2$.
$Zn + H_2SO_4 = Zn\,SO_4 + H_2$.

$Zn\,I_2 + Ag_2\,SO_4 = Zn\,SO_4 + 2\ Ag\,I.$
$Zn + 2\ Ag\,I = Zn\,I_2 + 2\ Ag.$
$Zn\,S + Fe_2\,Cl_6 = Zn\,Cl_2 + 2\ Fe\,Cl_2 + S.$
$Zn + Pb\,Cl_2 = Zn\,Cl_2 + Pb.$

REACTIONS OF TIN (Sn).

$Sn + O_2 = Sn\,O_2.$
$Sn\,O_2 + 2\ C = Sn + 2\ CO.$
$Sn + S = Sn\,S.$
$Sn\,O_2 + 2\ K\,Cy = Sn + 2\ K\,Cy\,O.$
$Sn + Hg\,Cl_2 = Sn\,Cl_2 + Hg.$
$Sn + 2\ Cl_2 = Sn\,Cl_4.$
$Sn\,Cl_4 + Sn = 2\ Sn\,Cl_2.$
$2\ Sn\,Cl_2 + O = Sn_2\,O\,Cl_2 + Cl_2.$
$Sn\,Cl_2 + Cl_2 = Sn\,Cl_4.$
$Sn + 2\ Hg\,Cl_2 = Sn\,Cl_4 + 2\ Hg.$
$3\ Sn\,Cl_2 + 2\ Au\,Cl_3 = 3\ Sn\,Cl_4 + Au_2.$
$Sn + 2\ H\,Cl = Sn\,Cl_2 + H_2.$
$Sn + 4\ H\,NO_3 = Sn\,OH_2\,O_2 + 4\ NO_2 + OH_2.$
$2\ Sn\,Cl_2 + 2\ Ag\,NO_3 = Sn\,Cl_4 + Sn\,O_2\,(NO_2)_2 + Ag_2.$
$Sn\,Cl_2 + Fe_2\,Cl_6 = Sn\,Cl_4 + 2\ Fe\,Cl_2.$

REACTIONS OF SILVER (Ag).

$2\ Ag + S = Ag_2\,S.$
$Ag_2\,S + O_2 = 2\ Ag + SO_2.$
$Ag + Cl = Ag\,Cl.$
$Ag\,Cl + H = Ag + H\,Cl.$
$Ag_2\,S + 2\ H = 2\ Ag + H_2\,S.$
$Ag\,NO_3 + H = Ag + H\,NO_3.$
$Ag_2\,S + 2\ Na\,Cl + 2\ O_2 = 2\ Ag\,Cl + Na_2\,SO_4.$
$Ag_2\,S + 2\ Cu_2\,S + 7\ O_2 = Ag_2\,SO_4 + 2\ Cu\,SO_4 + 2\ Cu\,O.$
$4\ Ag\,Cl + 2\ Na_2\,CO_3 + C = 4\ Ag + 4\ Na\,Cl + 3\ CO_2.$
$4\ Ag\,Cl + 2\ Fe = 2\ Fe\,Cl_2 + 4\ Ag.$
$4\ Ag\,Cl + 2\ Ca\,O + C = 4\ Ag + 2\ Ca\,Cl_2 + CO_2.$
$4\ Ag\,Cl + 2\ H_2\,O + C = 4\ Ag + 4\ H\,Cl + CO_2.$
$Ag_2\,SO_4 = Ag_2 + SO_2 + O_2.$
$Ag_2\,SO_4 + C = Ag_2 + SO_2 + CO_2.$
$2\ Ag + 2\ Cu\,Cl_2 = 2\ Ag\,Cl + Cu_2\,Cl_2.$
$2\ Ag + Fe_2\,Cl_6 = 2\ Ag\,Cl + 2\ Fe\,Cl_2.$

$2\ Ag + 2\ HgCl_2 = 2\ AgCl + Hg_2Cl_2.$
$Ag_2S + 2\ CuCl_2 = 2\ AgCl + Cu_2Cl_2 + S.$
$Ag_2S + 2\ Cu_2Cl_2 = Ag_2 + 2\ CuCl_2 + Cu_2S.$
$Ag_2S + 2\ Cu_2Cl_2 + 3\ O = 2\ AgCl + CuCl_2 + 3\ CuO + S.$
$2\ AgCl + 2\ Hg = Hg_2Cl_2 + 2\ Ag.$
$2\ AgI + Zn = ZnI_2 + 2\ Ag.$
$AgCl + KI = KCl + AgI.$
$Ag_2SO_4 + ZnI_2 = ZnSO_4 + 2\ AgI.$
$AgNO_3 + KCN = KNO_3 + AgCN.$
$AgCN + HCl = AgCl + HCN.$
$2\ Ag + 2\ H_2SO_4 = Ag_2SO_4 + SO_2 + 2\ H_2O.$
$4\ Ag + 6\ HNO_3 = 4\ AgNO_3 + N_2O_3 + 3\ H_2O.$
$6\ Ag + 8\ HNO_3 = 6\ AgNO_3 + N_2O_2 + 4\ H_2O.$
$Ag_2SO_4 + 2\ NaCl = 2\ AgCl + Na_2SO_4.$
$Ag_2SO_4 + 2\ HCl = 2\ AgCl + H_2SO_4.$
$AgNO_3 + NaCl = AgCl + NaNO_3.$
$AgNO_3 + HCl = AgCl + HNO_3.$

REACTIONS OF GOLD (Au).

$2\ Au + 3\ Cl_2 = 2\ AuCl_3.$
$AuCl_3 + 3\ H = Au + 3\ HCl.$
$2\ AuCl_3 = Au_2 + 3\ Cl_2.$
$Au_2S_3 + 3\ O_2 = Au_2 + 3\ SO_2.$
$Au_2S_3 + 3\ Cl + 3\ O_2 = 2\ AuCl_3 + 3\ SO_2.$
$2\ Au_3As + 18\ Cl + 3\ O = 6\ AuCl_3 + As_2O_3.$
$2\ AuCl_3 + 3\ H_2SO_3 + 3\ OH_2 = Au_2 + 3\ H_2SO_4 + 6\ HCl.$
$2\ AuCl_3 + 3\ (H_2C_2O_4) = Au_2 + 6\ CO_2 + 6\ HCl.$
$2\ AuCl_3 + 6\ FeCl_2 = Au_2 + 3\ Fe_2Cl_6.$
$2\ AuCl_3 + 6\ FeSO_4 = Au_2 + Fe_2Cl_6 + 2\ Fe_2(SO_4)_3.$
$2\ AuCl_3 + 3\ Cu_2Cl_2 = Au_2 + 6\ CuCl_2.$
$2\ AuCl_3 + AsH_3 + 3\ H_2O = Au_2 + As(HO)_3 + 6\ HCl.$
$2\ AuCl_3 + SbH_3 = Au_2 + SbCl_3 + 3\ HCl.$
$2\ AuCl_3 + PH_3 + 3\ H_2O = Au_2 + P(HO)_3 + 6\ HCl.$
$2\ AuCl_3 + 6\ KI = Au_2I_2 + 2\ I_2 + 6\ KCl.$
$2\ Au + 3\ HNO_3 + 9\ HCl = 2\ AuCl_3 + 3\ NOCl + 6\ H_2O.$

REACTIONS OF MERCURY (Hg).

$Hg + O = HgO.$
$HgO = Hg + O.$

$Hg S + O_2 = Hg + SO_2$.
$Hg S + Fe = Fe S + Hg$.
$Hg + Ag_2 S = Hg S + 2\ Ag$.
$2\ Hg + 2\ Ag Cl = Hg_2 Cl_2 + 2\ Ag$.
$2\ Hg Cl_2 + 2\ Ag = 2\ Ag Cl + Hg_2 Cl_2$.
$Hg_2 Cl_2 + Cl_2 = 2\ Hg Cl_2$.
$Hg_2 Cl_2 + Sn Cl_2 = Hg_2 + Sn Cl_4$.
$Hg_2 Cl_2 + 2\ K HO = 2\ Hg + 2\ K Cl + O + H_2 O$.
$2\ Hg Cl_2 + Sn Cl_2 = Hg_2 Cl_2 + Sn Cl_4$.
$Hg_2 SO_4 + 2\ Na Cl = Na_2 SO_4 + Hg_2 Cl_2$.
$Hg O + 2\ H Cl = Hg Cl_2 + H_2 O$.
$4\ Hg S + 4\ Ca O = 4\ Hg + 3\ Ca S + Ca SO_4$.
$4\ Hg S + 4\ Ca (HO)_2 = 4\ Hg + 3\ Ca S + Ca SO_4 + 4\ H_2 O$.
$Hg + 2 Na Cl + Mn O_2 + 2 H_2 SO_4 = Hg Cl_2 + Na_2 SO_4 + Mn SO_4 + 2\ H_2 O$.
$Hg SO_4 + 2\ Na Cl = Na_2 SO_4 + Hg Cl_2$.
$Hg + 2\ H_2 SO_4 = Hg SO_4 + 2\ OH_2 + SO_2$.
$2\ Hg + 4\ H NO_3 = Hg_2 (NO_3)_2 + N_2 O_4 + 2\ H_2 O$.
$3\ Hg + 8\ H NO_3 = 3\ (Hg\ 2\ NO_3) + 2\ NO + 4\ H_2 O$.
$3\ Hg_2 Cl_2 + 8\ H NO_3 = 3\ Hg Cl_2 + 3\ Hg (NO_3)_2 + 2\ NO + 4\ H_2 O$.

REACTIONS OF NICKEL (Ni) AND COBALT (Co).

$Ni + O = Ni O$.
$2\ Ni O + O = Ni_2 O_3$.
$Ni O + H_2 = Ni + H_2 O$.
$Ni + S = Ni S$.
$Ni O + 2\ H Cl = Ni Cl_2 + H_2 O$.
$Ni_2 O_3 + 3\ C = Ni_2 + 3\ CO$.
$Ni (HO)_2 = Ni O + H_2 O$.
$Ni_2 (HO)_6 = Ni_2 O_3 + 3\ H_2 O$.
$Ni + H_2 SO_4 = Ni SO_4 + H_2$.
$Ni SO_4 + 2\ K Cy = Ni Cy_2 + K_2 SO_4$.
$2\ Ni Cy_2 + Na Cl O + 5\ OH_2 = Ni_2 (HO)_6 + Na Cl + 4\ H Cy$.
$Co + O = Co O$.
$2\ Co + O = Co_2 O_3$.
$Co O + H_2 = Co + H_2 O$.
$Co_2 O_3 + 3\ H_2 = 2\ Co + 3\ H_2 O$.
$Co + S = Co S$.
$Co (HO)_2 = Co O + H_2 O$.
$Co Cl_2 + 2\ K HO = Co (HO)_2 + 2\ K Cl$.
$Co + H_2 SO_4 = Co SO_4 + H_2$.

$\mathrm{Co\,SO_4 + 2\ K\,Cy = Co\,Cy_2 + K_2\,SO_4.}$

$\mathrm{2\ Co\,Cy_2 + 8\ K\,Cy + O + H_2\,O = K_6\,Co_2\,Cy_{12} + 2\ K\,HO.}$

REACTIONS OF MANGANESE (Mn).

$\mathrm{Mn\,O_2 + 4\ H\,Cl = Mn\,Cl_2 + Cl_2 + 2\ H_2\,O.}$

$\mathrm{Mn\,O_2 + C_2\,H_2\,O_4 + H_2\,SO_4 = Mn\,SO_4 + 2\ CO_2 + 2\ H_2\,O.}$

$\mathrm{Mn\,O_2 + C_2\,H_2\,O_4 = Mn\,O + 2\ CO_2 + H_2\,O.}$

$\mathrm{Mn\,O_2 + 2\ Fe\,SO_4 + 2\ H_2\,SO_4 = Fe_2\,(SO_4)_3 + Mn\,SO_4 + 2\ H_2\,O.}$

$\mathrm{Mn\,O_2 + H_2\,SO_4 = Mn\,SO_4 + H_2\,O + O.}$

$\mathrm{Mn_3\,O_4 + 8\ H\,Cl = 3\ Mn\,Cl_2 + Cl_2 + 4\ H_2\,O.}$

$\mathrm{Mn\,Cl_2 + Ca\,CO_3 = Mn\,CO_3 + Ca\,Cl_2.}$

$\mathrm{Mn_2\,K_2\,O_8 + 3\ H_2\,SO_4 = 2\ Mn\,SO_4 + K_2\,SO_4 + 3\ H_2\,O + 5\ O.}$

$\mathrm{Mn_2\,K_2\,O_8 + 16\ H\,Cl = 2\ Mn\,Cl_2 + 2\ K\,Cl + 5\ Cl_2 + 8\ H_2\,O.}$

REACTIONS OF ANTIMONY (Sb).

$\mathrm{2\ Sb + 3\ O = Sb_2\,O_3.}$

$\mathrm{2\ Sb + 3\ OH_2 = Sb_2\,O_3 + 3\ H_2.}$

$\mathrm{2\ Sb_2\,O_3 + 9\ S = 2\ Sb_2\,S_3 + 3\ SO_2.}$

$\mathrm{Sb_2\,S_3 + 9\ O = Sb_2\,O_3 + 3\ SO_2.}$

$\mathrm{Sb_2\,S_3 + 3\ Fe = 3\ Fe\,S + 2\ Sb.}$

$\mathrm{2\ Sb + 3\ S = Sb_2\,S_3.}$

$\mathrm{Sb\,Cl_3 + Cl_2 = Sb\,Cl_5.}$

$\mathrm{2\ Sb\,Cl_3 + 3\ H_2\,S = Sb_2\,S_3 + 6\ H\,Cl.}$

$\mathrm{Sb_2\,O_3 + 3\ Na_2\,S_2\,O_3 = Sb_2\,S_3 + Na_2\,SO_4.}$

$\mathrm{2\ Sb_2\,O_3 + 3\ C = 4\ Sb + 3\ CO_2.}$

$\mathrm{2\ Sb_2\,O_3 + 6\ K\,Cy = 6\ K\,Cy\,O + 4\ Sb.}$

$\mathrm{2\ Sb_2\,S_3 + 6\ K\,Cy = 6\ K\,Cy\,S + 4\ Sb.}$

$\mathrm{Sb_2\,Zn_3 + 3\ H_2\,SO_4 = 3\ Zn\,SO_4 + 2\ Sb\,H_3.}$

$\mathrm{Sb\,H_3 + 3\ Ag\,NO_3 = Sb\,Ag_3 + 3\ H\,NO_3.}$

$\mathrm{Sb_2\,O_3 + 2\ I_2 + 2\ H_2\,O = Sb_2\,O_5 + 4\ HI.}$

REACTIONS OF ARSENIC (As).

$\mathrm{2\ As + 3\ O = As_2\,O_3.}$

$\mathrm{As_2\,O_3 + 12\ H = 2\ As\,H_3 + 3\ OH_2.}$

$\mathrm{2\ As_2\,O_3 + 3\ C = As_4 + 3\ CO_2.}$

$\mathrm{2\ As_2\,O_3 + 6\ K\,Cy = 6\ K\,Cy\,O + 4\ As.}$

$\mathrm{2\ As_2\,S_3 + 6\ K\,Cy = 6\ K\,Cy\,S + 4\ As.}$

$\mathrm{As\,S\,Fe_2 = As + Fe_2\,S.}$

$\mathrm{As_2\,Zn_3 + 3\ H_2\,SO_4 = 2\ As\,H_3 + 3\ Zn\,SO_4.}$

$\mathrm{2\ Au_3\,As + 18\ Cl = As_2\,O_3 + 6\ Au\,Cl_3.}$

$As H_3 + 6 Ag NO_3 + 3 OH_2 = As H_3 O_3 + 6 Ag + 6 H NO_3.$
$As_2 O_3 + 4 Cl + 2 H_2 O = As_2 O_5 + 4 H Cl.$
$As_2 O_3 + 2 I_2 + 2 H_2 O = As_2 O_5 + 4 HI.$
$As_2 O_5 + 2 SO_2 + 2 H_2 O = As_2 O_3 + 2 H_2 SO_4.$

APPENDIX E.

A SHORT DESCRIPTION OF THE PRINCIPAL ORES.

TABLE OF HARDNESS.

1. Talc. 2. Rock salt. 3. Calc-spar. 4. Fluor-spar. 5. Apatite. 6. Felspar. 7. Quartz. 8. Topaz. 9. Sapphire. 10. Diamond.

ORES OF LEAD (Pb).

Native Lead occurs rarely in thin laminæ, with the specific gravity 11·35.

Galena ($Pb S$).—Occurs in lead-coloured lustrous cubes and dodecahedra, also massive, with quartz ($Si O_2$), barytes ($Ba SO_4$), blende ($Zn S$), and pyrites ($Fe S_2$), in limestone and clay slate, and contains, when pure, 86·6 per cent of lead and 13·4 per cent of sulphur. It has a hardness of 2·5, and sp. gr., from 7·25 to 7·7. Gives a lead grey streak when scratched with a knife, or when drawn along unglazed porcelain.

Cerussite ($Pb CO_3$).—White lead, ore, or lead spar. Occurs in needle-shaped crystals of the trimetric or prismatic system, and also massive with limestone, and often associated with galena. It gives a colourless streak, has a hardness of 3 to 3·5, with sp. gr., 6·4, and contains, when pure, 77·5 per cent of lead.

Anglesite, or Lead Vitriol ($Pb SO_4$).—Occurs in white octahedra and right rhombic prisms, often associated with galena and cerussite, and, when pure, contains 68·3 per cent of lead. Sp. gr., 6·25 to 6·3; hardness, 2·75 to 3.

Pyromorphite ($Pb_3 O_{12} P_3 Cl$).—Lead phosphate. Brown or yellow, with yellowish streak. It has sometimes a resinous lustre, and occurs in prismatic system. Composition various. A brown variety gave 74 per cent of lead oxide, 15·8 per cent of phosphoric acid, and 10·2 per cent of lead chloride. Sp. gr., 6·5 to 7; hardness, 3·5 to 4.

ORES OF COPPER (Cu).

Native Copper is found in octahedral and cubical crystals, also massive, and often arborescent or filiform, or sometimes in the form of loose sand; often contains silver, gives metallic streak, is ductile, and has a sp. gr. of 8·9, and hardness, 2·5 to 3.

Cuprite ($Cu_2 O$).—Red copper ore. Occurs in regular octahedrons, sometimes massive, has a deep red colour and streak. Contains, when pure, 88·78 per cent of copper. Sp. gr., 6; hardness, 3·5 to 4.

Tenorite ($Cu O$).—Black oxide. Occurs as dull black powder or mass, and, when pure, yields 79·8 per cent of copper, but usually contains 60 per cent to 70 per cent. Black streak. Sp. gr., 5 to 5·6; hardness, 3 to 3·5.

Copper Pyrites ($Cu_2 S$, $Fe_2 S_3$).—Occurs in octahedral or tetrahedral crystals. Brass-yellow colour; streak unmetallic, greenish black, and but little shiny. When pure contains 34·8 per cent of copper, but usually 7 per cent or 8 per cent. Sp. gr., 4·16; hardness, 3·5 to 4. Distinguished from iron pyrites in that it can be scratched with a knife.

Copper Glance ($Cu_2 S$).—Redruthite, or vitreous ore. Occurs sometimes in modified tetrahedrons. Colour, blackish (lead coloured); streak, steel grey. When pure contains 79·8 per cent of copper. Sp. gr., 5 to 5·5; hardness, 3 to 4.

Blue Vitriol ($Cu SO_4$, $5 OH_2$).—In rhomboidal prisms. Colour, sky blue; soluble in water. Sp. gr., 2·2; hardness, 2 to 2·5.

Grey Copper Ore.—Fahl ore. Has a steel grey or iron black colour, with a black streak. Occurs massive and crystalline, and is very variable in composition, often containing Fe, Zn, Ag, As, Sb, Bi, and occasionally Au, Hg, and Pt. The copper ranges up to 48 per cent, and the silver up to 30 per cent. Sp. gr., about 5; hardness, 3 to 4.

Malachite ($Cu CO_3$, $Cu O$, $H_2 O$).—Green carbonate. Usually occurs as incrustations, with stalactitic surface. Colour and streak, pale green. Contains, when pure, 57 per cent of copper. Sp. gr., 4; hardness, 3·5 to 4.

Azurite ($2 Cu CO_3$, $Cu H_2 O_2$).—Blue carbonate. Occurs in modified oblique rhombic prisms. Colour and streak, blue. Yields, when pure, 55 per cent Cu. Sp. gr., 3·5; hardness, 4.

Chrysocolla ($Cu O$, $Si O_2$, $2 OH_2$).—Silicate of copper. Occurs usually as incrustations. Bright green or bluish green colour.

Sp. gr., 2 to 2·3; hardness, 2 to 3. One sample gave, on analysis, 42·6 of $Cu\,O$, 40 $Si\,O_2$, 16 OH_2, and 1·4 $Fe_2\,O_3$. Average amount of Cu, 30 per cent.

ORES OF IRON (Fe).

Native Iron occurs in meteors with nickel and cobalt; crystallises in regular octahedrons. Sp. gr., 7·5 to 7·8; hardness, 4·5.

Magnetite ($Fe_3\,O_4$).—Magnetic iron ore, or lodestone. Occurs both massive and also in cubes, octahedra and rhombic dodecahedra. Black, with black streak. Magnetic, that is can be attracted by a magnet, and sometimes will attract iron, when it will often exhibit polarity. Contains, when pure, 72·41 per cent of iron. Sp. gr., 5; hardness, 5·5 to 6·5, and is not scratched with a knife.

Franklinite.—Similar to magnetite, and slightly attracted by a magnet. Occurs in octahedral crystals, and also massive. Iron black in colour, dark reddish brown streak. Sp. gr., 4·8 to 5; hardness, 5·5 to 6. One analysis gave 41·56 per cent Fe, 9·38 Mn, and 20·3 Zn. Smelted for spiegeleisen.

Hematite ($Fe_2\,O_3$).—Called specular iron ore when crystalline. The crystals are rhombohedral, have metallic lustre, dark steel grey colour, and give a cherry red or reddish brown streak. Occurs also massive, as kidney ore, puddler's ore, and red ochre. The last mentioned earthy varieties are soft, and red in colour. When pure it contains 70 per cent Fe, has sp. gr. of 4·5 to 5·3, and hardness of crystals 5·5 to 6·5.

Brown Hematite (2 $Fe_2\,O_3$, 3 OH_2).—Usually massive, and often with a stalactitic surface, having a compact fibrous structure within. Colour, dark brown to yellow; streak, brownish yellow; sp. gr., 3·6 to 4; hardness, 4 to 5; earthy varieties, brown ochre, yellow ochre, bog iron ore, or limonite, and lake ore. *Göthite* ($Fe_2\,O_3$, OH_2) and *Turgite* are richer types of the same class, containing only about half as much water. Sp. gr., 4 to 4·2; hardness, 5.

Siderite ($Fe_2\,CO_3$).—Spathic ore in the pure form as hexagonal crystals, which contain 48·27 per cent Fe. Colour, light grey to brown, with white streak; sp. gr., 3·7 to 3·9; hardness, 3 to 4. *Clay ironstone* is an argillaceous variety, brown in colour, with a yellowish streak, and is often impregnated with bituminous matter, when it is known as *black band*.

Ilmenite ($Fe_2\,O_3$, $Fe\,O$, $Ti\,O_2$).—An oxide of iron containing oxide of titanium; rhombic. Colour, iron black; streak, metallic; slightly magnetic; sp. gr., 4·5 to 5; hardness, 5 to 6.

Chrome Iron Ore (FeO, Cr_2O_3).—Ferrous oxide and chromium sesquioxide, with about 10 per cent alumina and 7 per cent of magnesia. Monometric, usually massive; colour, black or brownish black, with dark brown streak; slightly magnetic; sp. gr., 4 to 4·5; hardness, 5·5.

Iron Pyrites (FeS_2).—Mundic. Monometric; occurs in cubes and also massive; colour, bronze or brass yellow, with metallic lustre and brownish black streak; contains 46·7 per cent of Fe and 53·3 per cent of S; sp. gr., 4·7 to 5; hardness, 6 to 6·5; sparks with steel, and will scratch glass.

Magnetic Pyrites (Fe_2S_3).—Hexagonal prisms and massive; colour, between bronze yellow and copper red; streak, greyish black; slightly magnetic; sp. gr., 4·7; hardness, 3·5 to 4·5. This and the last mentioned are not used as ores of iron.

ORES OF TIN (Sn).

Cassiterite (SnO_2).—Tinstone. Dimetric in modified square prisms and octahedrons, also massive, or in grains as stream tin. Colour, brown or black; streak, pale grey to brown; contains 78·4 per cent of tin; sp. gr., 6·5 to 7; hardness, 6 to 7. Sometimes occurs in reniform shapes, with concentric radiated structure, and called *wood tin. Toad's eye tin* is the same on a small scale.

Tin Pyrites, or bell metal ore, is a sulphide of tin and iron containing copper. Cubic system. Yellow-grey colour, with metallic lustre and black streak; sp. gr., 4·3; hardness, 4.

ORES OF ZINC (Zn).

Blende (ZnS).—Black Jack. Monometric; occurs in dodecahedrons, octahedrons, and allied forms; also massive, occasionally fibrous; colour, yellow, green, red, and black; streak, white to reddish brown; when pure contains 66·7 per cent of zinc; sp. gr., 4; hardness, 3·5 to 4.

Zincite (ZnO).—Red zinc ore. Trimetric; in foliated masses, or in disseminated grains; colour, red; streak, orange-yellow; brilliant lustre; contains usually about 70 per cent of zinc and 4 per cent of manganese; sp. gr., 5·5, and hardness, 4 to 4·5. It occurs usually with franklinite.

Calamine ($ZnCO_3$).—Rhombohedral, massive, reniform, and stalactitic; colour when pure, white, with pearly or vitreous lustre, with white streak, but usually brown in colour and streak, due to Fe_2O_3. Contains, when pure, 52 per cent of Zn, often contains Cd, and usually associated with blende and galena; sp. gr., 4·3 to 4·5; hardness, 5.

Electric Calamine (Zn_2SiO_4, OH_2).—Silicate of zinc. Trimetric, modified prisms, and massive; colour, white, but often tinted with blue, green, or brown, with a vitreous or pearly lustre; streak, white, and becomes electrified when heated; contains, when pure, 53 per cent of Zn and 7 per cent of water; sp. gr., 3·4; hardness, 4·5 to 5.

Willemite (Zn_2SiO_4) is an anhydrous variety of the above; colour and streak, yellow; sp. gr., 4; hardness, 5 to 5·5.

ORES OF MERCURY (Hg).

Native Mercury usually contains silver, and often gold, and is found in fluid globules throughout the gangue, but it sometimes accumulates in cavities in sufficient quantity to be removed in pails. It becomes solid, and crystallises in octahedrons at a temperature of $-39°$ F. It has a sp. gr. of 13·6.

Native Amalgam is a compound of Hg and Ag, containing about 70 per cent of Hg and 30 per cent of Ag; occurring in silver; white dodecahedrons; sp. gr., 12; hardness, 2.

Cinnabar (HgS).—Mercury sulphide. Rhombohedral prisms, also massive and earthy; colour, bright red to brownish red; streak, bright red; contains, when pure, 86·2 per cent of Hg and 13·8 per cent of sulphur, and is readily sectile; sp. gr., 7 to 8; hardness, 2 to 2·5. *Liver ore*, or *hepatic cinnabar*, contains bituminous matter and clay, and has a brown streak.

Horn Quicksilver (Hg_2Cl_2) occurs with cinnabar, and is of a yellow-grey colour and streak; it contains 85 per cent of Hg when pure; sp. gr., 6·5; hardness, 1 to 2.

ORES OF NICKEL (Ni).

Arsenical Nickel ($NiAs_2$).—Hexagonal, usually massive, pale copper red colour, and reddish brown streak. Composition, Ni 44 per cent, As 55 per cent, a portion of the arsenic being sometimes replaced by antimony. Sometimes called copper nickel or false copper, from its resemblance to that metal. Sp. gr., 7·5; hardness, 5 to 5·5.

White Nickel, *Placodine*, *Amorbite*, and *Nickel glance*, are varieties of this ore. White nickel contains 20 to 28 per cent of nickel; 70 to 72 per cent of As. Placodine, 57 per cent Ni, and has a bright yellow colour. Nickel glance, 30 per cent Ni, 40 per cent As, and 20 per cent S. Colour, silver white to steel grey. Amorbite contains 40 per cent Ni, and about 14 per cent of S.

Nickel Stibine contains about 26 per cent of Ni, with varying quantities of Sb and S, and is of a steel grey colour; sp. gr., 6·5; hardness, 5 to 5·5. *Antimonial nickel* contains 29 per cent of Ni, with varying quantities of Sb, but no S; its colour is pale copper red; sp. gr., 7·5; hardness, 5.

Nickel Pyrites, or Capiliary Pyrites (Ni S), contains about 64 per cent of Ni, and often occurs in strings or threads, hence its name; brass-yellow colour; hardness, 3 to 3·5.

Green Nickel Hydrate occurs generally in the stalactitic form and has a bright emerald green colour; contains about 38 per cent of water; sp. gr., 3; hardness, 3.

Nickel occurs alloyed with Fe in meteors. The proportion of Ni is sometimes as high as 15 per cent, but more usually 8 or 10 per cent.

ORES OF COBALT (Co).

Smaltine ($Co As_2$). — Monometric; occurs in cubes, also massive; colour, tin white to steel grey; streak, greyish black; composition varies from 18 per cent Co and 79 per cent As to 24 per cent Co and 69 per cent As; sp. gr., 6·5 to 7; hardness, 5·5.

Cobalt Oxide occurs as a black or blue earthy mineral, containing $Co O$ and $Mn_2 O_3$, and frequently Ni, Fe, and Cu.

Cobalt Bloom is an arsenate and occurs both crystalline and as an incrustation; colour, crimson red; streak, slightly paler. One analysis gave $Co O$ 39·2 per cent, $As_2 O_3$ 37·9 per cent, and OH_2 22·9 per cent; sp. gr., 3; hardness, 1·5 to 2.

ORES OF ARSENIC (As).

Native Arsenic.—Rhombohedral; also massive and granular; colour and streak, tin white; brittle; occurs with lead ores; sp. gr., 5·75; hardness, 3·5.

White Arsenic ($As_2 O_3$).—Occurs in minute capillary crystals; sp. gr., 3·7; hardness, 1·5.

Orpiment ($As_2 S_3$).—Occurs in foliated masses, and occasionally in prismatic crystals; colour and streak, fine yellow; sp. gr., 3·4; hardness, 1·5 to 2.

Realgar ($As_2 S_2$).—In oblique prisms, and also massive; colour, red to orange; streak, orange; sp. gr., 3·5; hardness, 1·5 to 2. Arsenic also occurs with Ni, in arsenical nickel, &c., and with cobalt in smaltine, &c.

ORES OF ANTIMONY (Sb).

Native Antimony.—Rhombohedral; usually massive; colour and streak, tin white; occurs with Ag and Pb ores, and contains those metals as well as Fe; sp. gr., 6·7; hardness, 3·5.

Stibnite ($Sb_2 S_3$).—Grey antimony ore; trimetric, commonly fibrous; colour and streak, lead grey; is brittle, and has metallic lustre; occurs with Ag, Pb, and Zn ores; sp. gr., 4·5; hardness, 2. Several sulphides of antimony and lead are known as *Jamesonite;* steel grey colour; composition, 35 per cent Sb, 41 per cent Pb, 24 per cent S. *Feather ore;* finely capillary, lead grey colour; composition, 31 per cent Sb, 47 per cent Pb; 20 per cent S. *Boulangerite;* lead grey colour, with 25 per cent Sb, 55 per cent Pb, and 20 per cent S; sp. gr., 6; hardness, 2·5. And *Geocronite;* light grey colour; composition, 14 per cent Sb, 69 per cent Pb, 16 per cent S, and frequently As; sp. gr., 6; hardness, 2·5.

Red Antimony is a mixture of sulphide and oxide of Sb, of a cherry red colour, and gives a brownish red streak; sp. gr., 4·5; hardness, 1 to 1·5.

White Antimony ($Sb_2 O_3$).—Occurs in grey rectangular crystals; sp. gr., 5·6; hardness, 2·5 to 3.

ORES OF BISMUTH (Bi).

Native Bismuth.—Monometric; occurs in cubes or octahedrons, but usually massive. Colour and streak white, with slight tinge of red. Generally pure Bi, but occasionally a trace of As. It occurs with ores of Sb, Co, and Pb. Sp. gr., 9·7 to 9·9; hardness, 2 to 2·5.

Bismuth Sulphide ($Bi_2 S_3$).—Bismuth glance. Lead grey colour and streak. Sp. gr., 6·5; hardness, 2·5.

Bismutite is a carbonate of Bi. Colour, greenish yellow. Sp. gr., 6·8; hardness, 4 to 4·5. Bismuth ochre is also a carbonate, occurring massive and earthy. Colour, pale yellow or green. Sp. gr., 5 to 6; hardness, 2 to 2·5.

Bismuth Blende is a silicate of Bi. Colour, dark brown or yellow. Sp. gr., 6; hardness, 3·5.

ORES OF SILVER (Ag).

Native Silver.—Monometric in octahedrons; often occurs as filiform threads, having a crystalline character. Colour and streak, white and metallic. Malleable. It usually contains Cu, and occasionally Au. Sp. gr., 10·5; hardness, 2·5 to 3. Ag is always present to some extent in native Au.

Silver Glance (Ag_2S), *or Silver Sulphide.*—Occurs in monometric forms as cubes or octahedrons, also reticulated and massive. It has metallic lustre, and a lead grey colour and streak. Contains, when pure, 87 per cent of Ag, but usually some of the Ag is replaced by Pb, Cu, Sb, &c. Sp. gr., 7·2 to 7·4; hardness, 2·25. *Stromeyerite* is a steel grey sulphide of Ag and Cu, with 52 per cent of Ag. Sp. gr., 6·25. *Sternbergite*, a sulphide of Ag and Fe, with 33 per cent of Ag.

Stephanite ($5\,Ag_2S, Sb_2S_3$), *or Brittle Silver Ore.*—Is a double sulphide of Ag and Sb. Occurs in the trimetric system as modified right rhombic prisms, also massive. Metallic lustre, with black or iron grey colour and streak. It contains about 70 per cent of Ag, and usually about 14 per cent of Sb, with traces of Cu. Sp. gr., 6·27; hardness, 2·25. *Polybasite* same as last, but in addition contains As, 64 per cent of Ag. *Margyrite* has a dark cherry red streak, but its colour is iron black. Contains about 37 per cent of Ag. *Red silver ore*, rhombohedral, streak red. Contains about 60 per cent of Ag, with Sb and As. Sp. gr., 5·5; hardness, 2 to 2·5.

Horn Silver ($Ag\,Cl$).—Monometric; in cubes, and also massive. Colour, grey to bluish green, and has the appearance of horn or wax. Streak, shiny; semi-metallic; can be cut with a knife. Contains, when pure, 75·25 per cent of Ag. Sp. gr., 5·5; hardness, 1 to 1·5.

Bromargyrite ($Ag\,Br$).—Is yellow, soft, and sectile. Sp. gr., 5 to 6. Contains 58 per cent of Ag. *Iodargyrite* ($Ag\,I$), yellow, soft, and sectile. Sp. gr., 5·3 to 6; hardness, 1 to 1·5. Contains 46 per cent of Ag.

Telluric Silver.—Steel grey colour. Contains 62 per cent of Ag and 36 Te. Sp. gr., 8·5.

Silver is also obtained from argentiferous galena, and from fahl ore, described under the head of copper ores.

ORES OF GOLD (Au).

Gold occurs chiefly native, either pure or alloyed, with Ag, Cu, &c.

Native Gold.—Monometric, in cubes, and also in grains. Sometimes filiform or reticulated. Colour, various shades of yellow. It is both ductile and malleable. An analysis of native Au from Russia gave 98·96 per cent of Au, ·16 per cent of Ag, ·35 per cent of Cu, ·05 per cent of Fe, and had the sp. gr. of 19·1. The sp. gr. of native Au varies from 12 to 20; hardness, 2·5 to 3. Colour and sp. gr. vary according to the alloys. Ag often present as high as 25 per cent.

Nagyagite, a native telluride of Au and Pb, is soft, with a lead grey colour and streak. Contains about 50 per cent of Pb, 30 per cent of Te, 10 per cent of Au, and small quantities of Ag and Cu.

Aurotellurite and *Graphic Tellurium*, are two minerals containing Au and Te.

Native Platinum is found in flattened or rounded grains, of a steel grey colour and streak, and metallic lustre. It usually contains the rare metals, iridium (Ir), rhodium (Rh), palladium (Pd), and osmium (Os), and also Cu and Fe. It contains from 70 per cent to 85 per cent of Pt, is ductile, and malleable. Sp. gr., 16 to 20; hardness, 4 to 4·5.

APPENDIX F.

TABLE OF FACTORS OR CO-EFFICIENTS.

To Use the Table.—Multiply the weight of the substance found by the co-efficient, and the product gives the weight of the body sought, from which the percentage may be readily calculated. *Example:* If a precipitate of $Ba\,SO_4$ weighs 1·538 grs., then 1·538 × ·13734 = ·21122892, which is the weight of S in grs. in that quantity of ppt.

The co-efficient is found by dividing the molecular weight into the atomic weight of the element sought, or, in the case of a compound body, into the sum of its atomic weights.

ELEMENT.	FOUND.	CO-EFFICIENT.	SOUGHT.
Ag	Ag Cl	·75174	Ag
	Ag	1·328	Ag Cl
	Ag I	·8025	Ag
	Ag Cl	·24738	Cl
	Ag Cl	·4091	Na Cl
	Ag Br	·4256	Br
	Ag Cl	·2542	H Cl
	Ag I	·5405	I
	Ag Cy	·1941	CN
	Ag Cy	·8055	Ag

ELEMENT.	FOUND	CO-EFFICIENT.	SOUGHT.
	$AgCl$	1·1847	$AgNO_3$
	$AgCl$	·521	KCl
Al	Al_2O_3	·5334	Al
Ba	$BaSO_4$	·13734	S
	$BaSO_4$	·4215	SO_4H_2
	$BaSO_4$	·2578	FeS_2
	$BaSO_4$	·6096	Na_2SO_4
	$BaSO_4$	·5844	$CaSO_4$
	$BaSO_4$	·5878	Ba
	$BaSO_4$	·8455	$BaCO_3$
	$BaSO_4$	·8927	$BaCl_2$
	$BaSO_4$	1·1202	$Ba\,2NO_3$
	$BaSO_4$	·34335	SO_3
	$BaSO_4$	·412	SO_4
	$BaSO_4$	·691	$ZnSO_4$
	$BaCO_3$	·22312	CO_2
Ca	$CaSO_4$	·2353	S
	$CaSO_4$	·4117	CaO
	$CaSO_4$	·2941	Ca
	$CaSO_4$	·7353	$CaCO_3$
	$CaCO_3$	·56	CaO
	$CaCO_3$	·4	Ca
	$CaCO_3$	·44	CO_2
	$CaCO_3$	1·36	$CaSO_4$
	CaO	·7143	Ca
Cr	Cr_2O_3	·6847	Cr
Co	CoO	·7861	Co
	Co	1·2731	CoO
	$CoSO_4$	·38	Co
Cu	CuO	·79873	Cu
	Cu_2S	·79873	Cu
Fe	Fe_2O_3	·7	Fe
	Fe_2O_3	·9	FeO
	Fe	1·2142	FeO
	Fe	1·429	Fe_2O_3
	FeO	·7778	Fe
H	H_2O	·88889	O
K	K_2PtCl_6	·1603	K
	K_2PtCl_6	·30615	KCl
Mg	MgO	·6	Mg
	$MgSO_4$	1·1333	$CaSO_4$
	$Mg_2P_2O_7$	·2162	Mg

ELEMENT.	FOUND.	CO-EFFICIENT.	SOUGHT.
	$Mg_2 P_2 O_7$	·3603	$Mg O$
	$Mg_2 P_2 O_7$	·2793	P
	$Mg_2 P_2 O_7$	·63964	$P_2 O_5$
	$Mg Cl_2$	1·424	$Mg\ 2\ NO_3$
	$Mg Cl_2$	1·2315	$Na Cl$
Mn	$Mn_3 O_4$	·7205	Mn
	$Mn_3 O_4$	·9301	$Mn O$
	$Mn_3 O_4$	1·1397	$Mn O_2$
	$Mn SO_4$	·3642	Mn
	$Mn SO_4$	·4702	$Mn O$
Mo	Molybdate pp'ate	·0372	$P_2 O_5$
	Molybdate pp'ate	·0163	P
Na	$Na Cl$	·6068	Cl
	$Na Cl$	·3938	Na
	$Na Cl$	1·2735	$K Cl$
Ni	$Ni O$	·78387	Ni
	$Ni SO_4$	·3766	Ni
	Ni	1·2758	$Ni O$
	$Ni SO_4$	·4805	$Ni O$
P	$P_2 O_5$	·43662	P
Pb	$Pb S$	·8671	Pb
	Pb	1·1573	$Pb S$
	$Pb SO_4$	·6824	Pb
	$Pb Cr O_4$	·64031	Pb
	$Pb Cr O_4$	·7395	$Pb S$
	$Pb O$	·92825	Pb
	Pb	1·0775	$Pb O$
Pt	$Pt Cl_4 (NH_4 Cl)_2$	·076577	NH_3
	$Pt Cl_4 (NH_4 Cl)_2$	·24099	$NH_4 Cl$
	$Pt Cl_4 (NH_4 Cl)_2$	·063063	N
	$Pt Cl_4 (NH_4 Cl)_2$	·439161	Pt
Sb	$Sb_2 S_3$	·7143	Sb
	$Sb_2 O_3$	·8357	Sb
	$Sb_2 O_4$	·7922	Sb
Si	$Si O_2$	·4666	Si
Sn	$Sn O_2$	·7867	Sn
	$Sn O_2$	1·7333	$Sn Cl_4$
Ti	$Ti O_2$	·5102	Ti
Zn	$Zn O$	·80247	Zn
	$Zn O$	1·679	$Zn Cl$
	$Zn CO_3$	·52	Zn
	$Zn S$	·67031	Zn

APPENDIX G.

A TABLE

SHOWING THE AMOUNT OF GOLD OR SILVER PER TON OF ORE, &c., FROM THE WEIGHT OF BUTTON FROM 300 GRS.

grs. of ore, or alloy, gives of fine metal in grs.	One ton of ore, or alloy, will give			300 grs. of ore, or alloy, gives of fine metal in grs.	One ton of ore, or alloy, will give		
	ozs.	dwts.	grs.		ozs.	dwts.	grs.
·001	0	2	4	·034	3	14	0
·002	0	4	8	·035	3	16	4
·003	0	6	13	·036	3	18	9
·004	0	8	17	·037	4	0	14
·005	0	10	21	·038	4	2	19
·006	0	13	1	·039	4	4	23
·007	0	15	5	·040	4	7	3
·008	0	17	10	·041	4	9	7
·009	0	19	14	·042	4	11	11
·010	1	1	18	·043	4	13	15
·011	1	3	23	·044	4	15	20
·012	1	6	3	·045	4	18	0
·013	1	8	7	·046	5	0	4
·014	1	10	11	·047	5	2	8
·015	1	12	16	·048	5	4	12
·016	1	14	20	·049	5	6	17
·017	1	17	0	·050	5	8	21
·018	1	19	5	·051	5	11	1
·019	2	1	9	·052	5	13	5
·020	2	3	13	·053	5	15	10
·021	2	5	17	·054	5	17	14
·022	2	7	21	·055	5	19	18
·023	2	10	2	·056	6	1	23
·024	2	12	6	·057	6	4	3
·025	2	14	10	·058	6	6	7
·026	2	16	14	·059	6	8	11
·027	2	18	18	·060	6	10	15
·028	3	0	23	·061	6	12	20
·029	3	3	3	·062	6	15	0
·030	3	5	7	·063	6	17	4
·031	3	7	11	·064	6	19	9
·032	3	9	15	·065	7	1	13
·033	3	11	20	·066	7	3	17

300 grs. of ore, or alloy, gives of fine metal in grs.	One ton of ore, or alloy, will give ozs.	dwts.	grs.
·067	7	5	21
·068	7	8	2
·069	7	10	6
·070	7	12	11
·071	7	14	15
·072	7	16	19
·073	7	18	23
·074	8	1	3
·075	8	3	7
·076	8	5	12
·077	8	7	16
·078	8	9	20
·079	8	12	1
·080	8	14	5
·081	8	16	9
·082	8	18	13
·083	9	0	18
·084	9	2	22
·085	9	5	3
·086	9	7	7
·087	9	9	11
·088	9	11	15
·089	9	13	20
·090	9	16	0
·091	9	18	4
·092	10	0	8
·093	10	2	12
·094	10	4	17
·095	10	6	21
·096	10	9	1
·097	10	11	5
·098	10	13	10
·099	10	15	14
·100	10	17	19
·110	11	19	13
·120	13	1	8
·130	14	3	3
·140	15	4	21
·150	16	6	8
·160	17	8	11
·170	18	10	5
·180	19	12	0
·190	20	13	19
·200	21	15	14
·210	22	17	9
·220	23	19	3
·230	25	0	22
·240	26	2	16
·250	27	4	11
·260	28	6	6
·270	29	8	0
·280	30	9	19
·290	31	11	13
·300	32	13	8
·310	33	15	3
·320	34	16	22
·330	35	18	16
·340	37	0	11
·350	38	2	5
·360	39	4	0
·370	40	5	19
·380	41	7	14
·390	42	9	8
·400	43	11	3
·410	44	12	22
·420	45	14	16
·430	46	16	11
·440	47	18	5
·450	49	0	0
·460	50	1	19
·470	51	3	14
·480	52	5	8
·490	53	7	3
·500	54	8	21
·520	56	12	12
·540	58	16	0
·560	60	19	13
·580	63	3	3
·600	65	6	16
·620	67	10	5
·640	69	13	18
·660	71	17	8

300 grs. of ore, or alloy, gives of fine metal in grs.	One ton of ore, or alloy, will give		
	ozs.	dwts.	grs.
·680	74	0	22
·700	76	4	10
·720	78	8	0
·740	80	11	14
·760	82	15	4
·780	84	18	16
·800	86	22	6
·820	89	5	20
·840	91	9	8
·860	93	12	22
·880	95	16	11
·900	98	0	0
·920	100	3	14
·940	102	7	4
·960	104	10	16
·980	106	14	5
1·000	108	17	18
2·000	217	15	12
3·000	326	13	8
4·000	435	11	0
5·000	544	8	21
6·000	653	6	16
7·000	762	4	11
8·000	870	22	0
9·000	980	0	0
10·000	1,088	17	19
20·000	2,177	15	13
30·000	3,266	13	8
40·000	4,355	11	2
50·000	5,444	8	21
60·000	6,533	6	16
70·000	7,622	4	11
80·000	8,910	22	4
90·000	9,800	0	0
100·000	10,888	17	18
110·000	11,977	15	13
120·000	13,066	13	8
130·000	14,155	11	3
140·000	15,244	8	22
150·000	16,333	6	16
160·000	17,422	4	8
170·000	18,511	2	5
180·000	19,600	0	0
190·000	20,688	17	19
200·000	21,777	15	12
210·000	22,866	13	7
220·000	23,955	11	2
230·000	25,044	8	20
240·000	26,133	6	16
250·000	27,222	4	9
260·000	28,310	22	6
270·000	29,400	0	0
280·000	30,488	17	20
290·000	31,577	15	13
300·000	32,666	13	8

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