

## GOLD, SILVER, LEAD AND MERCURY

## SYNOPSIS

*Ores:* Native gold · Silver · Galena · Cinnabar. *Mining and Extraction:* Panning · Smelting. *Refining:* Amalgamation · Cupellation · Pattison's process · Liqutation · Conversion to silver chloride or sulphide · Gold refining · Silver refining. *Alloys:* Gold · Carat · Touchstone · Sterling silver · Pewter. *Working:* Gold leaf · Filigree · Granulation · Solders · Pickling. *Gilding and Silvering:* Leaf-gilding · Amalgam-gilding · Silvering.

## ORES

UNLIKE THE OTHER metals worked in antiquity, gold occurs more commonly as the native metal than as an ore, and in early periods the native metal appears to have been the only source of gold known. The metal is found either as veins in quartz rocks or in sediments, known as *placer* deposits, derived from the weathering of these rocks. In these, the gold may be present either in the form of *nuggets*, or more finely divided as *gold dust*, in which case its recovery depends upon the possibility of separating it from the sand particles.

By contrast native silver, in the Old World at least, does not appear to have been an important source of the metal. Native silver, furthermore, generally contains a fairly high proportion of alloyed copper. Silver does, however, occur with gold in the natural alloy *electrum*, from which it can be separated. There is little evidence that the common ores of silver, *horn silver* (silver chloride,  $\text{AgCl}$ ), *silver glance* (silver sulphide,  $\text{Ag}_2\text{S}$ ), *ruby silver* (silver antimony sulphide,  $3\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$ ) or *silver copper glance* ( $\text{Ag}_2\text{S} \cdot \text{Cu}_2\text{S}$ ) were smelted in antiquity and apart from native silver and *electrum* the principal source appears to have been the lead ore *galena* (lead sulphide,  $\text{PbS}$ ) in which small quantities of silver sulphide are almost invariably present.

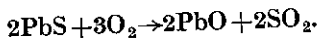
Galena was, equally, the principal source of lead in antiquity. Other lead ores such as *cerussite* (lead carbonate,  $\text{PbCO}_3$ ) and *anglesite* (lead sulphate,  $\text{PbSO}_4$ ) may have been worked, but were relatively unimportant.

Mercury occurs native in small quantities, normally with copper, zinc and lead as impurities; but the chief source was the sulphide ore, *cinnabar* ( $\text{HgS}$ ) which was sometimes found mixed with the chloride, *calomel* ( $\text{Hg}_2\text{Cl}_2$ ).

## MINING AND EXTRACTION

The simplest, although the most tedious, method of recovering the metallic content of gold-bearing sands was by *panning*, in which some of the sand was placed in a shallow dish with water and made to swirl around by a rotary movement of the hands in such a way that the lighter quartz and other rock particles were brought to the edge of the pan and allowed to slop over the edge, while the heavier gold particles remained in the bottom of the dish. Slightly more advanced were water-driven rocking devices, usually wooden troughs moved by an eccentric wheel, which performed the same function. Alternatively the gold-bearing sand might be washed down a long wooden trough in which the heavier gold particles would settle, and which often also contained some material to which the smaller particles of gold might adhere; hides, cloth, fleece and branches of the prickly rosemary bush have all been used for this purpose. Fundamentally the same methods were also used for recovering mined gold, especially where the veins were thin, the gold-bearing quartz being crushed to a small particle size and then washed to recover the gold, the crushing being done either by hand-operated equipment or by water-driven stamping machinery.

Galena was generally crushed and roasted before smelting to convert the sulphide to lead oxide:



The oxide was then smelted under reducing conditions, the lead, having a low melting point, being tapped off from the furnace. On the other hand, cinnabar could be smelted directly, the mercury having a very low boiling point (357°C.) and vaporizing during the process. The liquid metal could be collected by allowing it to condense on a cool surface, as for example a jar filled with cold water, from which it could be scraped.

## REFINING

Before discussing the refining of gold and silver it will be necessary to describe four simple chemical processes that may have been involved in the refining methods:

(1) Mercury very readily forms alloys, called *amalgams*, with a number of metals including gold, silver and copper. For example, the copper amalgam that is soft when first mixed and later sets hard was at one time used for stopping teeth in dentistry. When an amalgam is heated most of the mercury is given off, because of its low boiling point, leaving behind only the metal with which it was amalgamated. The mercury, of course, can be recovered by allowing the vapourized metal to condense on a cold surface.

(2) Some metals, for example copper and lead, oxidize readily when heated in an ample supply of air, and the oxides may either be carried away by the draught or be absorbed by the crucible in which they are heated, or by some other porous material such as clay, brick dust or bone ash, while the noble metals, gold and silver, remain unoxidized. Porous

crucibles designed for this purpose are called *cupels* and the whole process is referred to as *cupellation*. Even so, cupellation was not always a crucible process, and furnaces were designed for the purpose, usually with a thick bed of bone ash to absorb the oxides being formed.

(3) When an alloy of lead with silver is melted and then allowed to cool pure lead tends to crystallize before the bulk of the alloy, and at this stage the still fluid alloy may be decanted. If this process is repeated many times, the decanted material will become progressively richer in metals other than lead. This method of enriching a lead alloy is now known as *Pattinson's process*, named after the nineteenth-century metallurgist. To what extent the process was practised before this is frankly unknown; but the method should not be confused with that of *liquation* in which a metal may be separated from others, or extraneous matter, by virtue of its lower melting point. Gold, for example, could have been separated from quartz rock simply by heating until the molten gold ran free, leaving the quartz unaltered.

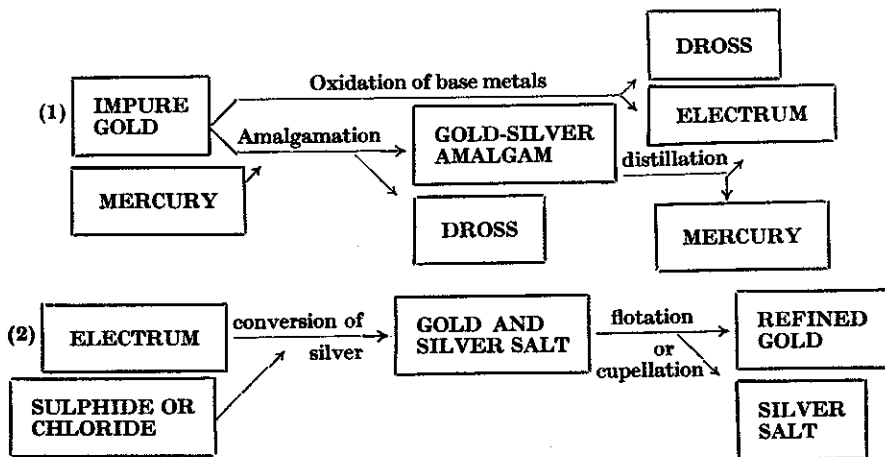
(4) While silver is not easily converted into an oxide by heating in a current of air, it is readily turned into a chloride or into a sulphide by heating with the appropriate salts of other metals. Thus, if silver is heated with common salt (sodium chloride) silver chloride is formed; while if it is very gently heated with a sulphide, as for example stibnium (antimony sulphide), silver sulphide is produced. Although in modern chemical terminology both these processes may be referred to as oxidations, it will be less confusing if they are here called conversions to sulphide or chloride.

Native gold is seldom found even in a moderately pure state, but is normally an alloy of gold with copper or silver, or both, as well as traces of other metals. The refining of gold thus often demanded two separate stages; in the first, the copper and other base metals were removed to provide an electrum; and in the second the gold-silver alloy was treated to remove the silver. The first stage might be achieved simply by melting the alloy in an ample air supply, the copper oxide and other base metal oxides formed during heating being removed as dross or simply blown away in the current of air. Again, some of the base metals might first be removed by amalgamating the crude gold with mercury, the base metals not being taken up by the mercury as readily as gold and silver. The more or less pure gold-silver amalgam was then heated to drive off the mercury.

The silver could be removed from the electrum by converting the silver to either the sulphide or the chloride. Both these compounds could be removed by flotation in a stream of water, neither being appreciably soluble in water. More efficient than washing by flotation was further cupellation in which these silver compounds were absorbed by the cupel.

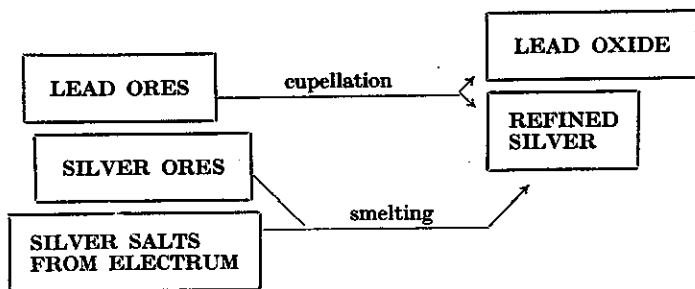
The two stages of gold refining may be summarized as on page 94.

Both these stages could, however, be carried out in one process. Thus, if gold were heated with common salt and charcoal in a closed cupel, the silver would first be converted into the chloride, and if, after this, air were blown into the cupel, the silver chloride and oxides of other metals would be absorbed by it, leaving only the pure gold.



The refining of silver must clearly depend upon the source of the metal. Silver may be obtained from lead ores either by the use of Pattison's process, followed by cupellation, or directly by cupellation; the silver salts absorbed by the cupel during the refining of gold from electrum could readily be reduced to the metal by smelting, and silver-lead ores might equally be smelted to provide crude silver. This, in turn, would require refining by cupellation.

The stages in the refining of silver may be summarized:



### GOLD, SILVER AND LEAD ALLOYS

Pure gold is rather too soft for most practical purposes and for making jewellery it was generally alloyed either with copper or silver, or with both; the silver tending to make the metal white, and the copper reddening it. Today, the proportion of gold in an alloy is indicated in carats, a *carat* being a twenty-fourth part of the metal. The disadvantage of using this system when referring to ancient gold alloys is that it takes no cognizance of the other alloyed metals. Hence, eighteen carat gold, apart from eighteen parts of gold, might contain varying proportions of silver and copper—six parts of silver, six parts of copper, or a balance of the two to make six parts. For this reason it is preferable when referring to gold alloys from antiquity to state the metals present as a percentage of the whole.

The purity of gold could be estimated by measuring its specific gravity, gold having a higher specific weight than either silver or copper, but this was often difficult to do, and *assaying* was more commonly done with the help of *touchstones*. These were made of extremely hard, fine-grained stone against which the gold was lightly rubbed, the colour of the streak giving an indication of the nature of the alloy by comparison with streaks made on the same stone from needles of gold having a known composition.

As with gold, pure silver is too soft for most purposes and the metal was commonly alloyed with copper. *Standard English (sterling)* silver contains a maximum of 7.5% alloying metals other than silver, but here again it is always preferable to state the percentage of alloyed metals when speaking of ancient silver.

For many functions lead was used unalloyed, its softness often being an advantage as, for example, when used as a roof covering, for lining water conduits or as lead piping. The use of lead as an ingredient of ternary bronzes (p. 69) and of soft solder (p. 76) has already been mentioned, but the metal was also alloyed with tin to provide *pewter*. The alloy normally contained about 80% tin and 20% lead, although the composition varied considerably, and some silver might be included in the alloy. The merit of the material lay, of course, in its relative cheapness, its resistance to corrosion and its strength compared with other materials used for making vessels, dishes and so on. Modern pewter, it should be noted, has a quite different composition, being made of an alloy of tin and antimony with a very small percentage of copper. Lead is excluded because its salts are cumulative poisons.

### WORKING OF GOLD AND SILVER

Gold is exceptionally malleable, and can be beaten into very thin *leaf* without the need to anneal. While the metal is being reduced in thickness a stage is reached when it is no longer possible to beat the metal directly and in antiquity the final beating to produce leaf metal was carried out with the gold interleaved between sheets of thin leather or vellum, which might be piled into a pack in the final beating.

The malleability of gold makes it an easy metal to work, and equally allows exceptionally delicate shaping. Apart from shaping by hammering and piercing, however, much ancient gold jewellery was produced by soldering gold wire (*filigree*) or by soldering small spherical drops of the metal on to a backing (*granulation*). The wire used in filigree work might either be plain or vary in section or thickness throughout its length, wires of different section usually being made by drawing through draw-plates with perforations of various shapes; while wires of varying thickness, as for example beaded wires, were prepared in specially designed swages. Granules of gold were presumably made by melting the metal and pouring it slowly into cold water, the droplets afterwards being sorted for size, probably by sieving, or by cutting short lengths of wire and heating until a drop formed.

The solder used in this kind of work was normally a gold-copper alloy, the eutectic proportions being 18% copper to 82% gold, giving a melting

point of 878°C., which is 185°C. below that of pure gold. Gold solder might be prepared before use and applied by the normal methods (p. 76), or the alloying might be carried out on the surface of the gold. One such process, which was re-discovered and patented in this century, employs an animal or vegetable adhesive mixed with a copper compound. The mixture was used to stick each granule exactly in position and was then heated with a blow-pipe. The adhesive first decomposed to give free carbon and as the temperature was raised this in turn promoted the reduction of the copper compound to metallic copper. Finally, the copper in contact with the gold surfaces became alloyed with the gold to provide a gold-copper solder.

Silver is not as malleable as gold and after prolonged hammering requires annealing. It was thus not practicable to produce silver leaf, although the other methods applied to gold working were employed in the making of silver jewellery. The normal solder was a silver-copper alloy, the eutectic being 71.5 % silver and 28.5 % copper, giving a melting point of 779°C., which is 181°C. below that of pure silver. Both the methods of soldering described for gold were apparently used.

The appearance of both gold and silver alloys could, in the final stages, be 'improved' by *pickling* (Fr. *mise-en-couleur*). Copper oxides are soluble in a number of acids and if the completed object were heated in air to form a thin film of oxides and then treated with an acid the copper at the surface could be removed, to give the impression that the metal had a higher gold or silver content than it indeed had. The surface enrichment of gold alloys could also be carried out by removing the silver as well as copper. Hence, if the object were heated in a mixture of common salt and brick dust, the copper and silver would have been converted to the chlorides by the salt and these compounds would have been absorbed, as in cupellation, by the brick dust.

### GILDING AND SILVERING

The surface of many objects may be covered with gold leaf no matter what they are made of—wood, ivory, metal—using a suitable adhesive, such as size (p. 163), to hold the leaf in place. This process is perhaps better described as *leaf-gilding* than as gilding when applied to metal objects, since the gold is not in contact with the underlying metal, as is the case with other forms of gilding.

True gilding was most commonly applied to copper or its alloys. In *amalgam-gilding* one of two procedures might be followed. The gold might first be mixed with mercury to form an amalgam, and this was applied to the surface of the object, following which the whole was heated to expel the mercury. Alternatively, a copper or bronze object might be treated with mercury to form a copper amalgam on the surface to which gold leaf was applied, the whole again being heated to get rid of the mercury.

An alternative system of gilding has been suggested in which a copper object was supposedly first flushed with gold solder, and afterwards pickled to remove the surface copper from the solder. To what extent this was practised is a matter of conjecture.

*Silvering* was carried out by similar means. Clean copper or bronze might be rubbed with mercury to produce an amalgam and to this was applied silver amalgam, the whole being heated to remove the mercury. Alternatively the surface might be flushed with silver solder and then pickled to remove the copper.

The use of dipping solutions for gilding and silvering in which one of the noble metals as a salt in solution replaces the baser metal on the surface of the object, because of the lack of chemical reagents capable of dissolving the noble metals, appears to have been unknown in antiquity, as too, of course, was the practice of electro-plating. Sheffield plating, in which copper is sandwiched between sheets of silver and rolled hot to form a weld, is equally a relatively recent technique, demanding fairly elaborate equipment.

Apart from pickling, one other deception was practised on silver objects in antiquity. If the surface of silver was smeared with arsenious sulphide (orpiment) and heated, the surface appeared to be gilded due to the formation of a thin layer of silver sulphide.

TABLE OF MELTING AND BOILING POINTS OF SOME METALS AND ALLOYS OF ANTIQUITY

°C.	
183	Lead solder melts (lead 38%; tin 62%).
232	Pure tin melts.
327	Pure lead melts.
357	Mercury boils.
420	Pure zinc melts.
779	Silver solder melts (copper 28.5%; silver 71.5%).
878	Gold solder melts (copper 18%; gold 82%).
907	Zinc boils.
960	Pure silver melts.
1,000	12% tin bronze melts.
1,063	Pure gold melts.
1,083	Pure copper melts.
1,150	Lead boils.
1,525	Pure iron melts.