

ALLOYS.

Some general remarks respecting metallic alloys are given, §§ 5 and 6.

§ 43. *Copper-Tin Alloys.**

Exp. 96. Weigh out 842 grains of copper and 158 grains of tin; place the copper in clay crucible with a little charcoal; cover with lid, and place in hot fire. When melted add the tin; take out of furnace; remove lid; give a rotatory motion to crucible to well mix the contents, or stir with a charred stick, and pour into rectangular mould (Fig. 17 *e*). When cold fix the ingot in vice and strike with hammer until fracture occurs. Observe the reddish yellow colour, close fine-grained fracture, and moderate toughness. It corresponds to Cu_{10}Sn , and is fairly malleable.

Exp. 97. Take 828 grains copper and 172 grains tin. Melt with charcoal, as before. Notice that it resembles the alloy (Exp. 96) but is less malleable and tough, and may be represented by Cu_9Sn .

Exp. 98. Take 810 grains copper and 190 grains tin. Melt and cast as before. Notice the yellowish red colour and fine-grained fracture. It is still less malleable and tough than No. 96. Formula Cu_8Sn .

Exp. 99. Take 789 grains copper and 211 tin. Melt and cast into mould. Observe that the colour is similar to No. 98, that the fracture is vitreous and conchoidal and the metal feebly malleable. Formula = Cu_7Sn .

* $\text{Cu} = 63$; $\text{Sn} = 118$.

Exp. 100. Take 762 grains copper and 238 tin. Melt and cast as before. Notice the pale red colour, the fine-grained-vitreous fracture, its brittleness in the cold and malleability at red heat. Formula = Cu_6Sn .

The alloys given in Exps. 96 to 100 are used for bell-metal.

Exp. 101. Take 727 grains copper and 273 grains tin. Melt and cast as usual. Observe its yellowish white cast of colour, its extremely fine-grained conchoidal fracture, its great brittleness and ready fusibility as compared with copper. Formula = Cu_5Sn .

Exp. 102. Take 681 grains copper and 319 grains tin. Melt and cast as usual. Observe that this alloy is also very fine grained, very brittle, easily pulverable, and has a conchoidal fracture. This mixture is termed Speculum Metal. Formula = Cu_4Sn .

Exp. 103. Take 616 grains copper and 384 grains tin. Melt and cast. Observe the dark bluish grey, crystalline structure, the brittleness, and that it may easily be pulverised in a mortar. The long crystalline plates run in a direction transverse to the longer axis of the ingot, producing a somewhat rough appearance, quite different from the preceding alloys. Formula Cu_3Sn .

Exp. 104. Take 516 grains copper and 484 grains tin. Melt and cast. Observe the greyish white colour, the vitreous and conchoidal fracture inclining to crystalline, and that it is very brittle. This may be termed white bronze. Formula Cu_2Sn .

Exp. 105. Take 348 grains copper and 652 grains tin. Melt and cast. Observe its whitish grey colour, and large crystalline plates, which give it a lamellar structure, and its brittleness. Formula CuSn .

Exp. 106. Take 211 grains copper and 789 grains tin. Melt and cast. Notice its irregularly crystalline fracture and tin grey colour; that it is whiter than the preceding one; moderately hard, and somewhat malleable. Formula CuSn_2 .

Exp. 107. Take 151 grains copper and 849 grains tin. Melt and cast. Notice that the colour is whiter than the preceding alloys; that it is crystalline when cooled slowly; tough, fairly malleable, soft, and easily fusible. Formula CuSn_3 .

Exp. 108. Take 96 grains copper and 904 grains tin. Melt and cast. Observe that it is as soft as tin, of a greyish white colour, partly crystalline and partly granular, giving a rough heterogeneous appearance to the fractured surface; and that it is tough and malleable. Formula = CuSn_5 .

§ 43A. With regard to the foregoing series of copper-tin alloys, only SnCu_3 and SnCu_4 remain unchanged when solidified; all the others undergo a certain amount of liquation, causing a different composition at the top to that at the bottom of the ingot, so that in determining the mean specific gravity two experiments must be made—one with a piece from the top portion, and the other with a piece filed off the bottom. In alloys rich in tin expansion takes place, so that the specific gravity is less than the mean of the two metals, down to the proportion CuSn_2 . Alloys rich in copper undergo a contraction which reaches a maximum at SnCu_3 ; therefore, the specific gravity is greater than the mean. The greatest density is found in the alloy SnCu_3 , which is 8.91; even gun metal has only a density of 8.84.

The alloy SnCu_3 is distinguished from all the rest by several characters: it has the same homogeneous con-

position after repeated fusions; is peculiar in colour; has the greatest density, and is very brittle.

The hardness, reckoning from pure tin, increases with the proportion of copper up to CuSn_2 . This and all alloys up to SnCu_5 are very brittle, and from this the hardness diminishes as the proportion of copper increases. It must be understood that the formula given with each does not imply that they are all true chemical compounds.

§ 43B. Exp. 109. Make the bronzes (Exp. 98 and 99) red hot, and cool by plunging into water; prove that the density has increased, and that they are comparatively soft when tested with a file. Repeat the heating, and allow to cool slowly; prove that the density is lowered and that the alloy is harder. It will be observed that this is the opposite of steel under the same conditions. These bronzes readily break when worked at the ordinary temperature; but at temperatures a little below dull redness they may be forged like bar iron, and easily hammered into thin plates. "Alloys containing 88 to 94 per cent. of copper, which are malleable at ordinary temperatures, are not increased in density by slow or sudden cooling."
—A. Riche.

§ 44. *Copper-Zinc Alloys.**

The effect of small quantities of zinc on copper is to render its red colour paler; a larger quantity makes it yellow, the brightest yellow being obtained by the alloy containing equal parts of copper and zinc. Beyond this, when the zinc largely predominates, the colour gets paler; and when the proportions equal the alloy CuZn_3 , the colour is bluish white, resembling impure zinc. With regard to this subject, Karsten makes the following remarks: "In certain proportions the alloy of copper and zinc is more ductile than copper at ordinary temperatures, but generally brittle at a red heat. Very small quantities of zinc do not impair the ductility of copper at ordinary temperatures, excepting that when thus alloyed it sooner becomes hard and brittle by hammering, and therefore requires to be oftener heated to redness; but even 6 per cent. of zinc is sufficient to cause copper to crack when hammered at a red heat. The most ductile of the alloys of copper and zinc are those which contain 84.5 per cent. copper to 15.5 per cent. zinc (tombac), and 71.5 copper to 28.5 zinc (brass). The alloy formed of equal weights of the two metals cracks in rolling. Excess of zinc renders the alloy brittle, the most brittle being Cu_2Zn_3 and CuZn_2 . Small quantities of lead in copper-zinc alloys diminishes the ductility; tin increases their hardness." Brass turns red when rubbed with hydrochloric acid, because zinc is dissolved in preference to copper; but when rubbed with ammonia it turns white, because the ammonia dissolves out the copper.

Exp. 110. Take 906 grains copper, 94 zinc. Place the copper in a clay crucible with a little charcoal, in sufficient quantity to cover the surface when melted;

* Cu=63. Zn=65.

place in a hot fire and melt. Now remove from furnace, and drop in the lump of zinc weighing 94 grains, and quickly mix the contents by stirring with a piece of wood. The crucible is by this means filled with flame and gases from the decomposition of the wood, keeping out the air to a great extent, and diminishing the oxidation of the zinc; then pour the alloy into a rectangular mould; allow to cool, and weigh. The loss of weight may be taken roughly to indicate the loss of zinc. Now calculate the proportion of copper to zinc on the above assumption, i.e., if the metal has been poured clean from the crucible. If the above operation is not very rapidly performed, the metal will solidify and require remelting, in which case more charcoal should be added, but the loss of zinc will be considerable. It would be better in such a case to repeat the experiment. Suppose the alloy as above to weigh 990 grains. Assuming that 990 grains contain 906 grains copper and 84 grains of zinc, 1000 grains will contain:—

$$\frac{906 \times 1000}{990} = 915.1 \text{ copper.}$$

The alloy then contains 91.51 grains copper to 8.49 grains of zinc per cent. Repeat the experiment, adding zinc in excess of the stipulated quantity. The alloy should have a reddish yellow colour when filed, a fracture resembling dry copper, partly granular, partly fibrous; be somewhat tough, and malleable. This may be termed red brass. The proportions given correspond to the formula Cu_{10}Zn .

Exp. 111. Take 829 grains copper and 171 grains zinc. Melt the copper first, and add the zinc with precautions as in Exp. 110. The colour should be yellowish red, with fine fibres running across the fractured surface; it should be malleable, tough, and correspond to the

formula Cu_2Zn . It is known as Princes metal or Bath metal.*

Exp. 112. Take 795 grains copper and 205 grains zinc. Melt copper and add zinc as before. Notice the yellowish red colour and fine fibred fracture, also that it is tough but less malleable than the preceding one. This is the composition of Tombac,* and when hammered into leaves is called Dutch metal. Formula = Cu_4Zn .

Exp. 113. Take 744 grains copper and 256 grains zinc. Melt copper and add zinc. Observe the pale yellow colour, and nature of the fractured surface with fine fibres. It is less tough than the preceding one, but more malleable, easily fusible, and moderately hard, the working qualities being about the same as common brass. It is known as Mosaic gold.* Formula = Cu_3Zn .

Exp. 114. Take 660 grains copper and 340 grains zinc. Melt and add zinc as before. Notice the deep yellow colour, the finely fibrous fracture. This forms English yellow brass. It is very malleable and ductile, moderately soft, tenacious, and melts at a medium temperature. Formula = Cu_2Zn .

Exp. 115. Take 492 grains copper and 508 grains zinc. Melt copper and add zinc as before. Observe the deep yellow colour, coarsely granular fracture, and that it is only moderately tough and malleable in the cold. Very flexible when hot, but not adapted for wire drawing. It is known as German brass.* It is also the composition for hard solder for brazing. Formula = CuZn .

Exp. 116. Take 326 grains copper and 674 grains zinc. Melt copper and add zinc as before. Notice the yellowish

* These names are used for alloys containing various proportions of copper and zinc. For further information see author's work on "Mixed Metals," pp. 90 and 102.

white colour, coarsely granular fracture, its brittleness and low fusing point. It is very tenacious, being far superior in this respect to several of the preceding alloys. It is said to be used by watchmakers. Formula = CuZn_2 .

Exp. 117. Take 353 grains copper and 647 grains zinc. Melt copper and add zinc as before. Notice its white colour, conchoidal vitreous fracture, its great brittleness, hardness, and easy fusibility. This may be termed white brass. Formula = $\text{Cu}_8\text{Zn}_{17}$.

Exp. 118. Take 244 grains copper and 756 grains zinc. Melt and add zinc as before. Notice its bluish white colour, fine grained fracture, brittleness, hardness, and easy fusibility. Formula = CuZn_3 .

§ 45. Besides the alloys of copper with zinc mentioned in the foregoing examples, many other preparations are in general use, thus:—

Muntz metal, formerly largely used for sheathing for ships, as it keeps them cleaner and is less costly than copper sheathing, consists of 600 copper and 400 zinc; but the proportions of copper vary from 56 to 63 per cent. according to the ideas of the manufacturer. In some cases 2 to 3 per cent. of lead is added.

Brass Solder.—Two parts by weight of ordinary brass, with one part of zinc. This corresponds to $44\frac{1}{2}$ parts copper and $55\frac{1}{2}$ parts zinc.

The following table shows the composition of some ancient and modern bell metals containing zinc:—

	Cu.	Sn.	Zn.	Nl.	Fe.
Modern English Bell Metal,	80.0	14.4	5.6	0	0
Darmstadt Chimes (1670),	73.9	21.6	1.2	1.2	2.1
Bells of Rouen, 12th century,	70	26.0	1.8	.6	1.6

Useful Alloys of Copper and Zinc.

	Cu.	Zn.	Sn.	Pb.	Sb.	Fe.
Bronze for Statues, -	91.4	5.53	1.7	1.37		
Brass for gilding, -	82.16	17.48	2.4	1.2		
Do. do., -	80	16.5	2.5			
Sheet brass, -	84.7	15.3				
Gilding metal, -	83	17				
Pinchbeck, -	90	10				
Prince's metal, -	75	25				
Dutch metal, -	80	20				
English wire, -	70	30				
Gun metal, -	90		10			
Muntz metal, -	60	40				
Brass for turning and for machinery, -	65	33		2		
Britannia metal, -	3		90		7	
Brass for ship nails, -	62.82	25.64	2.64	8.89		
Tombac, -	80 to 90	20 to 10				
Bronze colour, pale yellow	83.33	16.66				
„ „ deep „	84.6	15.3				
„ „ orange,	98.9	1.1				
„ „ copper red,	99	1				
„ „ violet,	98.5	1.5				
„ „ yellow,	84.62	15.37				
Aich metal, -	60.0	38				2
Sterro metal, -	58	38	2			2

Exp. 119. Calamine brass is a variety of brass made from calamine, instead of adding zinc direct to the copper.

Take 500 grains of oxide of zinc, 100 grains charcoal, and 330 grains of sheet copper, cut up fine. Place in clay crucible; cover with a layer of charcoal; cover with lid; lute on with clay, and heat very strongly for an hour. Remove from fire; allow to cool; break open the crucible, and examine the button of brass.

§ 46. Other Alloys of Copper.

* *Bronzes*—(a) *Phosphor bronze*. This is an alloy of copper, tin, and phosphorus prepared first by Dr. Künzel of Dresden, although other ingredients are now added. It may be made as ductile as copper and as hard as steel, by varying the proportions of the constituents. It forms a very fluid metal for castings, which are sound and uniform. It is stronger, tougher, and more durable than gun-metal or brass, and does not become crystalline with repeated shocks or bends; hence its use for wire rope. It is less acted on by sea water than copper. This alloy may be made by adding a rich alloy of phosphor tin to the right proportion of copper and tin, or a rich phosphor copper may be used. See Exps. 12a and 17 for the production of this substance. Although no phosphorus may remain in the bronze, it removes the oxygen, and promotes a more intimate mixture of the particles of copper and tin. With too much phosphorus, the alloy becomes very hard and brittle.

(b) *Silicon bronze*. This is a similar alloy to phosphor bronze, the phosphorus being replaced by silicon, which produces an alloy having a much higher conductivity than phosphor bronze, as the presence of phosphorus has a most injurious effect on electrical conductivity. Silicon bronze has great strength and durability, so that with this alloy the wires may be thinner than the ordinary wire, and yet have the same strength. Also when broken they coil up and spring back in consequence of their elasticity, instead of falling to the ground. This alloy may be prepared by strongly heating copper with sand and carbon, then alloying the silicon-copper with the necessary amount of tin. Or take 250 grains of potassium-silico-fluoride, 300 grains of glass, 125 grains of

* See author's work on "Mixed Metals," pp. 192 to 229.

common salt, 40 grains of carbonate of soda, 30 grains of carbonate of lime and 250 grains of dried calcium chloride. Heat in a plumbago crucible until they just begin to act on each other, then add molten copper or bronze as the case may be.

(c) *Manganese bronze.* This alloy is prepared by mixing a small proportion of rich ferro-manganese with copper and tin. The ferro-manganese is melted in a separate crucible and added to the molten copper. In this way the manganese unites with any oxygen in the copper, and rises to the surface as slag, so that its action resembles that of phosphorus; but a little manganese and iron alloy with the copper, which is then used for making alloys with tin and zinc. The toughness, hardness, and strength is thereby increased, which can be modified in different degrees by altering the proportion of ferro-manganese used, so that the amount of manganese can be regulated with great nicety. About four varieties of ferro-manganese are employed, containing 10 to 40 per cent. of manganese. The lower qualities are used for those copper alloys in which zinc exceeds the tin, and the higher qualities for those in which tin alone is used with copper. The amount of ferro-manganese added varies from 2 to 4 per cent. The bronze forms very sound and uniform castings, and is claimed to have the strength, toughness, and hardness of mild steel, without any of its defects. It also offers great resistance to pressure. Manganese bronze may be made by adding 10 per cent. of cupro-manganese to an alloy of 800 parts copper and 100 parts tin. See Exp 23a.

(d) *Delta metal.* This alloy, so named by Mr. Dick, is an alloy of copper, zinc, and iron, having a close analogy to the corresponding manganese bronze, but contains no manganese. Attempts were made some twenty-five years ago to utilise such a combination, but the alloys were

uncertain in their character from the amount of iron being very variable, and Mr. Dick set himself to discover a means of introducing a known and definite quantity of iron in each alloy. He does this by melting iron in zinc, till the latter is saturated, and using this ferro-zinc to alloy with the copper, with or without pure zinc. The alloy is liable to oxidise when re-melting for casting, thus altering the composition; to remedy this a little phosphorus is used in combination with the copper. In some special alloys a little manganese, tin, or lead is added to impart particular properties. Delta metal has a specific gravity of 8.4; is very liquid when melted, producing sound and fine grained castings. The cast metal resists a tensile strain of 20 tons to the square inch. When forged at a dark red heat, its breaking strain is raised to 35 tons, and when hammered cold, it reaches 40 tons to the square inch. It is stated that the iron in the alloy is chemically combined, as the metal does not rust in moist air nor does it affect the magnetic needle. The copper varies from 58 to 63, and the iron from 1 to 3 per cent., and the remainder is zinc.

(e) *Aluminium bronze and Aluminium brass.* This was originally composed of ninety parts copper and ten parts aluminium, and is stated to be a definite compound of the formula Cu_9Al . It has a gold colour; is extremely hard; takes a high polish; has a high tenacity (43 tons to the square inch), and is very malleable.

An addition of 2 to 3 per cent. of brass to aluminium bronze increases its strength, and renders it less susceptible to oxidation.

When the aluminium reaches 19 to 20 per cent. in a copper-aluminium alloy, a brittle compound is produced. Aluminium bronze may be made by melting the two metals together, but the aluminium must be placed at the bottom of the crucible and the metals covered with charcoal, as well as the crucible being covered with a lid,

so as to exclude the air. Other metals, such as zinc, tin, and iron, may be added for special purposes. Aluminium brass is manufactured by adding zinc or brass to aluminium bronze. The composition is between the following limits:—Copper 67 to 71, zinc $31\frac{1}{2}$ to $25\frac{1}{2}$, aluminium $1\frac{1}{4}$ to $3\frac{1}{2}$.

It is sometimes stated as an objection that some kinds of aluminium bronze contain no aluminium; still the small amount of this metal used in its manufacture may have a very beneficial effect on the resulting alloy in the same way as phosphorus has in phosphor-bronze, of which some varieties retain only a mere trace of phosphorus.

§ 47. *Alloys containing Nickel and Cobalt.*

The chief alloys of these metals are those with copper and zinc, known as German silver or nickel silver. The copper and nickel are first melted, then heated zinc is added as in making brass. Or sheet copper and nickel may be cut up small, mixed with zinc; placed in a crucible, covered with charcoal, the lid luted on, and the whole strongly heated together for half an hour; then removed from fire, allowed to cool, and the pot broken to recover the alloy. It has a white colour and crystalline structure, but after careful annealing may be rolled into sheet. When the crystalline structure has once been destroyed, German silver may be worked like brass. It is white like silver, harder, and admits of a fine polish.

(a) Weigh out 600 grains of copper and 80 grains of nickel, place in clay crucible with a little charcoal, cover with a lid and heat very strongly until the whole is melted, then add a lump of zinc weighing 340 grains, and quickly mix the contents by stirring with a piece of wood. (See Exp. 110.) Pour into a rectangular mould, cool, and weigh. Then break the ingot, and observe that

the colour is much paler than brass. Also notice that it is very tough and fairly malleable. It contains 8 per cent. of nickel.

(b) Repeat the previous experiment with 570 parts of copper, 120 parts of nickel, and 325 parts of zinc. Test its malleability and toughness as in previous case. Observe that it is also whiter in colour. It contains 12 per cent. of nickel.

(c) Repeat Experiment (a) with 540 parts of copper, 160 parts of nickel, and 315 parts of zinc. Observe that it is whiter than (b), also very tough and malleable. It contains 16 per cent. of nickel.

(d) Repeat Experiment (a) with 540 grains of copper, 200 grains of nickel, and 270 grains of zinc. Observe that this alloy is still whiter than the last, and that it is malleable and tough. It contains 20 per cent. of nickel.

(e) The following analyses give the composition of some higher qualities of German silver:—

Copper.	Nickel.	Cobalt.	Zinc.	Lead.
50	31	—	19	—
53	27	—	20	—
$48\frac{1}{2}$	$24\frac{1}{2}$	—	24	3
59	22	—	19	—
55	22	—	23	—
60	19	3	18	—

§ 48. Messrs. Wiggin & Co., of Birmingham, have introduced an alloy called "silveroid," consisting of copper, nickel and zinc, with tin, or lead in various proportions, which has great whiteness, closeness of grain, and great tensile strength.

Cobalt bronze is still whiter than silveroid, has a close grain, brilliant lustre, great toughness and tensile strength as well as hardness. It contains, in addition to the above, small quantities of cobalt

§ 49. *Lead Alloys.*

(a) Lead alloys with tin in all proportions, but the specific gravities are less than the mean of the constituents. K pffer investigated this subject with the following results. The symbols represent atomic proportions :—

Alloy.	Specific Gravity.		Melting Point.
	Found.	Calculated.	
SnPb,*	9.426	9.437	241°C.
SnPb ₂	10.078	10.094	—
SnPb ₃	10.387	10.412	239°
SnPb ₄	10.555	10.600	—
Sn ₂ Pb,	8.745	8.752	196°
Sn ₃ Pb,	8.291	8.398	186°
Sn ₄ Pb,	8.173	8.151	189°
Sn ₅ Pb,	8.028	8.037	194°
Pb,	11.380	—	335°
Sn,	7.291	—	230°

* Sn=118 : Pb=207.

The above is also interesting as showing the influence of different proportions on the melting point.

The effect of lead on tin is to harden it, notwithstanding that lead is so soft when alone. The softest alloys of lead and tin are those with excess of lead.

(b) With 750 parts lead and 250 parts tin, the alloy has a rough and dull surface. This may be termed common solder. With equal parts of lead and tin, the surface is brighter. This may be termed medium solder. With 250 parts lead and 750 parts tin, the surface is bright, with a dull longitudinal furrow. This is more fusible than the above, and may be termed best solder.

(c) Lead-tin alloys are largely used for soft soldering by plumbers and others, the composition varying with the work required to be done. Solders may be roughly classified into fine, medium, and common.

In fine solders the tin is in excess as Sn₃Pb, Sn₄Pb, etc. In medium, the proportions are about equal. In common, the lead is greater than the tin. Plumbers' solder consists of 1 part tin to 2 parts lead. For soldering cast iron the alloy of 1 to 1 is used. For fine metal work the best solders are used, viz., those with excess of tin.

(d) In many kinds of work it is necessary to solder a part without over-heating the article, so as not to discolour or fuse it, in which case a very easily melting alloy is required. These are known as "quick" solders or "fusible" alloys, in which bismuth is an important constituent. The alloys in the following table, with their melting points, are those given by Messrs.

Parkes & Martin. The temperatures given are probably too low.

Bismuth, 8 pts.	Lead, 5 pts.	Tin, 3 pts.	Melts at 95°C.
" 8 "	" 6 "	" 3 "	" 98°
" 8 "	" 8 "	" 3 "	" 110°
" 8 "	" 8 "	" 4 "	" 112°
" 8 "	" 8 "	" 6 "	" 116°
" 1 "	" 1 "	" 1 "	" 122°

(e) *Pewter* is an alloy of lead and tin. Common pewter contains 80 parts tin and 20 parts lead; it is also made with equal parts of the two metals. Other metals, as antimony, zinc, and copper, are sometimes added. The finest pewter consists chiefly of tin with only a little lead and copper. The copper is melted, and twice its weight of tin added; then from $\frac{1}{2}$ lb. to 7 lbs. of this alloy are added to 390 lbs. of block tin. A little zinc is sometimes added to purify the alloy and bring the dross to the surface.

§ 50. *Antimony Alloys.*

The effect of antimony on other metals is to harden them and make them brittle. It is also a volatile metal, therefore the atmosphere should be excluded by means of a covering of charcoal while melting antimony or any of its alloys.

(a) 50 parts copper melted in a crucible, then 50 parts of antimony added, produce a very brittle alloy of a violet colour termed "Regulus of Venus."

(b) 50 parts lead, 25 parts tin, 25 parts antimony, produce a hard brittle alloy, with a fine crystalline struc-

ture, used for stereotype and type, and known as type metal.

(c) 80 parts tin, 10 parts copper, 9 parts antimony, and 1 part lead, is a typical mixture for Britannia metal. It is greyish white in colour, with a tendency in one portion of the alloy to liquate out on cooling, producing a partly crystalline and partly granular fracture. It is brittle when cold. These proportions, as well as the metals, are varied by different makers. The following table illustrates this point:—

	a.	b.	c.	d.	e.
Tin, - -	94	90	84	80	75
Antimony, -	5	7	10	10	8.5
Copper, -	1	3	4	9	—
Bismuth, -	—	—	2	—	8
Lead, - -	—	—	—	1	8.5

§ 51. *Silver Alloys.*

(a) The most important alloys of silver are those with copper. The two metals can be melted together in almost any proportion, forming for the most part ductile and malleable alloys, with great hardness and elasticity, and are capable of taking a higher polish than pure silver. The specific gravities of silver-copper alloys are less than the mean of the two metals. The colour is white until the copper exceeds one half. The hardest alloy is stated by Guettier to contain one part silver and two parts copper. Prof. Roberts-Austen has determined the melting points, and states that the alloy containing 630.29 of silver per 1000, and represented by the formula AgCu, has a lower melting point than silver, or than any other alloy of silver and copper. His results are given in the following table, but he has since pointed out that

they are too high, as more recent determinations of the melting point of silver make it 940° C., and that of copper 1050° C.

No.	Pure Silver per 1,000.	Approximate Formula.	Melting Point.
1.	1000	Ag	1040° C.
2.	925	Ag ₇ Cu	931.1°
3.	820.7	Ag ₅ Cu	886.2°
4.	798	Ag ₅ Cu ₂	887°
5.	773.6	Ag ₂ Cu	858.3°
6.	750.3	Ag ₇ Cu ₄	850.4°
7.	718.93	Ag ₃ Cu ₂	870.5°
8.	630.29	AgCu	846.8°
9.	600	Ag ₇ Cu ₈	857°
10.	569.6	Ag ₇ Cu ₉	899.9°
11.	561.1	Ag ₃ Cu ₄	917.6°
12.	540.8	Ag ₂₀ Cu ₂₉	919.8°
13.	500	Ag ₃ Cu ₅	940.8°
14.	497	Ag ₂₅ Cu ₄₃	962.6°
15.	459.4	AgCu ₂	960.8°
16.	250.5	AgCu ₃	1114.1°
17.	Pure Copper.	Cu	1330°

No. 7 is Leval's homogeneous alloy, being uniform in composition, while many others undergo liquation on cooling. No. 8 has the simplest atomic relation and the lowest melting point.

(b) Silver-copper alloys, when cast into a mould and allowed to cool, have a different composition in different parts, the difference being in many cases much greater when rapidly cooled than when slowly cooled; Leval's

alloy being an exception, as its composition is uniform whether rapidly or slowly cooled.

(c) When a silver-copper alloy is heated in a muffle, the latter metal is oxidised in proportion to the amount in the alloy, and affords a rough indication of its composition, by examination of its oxidised surface.

(d) In this country there are two standards, known as the Old and New Standards—

Old, 925 parts Ag and 75 parts Cu, which is the proportion in the present silver coinage, also called sterling silver.

New, 959 parts Ag and 41 parts Cu. This was legalised in 1697, but is very seldom used, not being so durable as the 925 alloy. They are expressed per ounce thus:—

	Old Standard. oz. dwts. grs.	New Standard. oz. dwts. grs.
Fine silver,	0 18 12	0 19 4
Copper,	0 1 12	0 0 20
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	1 0 0	1 0 0

As standard silver may be Hall-marked, it is important that the full amount of precious metal be present, and as commercial fine silver is not absolutely pure, a little more than the above quantity must be used, thus:—

	Old Standard. oz. dwts. grs.	New Standard. oz. dwts. grs.
Fine silver,	0 18 14	0 19 6
Copper,	0 1 10	0 0 18
	<hr/>	<hr/>
	1 0 0	1 0 0

(e) The following list shows the composition of various commercial alloys of silver and copper:—

	oz.	dwt.	grs.	Ag per 1000.		oz.	dwt.	grs.	Ag per 1000.
1. Ag,	0	18	0	= 900	5. Ag,	0	13	12	= 675
Cu,	0	2	0		Cu,	0	6	12	
	1	0	0			1	0	0	
2. Ag,	0	16	0	= 800	6. Ag,	0	13	0	= 650
Cu,	0	4	0		Cu,	0	7	0	
	1	0	0			1	0	0	
3. Ag,	0	15	0	= 750	7. Ag,	0	12	12	= 625
Cu,	0	5	0		Cu,	0	7	12	
	1	0	0			1	0	0	
4. Ag,	0	14	0	= 700	8. Ag,	0	12	0	= 600
Cu,	0	6	0		Cu,	0	8	0	
	1	0	0			1	0	0	

The alloy No. 8 is as low as it is possible to make without a perceptible change of colour, so that if still inferior compositions are desired, other white metals must be added, such as nickel and zinc.

The French had three standards, viz. : 950, 900, and 800 of silver per thousand.

In Germany there are four standards, viz. : 950, 900, 800, and 750 of silver per thousand.

§ 52. *Silver Solders.*—These are silver alloys used for joining the various parts of articles together by fusion.

The solder must, therefore, have a lower melting point than the body to be soldered with it, yet the fusing point of the solder should approach as near as it conveniently can to that of the article, as a more perfect and more tenacious junction may thus be effected.

The hardest solders consist of copper and silver; the next in point of fusibility are those containing a little zinc in addition to the silver and copper, and the easiest consist of copper, silver, and tin; or brass, silver, and tin.

With regard to the alloys of silver and copper given on the previous page, the lower ones may be used as solders for the higher ones, it does not follow that the fusing point becomes lower, as the silver is diminished; for by reference to the table, § 51A, it will be seen that Nos. 6 and 8 have lower fusing points than No. 9. The following compositions are used as solders:—

	1.	2.	3.	4.	5.	6.	7.
Silver, - - -	384	384	360	336	300	300	300
Copper, - - -	84	12	96	108	144	—	—
Zinc, - - -	12	—	24	36	36	—	30
Brass (Cu66½ Zn33½),	—	84	—	—	—	150	150
Tin, - - -	—	—	—	—	—	30	—
	480	480	480	480	480	480	480

In making the above alloys the copper and silver must be melted first, and the zinc added, using the precautions mentioned in making brass.

§ 53. *Gold Alloys.*

Pure gold is a soft metal, which makes it unfit for many industrial purposes, so that it is usually alloyed with other metals to harden it and yet allow it to retain much of its malleability and ductility. The metals most

generally alloyed with gold are silver and copper. Pure gold is described as 24 carat fine; the pound or 1000 parts being divided into 24 carats; and different alloys are spoken of as being so many carats fine, according to the amount of gold present. The British coinage consists of 22 parts gold and 2 parts copper, hence it is 22 carats fine; this proportion is known as standard gold, although the copper may be replaced partially or wholly by silver. It is of the utmost importance that the alloying metals should be as pure as possible, as the small quantities of arsenic, antimony, lead, etc., which are often present in common copper, would entirely destroy the high malleability and ductility of the alloy. Pure gold has a beautiful yellow colour, but small quantities of other metals alter its peculiar tint, so that different coloured alloys may be formed, thus:—18 parts gold and 6 parts copper form a red, 18 parts gold and 6 silver a green, 18 gold and 6 iron blue, 12 gold and 12 silver, a white alloy. Platinum may be substituted for the silver.

18 carat gold is employed for the manufacture of the best kinds of jewellery, being the second English standard. It is hard, malleable, tenacious, and exceedingly ductile. It is composed of 18 parts gold, 3 parts silver, and 3 parts copper, which proportion is found to work better than with copper alone.

15 carat gold consists of 15 parts gold, 3 parts silver, and 6 parts copper. This is a good alloy to work and very durable.

13 carat gold contains 13 parts gold, 3 parts silver, and 8 parts copper.

12 carat gold—containing 12 parts gold, $3\frac{1}{2}$ parts silver, and $8\frac{1}{2}$ parts copper—is called best bright gold, to distinguish it from the higher alloys which admit of being coloured. It is tolerably soft, malleable, and ductile.

10 carat gold possesses properties very similar to the preceding one. It contains 10 parts gold, 4 parts silver, and 10 parts copper.

9 carat gold consists of 9 parts gold, $4\frac{1}{2}$ parts silver, and $10\frac{1}{2}$ parts copper. This is a good, tough, workable alloy, and is almost the lowest proportion of gold which will withstand the action of nitric acid.

The following table shows the proportion of various jewellers' alloys:—

Carat.	Copper.	Silver.	Gold.
23	$\frac{1}{2}$ part	$\frac{1}{2}$ part	23 parts
22	1 "	1 "	22 "
20	2 parts	2 parts	20 "
18	3 "	3 "	18 "
15	6 "	3 "	15 "
13	8 "	3 "	13 "
12	$8\frac{1}{2}$ "	$3\frac{1}{2}$ "	12 "
10	10 "	4 "	10 "
9	$10\frac{1}{2}$ "	$4\frac{1}{2}$ "	9 "
8	$10\frac{1}{2}$ "	$5\frac{1}{2}$ "	8 "
7	9 "	8 "	7 "

In addition to the above, a little brass is added in some cases to make a hard alloy; more than this makes the gold brittle and unworkable.

§ 54. Gold Solders.

The remarks made with respect to silver solders apply also to gold. Many goldsmiths make the solder from the same gold as that of which the article to be soldered is composed, by adding more copper and silver. The following three qualities may be taken as types:—

	Gold.	Silver.	Copper.
Best,	$12\frac{1}{2}$ parts	$4\frac{1}{2}$ parts	3 parts
Medium,	10 "	6 "	4 "
Common,	$8\frac{1}{2}$ "	$6\frac{1}{2}$ "	5 "

§ 55. Amalgams.

Gold and mercury readily unite in several proportions, the amalgam being still white when the proportion is 2

parts gold to 1 part mercury. The combination is more rapid when the metals are in a finely divided state and heated. The pasty amalgam of 2 parts gold and 1 part mercury was formerly much used for gilding, the mercury being afterwards volatilised by heat.

(a) Silver and mercury easily combine to form amalgams of different proportions in the cold, but they unite much more readily when heated. Native amalgams of the following composition have been found— Hg_2Ag_3 ; Hg_3Ag_2 ; Hg_6Ag_2 . The character of silver amalgams varies with the composition and mode of formation. They may be soft, granular, or crystalline. The amalgam used in plating consists of 85 per cent. mercury and 15 per cent. silver.

(b) Tin and mercury form amalgams in the cold, and more readily by pouring mercury into molten tin. A pasty amalgam of these metals is used for silvering mirrors. A bar of tin rubbed round the middle with mercury becomes exceedingly brittle and may be readily broken.

(c) An amalgam of 2 parts tin and 1 part cadmium with excess of mercury is used for stopping teeth. An amalgam made of 1 part gold, 3 parts silver, 2 parts tin, and 6 parts mercury, is used as a cement for teeth.

(d) Zinc used in voltaic batteries is amalgamated with mercury to prevent the action of acid when the circuit is open.

(e) Sodium amalgam is made by triturating the two metals together in a porcelain mortar fitted with a cover, when combination takes place with violence, with the production of heat, light, and a hissing sound. 30 parts mercury to 1 part sodium is moderately hard, with a

crystalline fracture; 60 parts mercury and 1 part sodium is pasty; 128 parts mercury to 1 part sodium is liquid.

Sodium amalgam is very effectual in promoting the amalgamation of gold and silver, in extracting these metals from their ores.

(f) Platinum and mercury do not unite when the former metal is in the compact state, but spongy platinum triturated with mercury and heated forms an amalgam.*

FORMATION OF METALLIC OXIDES.

§ 56. (a) The most important compounds of metals with non-metals are the oxides. Many valuable ores occur in this form, and in most cases it is the easiest combination from which to isolate the metal. When the oxides contain hydrogen they are said to be hydrated, thus: CuO is copper oxide; CuH_2O_2 , copper hydrate or the hydrated oxide of copper. The effect of oxygen is to entirely destroy the metallic character, to form hard and brittle compounds when in the native state, to lower the specific gravity, to raise the melting point, and to reduce the volatility. A few of the oxides, however, are volatile, such as those of arsenic. Most oxides are powerful bases, neutralising acid substances completely and forming neutral compounds.

(b) As a general rule, not without exceptions, the affinity of a metal for oxygen is in inverse ratio to its specific gravity; sodium and potassium being most easily oxidised, while gold and platinum have no tendency to combine with oxygen.

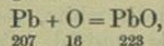
* For fuller information respecting alloys see the author's work on "Mixed Metals," Macmillan & Co, Ltd.

(c) Most metals combine directly with oxygen when heated in air, such as lead, zinc, iron, etc., an operation which is greatly facilitated by a fine state of division; thus when iron is reduced from its oxide by hydrogen gas and the metal brought into contact with air, a spontaneous combustion takes place, reproducing the oxide. Some metals such as sodium have so strong an affinity for oxygen that they require to be preserved in a liquid free from that element. Oxides are often formed by heating in air metallic compounds such as sulphides and arsenides. Many oxides when heated in air take up additional oxygen forming higher oxides; thus litharge (PbO) is converted into red lead (Pb₃O₄). Oxides are also formed from the decomposition of carbonates, most of which are decomposed at a red heat (as in burning limestone to form quicklime), or from the reduction of the nitrate by heat. Many metals decompose steam at a red heat, forming oxides. Lower oxides are sometimes formed from the higher ones, thus the red oxide of copper (Cu₂O) is formed by fusing together the black oxide (CuO) and metallic copper; the tetroxide of manganese (Mn₃O₄) by heating strongly the black oxide (MnO₂). The symbol for oxygen is O, and its atomic weight 16.

(d) Some oxides are built up on the H₂O type; as K₂O, Na₂O, Cu₂O, etc. Others contain an equal number of atoms of the element; as CuO, PbO, etc. Others contain double as many atoms of oxygen as the metal; as PbO₂, MnO₂, and SnO₂, generally called peroxides. In some cases the ratio is as 2:3; as Fe₂O₃, Al₂O₃, etc., called sesquioxides. In others, as 3:4; as Mn₃O₄, Fe₃O₄, Pb₃O₄, etc., called tetroxides. Some have a ratio as 2:5; as Sb₂O₅, As₂O₅, Bi₂O₅, etc. In a few cases the ratio is as 1:3; as CrO₃.

Exp. 120. Weigh 1000 grains of lead, place in a fat fire-clay vessel known as a roasting dish (Fig. 40), and

heat in a muffle, or over a good Bunsen burner, until melted, keeping the temperature low. A film of oxide soon forms, which may be scraped to one side by means of an iron rod flattened at the end, and turned up at right angles. This process is to be repeated until the whole is oxidised. Then raise the temperature, or push the dish further into the muffle, and press the mass in order to squeeze out any lead mechanically mixed with the oxide, which will soon become oxidised; remove from muffle; allow to cool, and weigh. The following shows the mode of calculation:—



taking 207 as the atomic weight of lead, and 16 that of oxygen; then by the equation, 207 parts by weight of lead unite with 16 parts by weight of oxygen to produce 223 parts by weight of lead oxide; therefore 1000 grains of lead will produce $\frac{1000 \times 223}{207} = 1077.3$ grains of lead oxide.

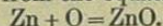
$$207 : 1000 :: 223 : 1077.3.$$

Great care is required in conducting the above experiment not to work with too high a temperature, or the oxide will fuse and unite with the silicate of which the dish is composed, so that some of the oxide will be lost, while a great part of the remainder will stick to the receptacle, so that it becomes impossible to remove it. In such a case the operation must be commenced again with fresh lead in a new dish. A safer plan, but one taking much longer time, is to heat the dish placed on a tripod stand over a Bunsen burner. The oxide produced in this way, by any one but an experienced workman, is generally much better and freer from lead than when a muffle is used. This oxide should be yellow. The experiment may also be conducted in an iron dish, heated by a circular burner.

Exp. 121. Take 500 grains of tin, place in a roasting dish, and oxidise in a muffle until the whole is converted

into white tin oxide (SnO_2). This operation is much easier than the last and more rapid, because oxide of tin is practically infusible, so that a higher temperature may be employed, and the action completed in half an hour; the lead requiring three or four times as long. Weigh and calculate as before:— $\text{Sn} + \text{O}_2 = \text{SnO}_2$.

Exp. 122. Take 1000 grains of zinc, place in dish, and oxidise as before. A low temperature must be used in this case, as metallic zinc is volatile, although the oxide is not so, neither does it fuse and unite with the fire-clay dish. Zinc oxide is white, very light and bulky, so that a large dish is required. Calculate the possible theoretical quantity from the equation—

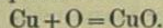


Exp. 123. Take 500 grains of antimony, melt and oxidise as before. This experiment requires the greatest care to obtain anything like an approximate result, the metal being very volatile, and requiring a higher temperature to melt it, so that the temperature must be kept very near the melting point, or very little oxide will be left. The following equation shows the change:— $\text{Sb}_2 + 3\text{O} = \text{Sb}_2\text{O}_3$.

This experiment may be performed, in a crucible partly covered with a lid, to show the nature of antimony oxide; it is white in colour, resembling zinc oxide (ZnO).

Exp. 124. Take a strip of copper, place in muffle on a roasting dish, and heat strongly for half an hour; remove, allow to cool, and examine. Notice that it is covered with a black scale; then peel off this film, and notice that it is red underneath on the side which was in contact with the copper. The greater part of the scale is red oxide (Cu_2O), and only the thin outside film which was freely in contact with the atmosphere consists of

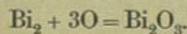
black oxide (CuO). Continue the oxidation until the whole strip, when broken, is brittle, and consists entirely of oxide, no trace of copper being left. If the strip of copper be weighed before commencing the experiment, then after its complete oxidation the residue may be taken to be CuO , and its theoretical amount may be computed from the following equation:—



Exp. 125. The red oxide of copper may also be prepared in a crucible thus: Take 200 grains of sheet copper cut up very fine, and add sufficient of the black oxide of copper to give the following reaction:— $\text{CuO} + \text{Cu} = \text{Cu}_2\text{O}$.

In conducting this experiment, care must be taken to select a proper crucible, as the red oxide has a great affinity for silicates, especially those in which the silica predominates. Morgan's small "London Round" is very suitable. The crucible, after adding the mixture, should be placed well down in a hot fire, loosely covered with a piece of coke, and the furnace well closed to exclude air as much as possible. In about ten to fifteen minutes the coke should be quickly removed from the top of the crucible, and the finishing stage watched through the space between the two bricks which cover the furnace. As soon as all action ceases, remove from fire, and pour into a round mould. If left after the action is completed, the oxide immediately acts on the crucible, and in a short time will permeate the bottom or sides. The possible quantity obtainable may also be calculated from the above equation.

Exp. 126. Melt 100 grains of bismuth; keep the temperature low, and scrape the surface as fast as the yellow trioxide forms. Weigh the product when cool. The following equation will indicate the possible amount to be obtained:—



Melt the oxide in a small crucible; pour into a round mould, and examine the colour and structure.

REDUCTION.

§ 57. (a) For metallurgical purposes the only reducing agents which play any conspicuous part are carbon and hydrogen, either alone or in combination; but in some instances the common metals, such as iron, manganese, and lead, as well as sulphides and arsenides, are employed.

Carbon is capable of removing $\frac{1}{3}$ rd or $\frac{2}{3}$ rd its weight of oxygen respectively, according to the kind of oxide it is mixed with, and the temperature employed for the reduction. In the first case CO is formed, and in the second case CO₂. The former gas is a reducing agent, whilst the latter is oxidising, so that in the case of oxidisable metals like iron, total reduction is impossible, unless the CO is in excess. Thus: suppose the two gases to exist in equal volumes in the presence of Fe₂O₃, this oxide cannot be reduced below FeO, in consequence of the opposing action of the two gases.

(b) In all cases where a high temperature is employed to reduce solid matter by carbon, it is most probable that the reduction is effected chiefly by carbonic oxide, which can easily penetrate the pores and fissures to the very centre of each fragment. Moreover, the reduction of oxides, the metals of which have an affinity for carbon, such as iron, nickel, cobalt, etc., is greatly facilitated by the double decomposition which the CO undergoes. The oxide is reduced thus—FeO + CO = Fe + CO₂; then the separated iron reacts on more oxide of carbon, thus—Fe + 2CO = CO₂ + C; which carbon unites with the iron.

(c) When hydrogen acts as a reducing agent for metallic oxides, steam is formed, which is a more powerful oxidiser than CO₂, so that reduction is impossible, unless the hydrogen is present in large excess, and a constant stream of gas maintained to carry away the steam as fast as it is produced.

§ 58. Reduction of Oxides.

Exp. 127. Weigh out 500 grains of oxide of lead (litharge) and mix with sufficient carbon to reduce it, calculated from the equation— $2\text{PbO} + \text{C} = \text{CO}_2 + \text{Pb}_2$.*

In determining the amount of carbon required to reduce a metallic oxide, it will be necessary to know whether the carbon is completely oxidised, forming carbonic acid, or partially oxidised, forming carbonic oxide, which depends on the temperature at which the reduction is effected. At a low temperature carbonic acid is produced, as in the above case; but at a high temperature the carbonic acid combines with solid carbon, forming carbonic oxide, thus— $\text{CO}_2 + \text{C} = 2\text{CO}$. Now if in the present case carbonic oxide was formed in reducing oxide of lead, double the quantity of carbon would be required thus— $2\text{PbO} + 2\text{C} = 2\text{CO} + \text{Pb}_2$.

That this is not so, will be illustrated by the next experiment. Having calculated the right amount of carbon to add to 500 grains of litharge, either in form of powdered charcoal, coke, or anthracite; thoroughly mix the oxide and reducing agent on a sheet of glazed paper; carefully brush the whole into a clay crucible (Fig. 35b); heat at a low temperature for seven to ten minutes, and pour into a round mould as soon as all action ceases, otherwise a silicate will be formed, and the lead button will be short in weight.—As 446 : 500 :: 414 : x = Pb.

* Pb = 207 : O = 16 : C = 12.