The Oldest Metallurgical Handbook

RECIPES OF A FOURTH CENTURY GOLDSMITH

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While the metallurgy of gold was undoubtedly the first to be practised by early man—its natural occurrence, its ease of working and its permanence have combined to leave us many hundreds of excellent examples of his craftsmanship—a great deal of our understanding of his technology has naturally had to be built up from careful examination of these archaeological finds rather than upon any written records.

Of the earlier civilisations nothing, of course, remains in documentary form and the earliest records we have that bear upon the mining and metallurgy of metals—brief and often inconsistent or even misleading—are to be found in occasional passages in the works of Pliny, Dioscorides, Theophrastus, Vitruvius and one or two other writers whose work has survived from the last few centuries B.C. and the first century A.D.

There is, however, one surviving document that is of considerable importance to metallurgists and to those interested in the working of gold and its alloys. This is known as the Leyden Papyrus X from its present location in the Museum of Antiquities in the Netherlands. Unlike the works of the classical authors, this displays an intimate practical knowledge and experience of what is described.

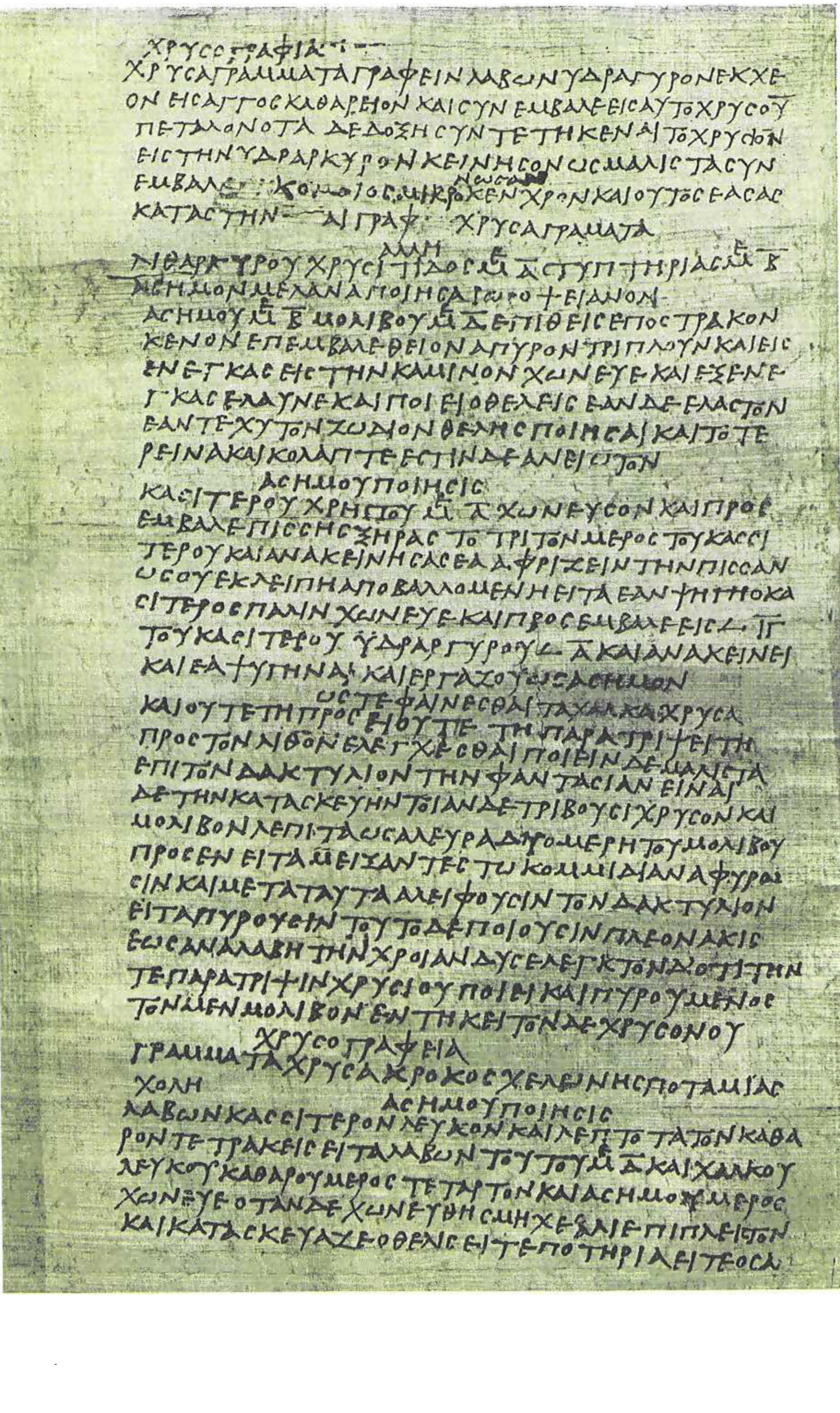
Early in the nineteenth century an Arab sold a number of papyri he had "found"—or most probably robbed from a tomb—to Giovanni Anastasi, a successful merchant in Alexandria, Consul-General for Norway and Sweden in Egypt, and an ardent collector and dealer in Egyptian antiquities. In 1828 Anastasi sold part of his collection of papyri to the Dutch government and on his death in 1857 bequeathed others to the Swedish government. The latter, the so-called Stockholm papyri, have to do mainly with precious and semi-precious stones and dyestuffs, but the Leyden collection includes one that is obviously the working note-book of a goldsmith and jeweller.

This remained unknown until in 1885 a full text with translation into Latin was published by the Director of the Leyden Museum, Conradus Leemans (1), who gave each individual papyrus an identifying letter from A to Z. It was then realised that in Papyrus X an important metallurgical and chemical text had been preserved for us. A French translation of this, with a lengthy commentary, was made available in 1887 by the well known chemist Marcellin Berthelot with the help of a philologist, Charles Rouelle, in their compilation of ancient alchemical texts (2). In 1913 a commentary in German was published by the distinguished historian Professor von Lippmann (3), while in 1926 an English version was produced by Earle Radcliffe Caley (4) who combined the skills of a professional chemist and an historian. (He later became a professor of chemistry at Princeton.) In the present paper some amendments to these translations have been made.

Written in Greek—which had been the official language of Egypt since the time of Alexander the Great—this papyrus shows clearly that the writer was no literary man. Although the writing is clear and fairly good, there are apparently errors of grammar and of spelling. Many of the recipes given are in abbreviated or incomplete form, but they would be understandable enough to aid the memory of the writer or to be read by a fellow workman or successor. They are put together in a haphazard manner, with quite a deal of repetition of similar recipes, and the whole work is reminiscent of the many collections of working formulae assembled by master craftsmen in Europe during the nineteenth century and handed down from father to son.

One of the sixteen pages of the Leyden Papyrus X found at Thebes in Egypt and now in the Museum of Antiquities at Leyden in the Netherlands. Written in Greek capital letters in the early part of the fourth century A.D., it is exceptionally well preserved and includes a number of recipes, some copied from even older works, for the refining, testing, alloying and soldering of gold, for gilding silver and other metals, and for the preparation of base metal alloys. This is the most ancient account that we possess of the techniques of working with gold and the few other metals that were known at that time

Photograph by courtesy of Dr Hans Schneider



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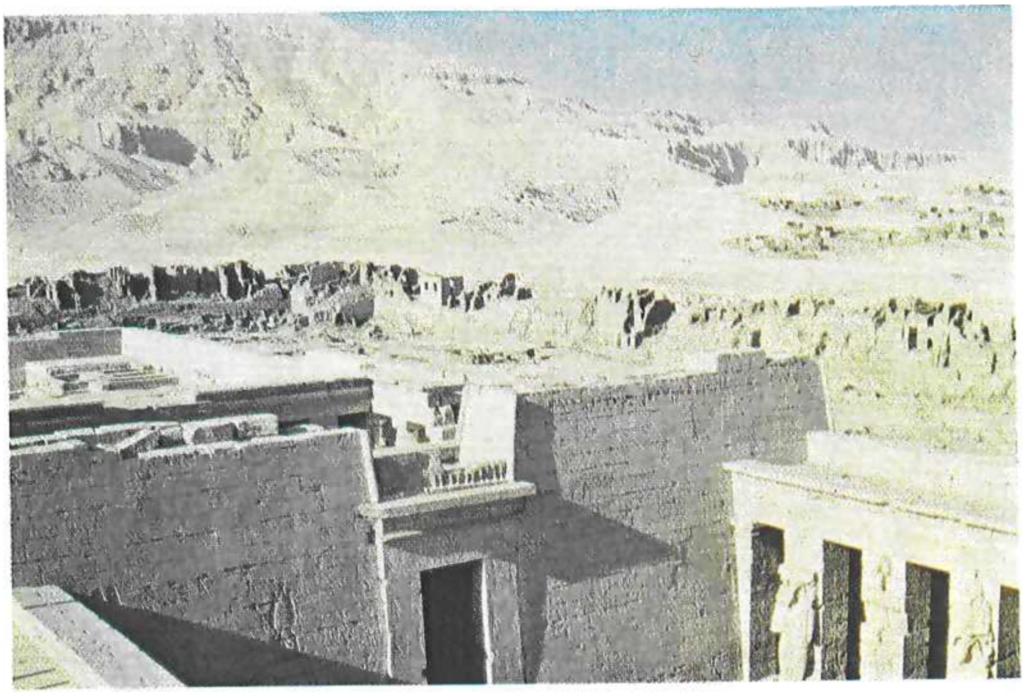


In the Roman period workmen's houses were built in Thebes in and alongside the ruins of the ancient Egyptian temples, and a cemetery used from the third to the fifth centuries A.D. has been discovered near by. This shows part of the Temple of Rameses III, built in about 1200 B.C., with the scattered remains of Roman buildings lying between the temple itself and the ancient outer wall of the temple enclosure. It was in surroundings of this kind that our master goldsmith lived and worked and was finally buried together with his metallurgical note-book

Photograph by T. G. H. James

There are in all some 111 recipes, most of them concerning metals and alloys; of these 34 deal with the various operations involving gold—its refining and testing, alloying it with copper, zinc and iron to produce what we would today call carat golds, the preparation of gold solders, the gilding of silver and base metals, and the production of gold inks for writing on manuscripts or other materials.

Interpretation and Dating of the Papyrus

These recipes include a few that can be shown to stem from an even older source, a first-century work called *Physica et Mystica* (5) compiled by an unknown author, falsely making use of the honoured name of Democritus, the Greek Philosopher who flourished around 400 B.C. and who was an early proponent of atomic theory. This pseudo-Democritus included in his treatise chapters on magic, on dyeing, and on the making of imitation gold and silver, his recipes being collected from a number of sources throughout the Near East. Some of the recipes are virtually identical with those of the Leyden papyrus, although they are much less succinct and are confused to some extent with mystical digressions. The last ten recipes, dealing with the minerals mentioned in the main body of the papyrus, are in fact short extracts from the *De Materia Medica* compiled by Pedacius Dioscorides, also in the first century A.D. (6).

Interpretations of the Leyden Papyrus X at one time tended to regard it as an alchemical treatise; one distinguished scholar even went so far as to write: "Closer examination of the recipes, however, has shown that they could not yield any practical results, and it may therefore be that they were snippets collected by an alchemist" (7). That it was in fact a practical compilation of the techniques of the time, completely down to earth and free from alchemical mysticism or speculation, is evident from an informed reading of the recipes, as was first pointed out by the Danish scholar Madame Ingeborg Hammer-Jensen in 1916 (8).

The papyrus was formerly ascribed to the third century B.C., but modern authorities on papyrology consider it to have been written in the early years of the fourth century—somewhere around 325 A.D.—and before we come to the recipes themselves it is perhaps worth while to dwell for a moment on the living and working conditions in Egypt—and particularly in Thebes—at around this time.

Since the deaths of Cleopatra and Antony in 30 B.C., Egypt had, of course, been a mere province of the Roman Empire. The splendour and the glory of

Thebes and of the Pharaohs who ruled there fifteen hundred or two thousand years earlier had long since departed, and with them the masterly skills of the craftsmen who produced the marvellous jewellery and other objects in gold that are familiar to us from the treasure of Tutankhamun. By the first century B.C., Thebes—once a major and powerful city of a hundred thousand inhabitants—had been virtually destroyed and reduced to scattered groups of habitations huddled among the ruins of the deserted but still magnificant temples. Strabo, visiting Thebes in about 25 B.C., wrote that "even now traces of its magnitude are pointed out, and there are several temples, but most of these too were mutilated by Cambyses, and now it is a collection of villages, partly on the eastern side of the Nile and a part on the far side of the river".

In the Roman period some rebuilding was undertaken, as well as some repairing of the temples, and recent excavations have disclosed many workmen's houses in the Christian townships that grew up in and around the temples, while a Roman cemetery has also been located close by that was in use from the mid-third to the fifth centuries (9). It was quite possibly from here that the papyri were taken.

Economic Conditions and Revolts in Roman Egypt

By this time Egypt as a whole was in a grievous state under its Roman rulers. Oppressive taxation—including a tribute in gold which the Egyptians had to purchase from the government at prices fixed by them—together with devaluation of the coinage and acute inflation had greatly impoverished the people; most of the gold had been drained away from the country, and production from the mines had declined.

A major revolt—and not the first—had occurred in 296, and the Emperor Diocletian came to Alexandria to suppress it. He then embarked on a massive programme of reorganisation and reform, but this at best served only to check the downward course of the country's economy for a time. Thus there was not available a great volume of purchasing power to support working goldsmiths, and although some good class jewellery was still called for by those able to afford it, more particularly in Alexandria, the major demand was for cheaper or imitation jewellery, as will be evident from many of the recipes.

In these recipes there are constant references to "asem". This term, ασημος in the original Greek, was for long thought to refer to an alloy which the Greeks called *elektron* and the Romans *electrum*—the naturally occurring alloy of gold and silver. More recently, however, Robert Halleux (10) has shown that it was used to describe virtually any white alloy made wholly of base metals that could be used for imitation jewellery.

Writers on the history of chemistry have often referred to the author of this papyrus as "a fraudulent goldsmith". This is possibly true in part, but let us also remember that many alloys such as ormolu, pinchbeck and German silver devised by nineteenth century metal workers acquired a considerable usefulness without any suggestion of deceit attaching to them.

The Recipes

Let us now look at a few of the actual recipes in detail and in the light of modern knowledge of the refining, alloying and working of gold. (There are, of course, many other recipes for alloys of copper, tin, zinc, and so on which are outside the scope of the present discussion.)

> *Treatment of Gold*
>
> ***For treating gold, or for thoroughly purifying it and making it brilliant. Misy 4 parts; alum 4 parts; salt 4 parts. Grind with water and having coated the gold with it place in an earthenware vessel put in a furnace and luted with clay and heat until these substances have become molten, then withdraw it and scour carefully.***

This mixture of iron or copper pyrites (or their oxidation products), alum and salt would, of course, evolve sulphuric and hydrochloric acids which would tend to dissolve out the base metals from the impure gold, while the silver chloride formed would sublime and be absorbed by the earthenware pot. This recipe is thus a reasonably accurate description of the early method of gold refining known as cementation. Actually the presence of iron salts is not necessary to the process, but their use—together of course with common salt, which is the only essential feature apart from the access of air through the pores of the earthenware vessel—is mentioned in numerous accounts from Pliny onwards.

Pliny's account reads:

> Gold is also heated with twice its weight of salt and thrice its weight of misy and again with two portions of salt and one of a stone called schist. When these substances are burnt together in an earthen crucible the poison is drawn out while it remains pure and uncorrupted itself (11).

The same procedure was given by Geber, by Albertus Magnus and later by both Biringuccio and Agricola in the sixteenth century. It was, of course, one of the very few known methods of refining gold prior to the discovery of the mineral acids and its use continued long afterwards in more primitive parts of the world, largely because of the then very high cost of acids. It was seen in operation as late as 1833 by

J. B. Boussingault, the French scientist then advising the government of Colombia on their mineral resources; he expressed his astonishment at "what was for me one of the most piquant circumstances in finding myself amidst this sixteenth century metallurgy" (12).

A reproduction of the process as described by Agatharchides in the second century B.C. was recently carried out by the writer's colleague J. H. F. Notton, whose findings fully confirmed the effectiveness of this ancient procedure (13).

Testing of Gold

If you wish to test the purity of gold, remelt it and heat it; if it is pure it will keep its colour after heating and remain like a piece of money. If it is whiter, it contains silver; if it becomes rougher and harder some copper and tin; if it blackens and softens, lead.

Here the formation of metallic oxides is relied upon to indicate adulteration, gold itself, of course, remaining completely free from oxidation. If the cementation process had not, as is quite likely, gone to completion, any remaining silver would diffuse to the surface and cause the gold to become paler. There is possibly some transposition by a copyist in the latter part of the recipe, as copper would of course give a blackening effect.

Preparation of Gold

Asem, 1 Stater, or copper of Cyprus 3; 4 Staters of gold; melt together.

This is a straightforward method of producing a gold alloy for jewellery purposes. Egyptian gold was almost certainly not fully refined, so that it is difficult to assess the carat value of the alloy resulting from either part of this recipe, but it would be little different from the alloys in use today. There is no element of fraud in this recipe; in present times we use the term gold to apply even to a 9-carat alloy which contains only 37.5 per cent by weight of gold (and only about half this amount as measured by volume!).

Amplification of Gold

To amplify gold, take cadmia of Thrace, make the mixture with cadmia in crusts or that from Galicia.

Here there has been interpolated a heading "Fraudulent Gold", and the recipe continues:

Misy and red of Sinope, equal parts to one part of gold. After the gold has been thrown in the furnace and it has become of good colour, throw upon it these two ingredients, remove it and let it cool, and the gold is doubled.

Cadmia was the name given to the mixture of oxides recovered from the flues in copper smelting, and would consist mainly of the oxides of copper, zinc and arsenic. Misy, as already mentioned, was iron pyrites, and the red of Sinope is red ochre (ferric oxide) and again according to Pliny was first discovered in the district of Pontus (now northern Turkey) and took its name from the Roman city and port of Sinope, the modern Sinop, on the Black Sea coast. In this process any copper sulphide would be reduced to copper and alloy with the gold, while copper sulphide would also react with the iron oxide, reducing it to metal which would also alloy to some small extent. Thus the "amplification" would result in a gold alloy containing copper, zinc and a small amount of iron, yielding quite a reasonable gold alloy not uncomparable with our modern 9-carat or 14-carat golds.

The use of iron oxide in the form of haematite, together with copper, is in fact described many years earlier on a clay tablet from Babylon dating to about 650 B.C. (14).

Gold Soldering

There are two recipes given for the preparation of gold solders—with a method of assessing the purity of tin sandwiched between them in the haphazard manner already mentioned. These are as follows:

Preparation of Chrysocolla

Chrysocolla is made this way: Copper of Cyprus, 4 parts; asem, 2 parts; gold, 1 part. The copper is melted first, then the asem and finally the gold.

The term chrysocolla was used indiscriminately by Pliny and others to refer both to the gold solder itself and to the flux used, malachite or basic copper carbonate. The unknown nature of the asem employed in this recipe makes it impossible to decide on the composition of the resulting solder except to say that it was clearly of low gold content, but the second formula, given below, would certainly produce an excellent brazing alloy comparable with those in use today.

To Prepare a Solder for Gold

How to go about making solder for works of gold: gold, 2 parts: copper, 1 part; melt and chop up. If you want a brilliant colour, melt with a little silver.

Assuming that the gold used was of reasonably high purity, this solder would have a very narrow melting range, around 920° to 930°C, and would flow readily, while the addition of silver would lower the melting temperatures to some extent. That a high degree of craftsmanship in the soldering of gold objects had been achieved in Ancient Egypt has been shown in an article in this journal a few years ago (15), and presumably something of these skills survived down to Roman times.

Methods of Gilding

Two distinct methods of gilding are described in the papyrus, both perfectly sound methods.

To Gild Silver in a Durable Fashion

Take some mercury and some leaves of gold and make into the consistency of wax; taking the silver vessel, clean it with alum, and taking a little of the wax-like material coat it with the polisher and allow the material to fix itself on. Do this five times. Hold the vessel with a clean linen rag in order not to ruin it, and taking some embers prepare some ashes, smooth with the polisher and use it like a gold vessel. It can be submitted to the test for true gold.

This method of gilding with a gold amalgam persisted for many centuries despite the grave risk to the health of the workers from the mercury vapour. This hazard in fact prompted the offering of a large monetary prize in Paris in 1818 for an alternative method of gilding and this helped materially to encourage the early development of the electroplating of gold.

The second method of gilding described is much older, antedating the discovery of mercury probably by many centuries. The recipe in the papyrus—it may be seen from lines 25 to 36 in the photograph on page 25—is as follows:

To Give to Objects of Copper the Appearance of Gold

And neither the touch nor rubbing against the touchstone will disclose it; but it can serve especially for making a ring of fine appearance. Here is the preparation. You grind gold and lead together to a fine powder like flour, 2 parts of lead and 1 of gold; having mixed them you incorporate them with gum and coat the ring with this mixture, then heat it. You repeat this several times until the object has taken the colour. It is difficult to detect because rubbing gives the mark of a gold object; and the heat consumes the lead but not the gold.

In this case an intention to deceive does seem to be clearly evident.

Writing in Letters of Gold

To judge from the number of formulae given for the preparation of gold inks, writing in gold must have been an important activity, but it is not stated on what material the writing preparations were to be used. The first of these recipes—the first seven lines in the photograph—reads:

A Procedure for Writing in Letters of Gold

To write in letters of gold, take some mercury, pour it into a clean vessel, and add some leaves of gold; when the gold appears to be dissolved in the mercury, shake vigorously, add a little gum, 1 grain for example, and, letting it stand, write the letters in gold.

Later on in the papyrus a similar recipe is repeated but more briefly:

Writing in Letters of Gold

Ductile leaves of gold, grind with mercury in a mortar, and use to write in the manner of black ink.

And yet again a brief recipe:

Preparation of Liquid Gold

Place some leaves of gold in a mortar, grind them with mercury and it is done.

It remains uncertain whether these preparations were for use on papyrus, parchment, glass, marble, or any other material. If they were to be used in the cold it would have been necessary to squeeze the amalgam through a skin or cloth of some kind to remove most of the mercury; if they were for use on glass it would have been necessary to heat the inscription or design to quite a high temperature to drive off the mercury. Possibly this was understood by the writer of the papyrus and by other skilled workmen. Examples of Egyptian glass are certainly known with a modest amount of gold decoration, and the use of a gold amalgam made by grinding or dissolving gold leaf with mercury was one procedure employed throughout the glass and pottery industries for many centuries yet to come—in fact down to the nineteenth or early into the present century.

One further recipe may well have reference to papyrus or other soft materials:

Writing in Letters of Gold

Grind some gold leaves with gum, dry and use like black ink.

A limited amount of decoration of papyri with gold leaf has been shown by Miss Shirley Alexander (16) to go back to about 1350 B.C. but she could find no evidence for the beginnings of the technique developed so wonderfully in Europe in the Middle Ages, in which a preparation of gold powder in some kind of vehicle was used for the illumination of manuscripts, although she considered that the Jewish Laws written in Jerusalem in the third century B.C. in letters of gold on leather might well have used this method. Parchment was certainly beginning to replace papyrus for manuscripts by the third century A.D., and scriptures from this period have been found in Palestine with decoration in both gold and silver.

The Edict of Diocletian

Thus we have the earliest written directions for the refining and alloying of gold, for its soldering and for other ancillary operations. The question that arises, of course, is "Why was the papyrus buried, as it presumably was, with the writer ?".

There are two possible explanations. The much older Egyptian practice of entombing with the body the articles that would be needed in the after-life may well have persisted into a period in which Christianity was fast taking hold.

Alternatively there might well have been a fear of confiscation of the work. After the revolt in Egypt in 296 A.D. the Emperor Diocletian issued an edict in which it is recorded that:

> "He also sought out the books written by the ancients on the chemistry of gold and silver and consigned them to the flames so that there should no longer be any wealth arising among the Egyptians from such craftsmanship and they should not thereby take encouragement to rebel against Rome in future."

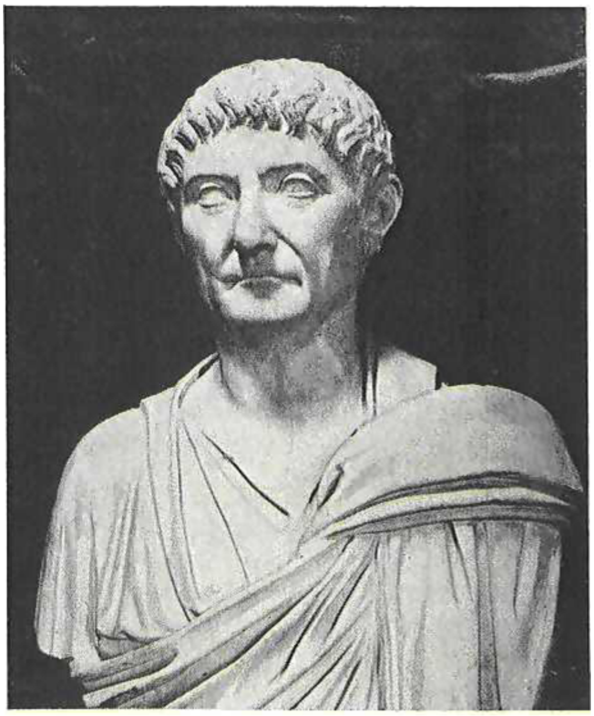
This edict, one of the very earliest, if not the earliest document to use the word "chemistry", was recorded in the Lexicon of Suidas, written in Greek in the tenth century (17). It is also quoted by Gibbon together with some facetious remarks on "the use and abuse of chemistry" and on the "vain science" of alchemy (18).

It is highly debatable whether Diocletian was intent upon destroying the early writings on the supposed transmutation of base metals into gold or silver, or whether he was seeking out genuine works on the chemistry of gold such as our papyrus, but, following on the highly repressive times, in which many thousands of Egyptians were massacred, it is quite likely that our working goldsmith or his family were afraid to preserve his records. One interesting point, however, is that the Leyden Papyrus is in fact a fair copy and was obviously not the one in use in the workshop. This might be held to support the first reason for its burial.

In either case some versions must have survived, because the same recipes, or closely similar versions, turn up time and again in manuscripts dating from the eighth to the fifteenth centuries such as the *Compositiones ad Tingenda*, an eighth-century manuscript based upon a seventh-century Greek original from Alexandria, and the *Mappa Clavicula*, a treatise on alloys and pigments written in the tenth century, as well as in the well-known treatise of Theophilus, *De Diversis Artibus*, written in about 1125 (19).

The Earliest Metallurgical Textbook

Whatever the reason for its being hidden in a tomb, we have preserved for us a most interesting set of instructions for the practical handling of gold and its alloys and of a number of base metal alloys. The author understood cupellation with lead for the refining of silver, he appreciated the difference in



**Diocletian
245 – 313**

Emperor of Rome from 284 until his abdication and retirement to his palace at Split in his native Dalmatia in 305, Gaius Aurelius Valerius Diocletianus is remembered chiefly for his persecution of the Christians and for his famous Edict of A.D. 301 which prescribed maximum prices for every commodity and maximum wages for every activity from those of the labourer to the advocate in an unsuccessful attempt to stabilise the economy. On a punitive visit to Egypt in 297 he also issued an edict for the burning of all books on the chemistry of gold and silver—one possible reason for the secretion of the Leyden papyri in the tomb of their compiler

melting points of his metals and the need for an ordered sequence in his alloying procedures, and he made use of pitch or bitumen where we should today use charcoal for a cover in melting.

The general impression one receives is of an experienced master goldsmith serving his richer customers with genuine gold jewellery and his more impecunious clients—including probably the tourists who even then came to visit Thebes from other parts of the Roman Empire—with imitation jewellery made from silver or from base metal alloys with or without gilding.

The papyrus, then, is the oldest text we have giving practical directions for refining, alloying and other metallurgical operations. It was written at about the time that the Emperor Constantine was establishing Byzantium as the new capital of the Roman Empire and summoning the first Council of Churches at Nicaea. It is in fact almost exactly as old as the earliest and beautifully produced complete copies of the Bible, made at Constantine's own command to the Bishop of Caesarea for use in Constantinople, such as the famous Codex Sinaiticus now preserved in the British Museum.

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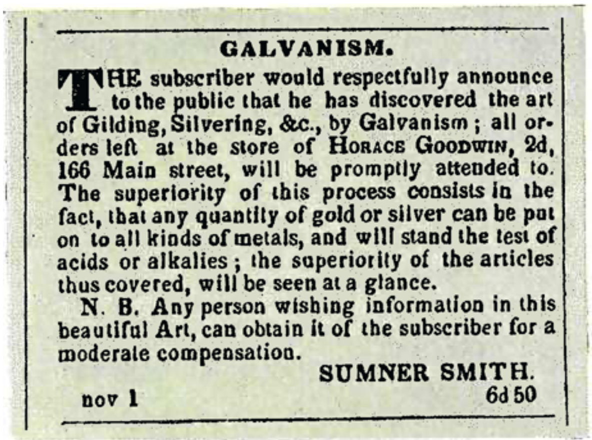
The First Gold Plating in America

The major part played by George Richards Elkington of Birmingham in taking the first practical steps towards the commercial development of gold plating is well known and has been described in an earlier issue of this journal (*Gold Bulletin*, 1973, **6**, (1), 16–27). In September 1840, together with his cousin Henry and the surgeon John Wright, he had filed a patent on the use of cyanide baths and, a year or two later, having failed in his attempts to license other manufacturers to use his process, he was about to establish his leading position in England as a gold and silver plater.

Unfortunately for him, Elkington did not file this patent in the United States, so leaving the field open to anyone to take advantage of his disclosure. Such an initiative was taken with astonishing alacrity—if not perhaps with too high a regard for the truth—by one Sumner Smith, a native of Brighton, Massachusetts, who had settled in Hartford, Connecticutt, where he was employed as a watch-maker and repairer by the jeweller Horace Goodwin.

Sumner Smith was also in practice as a patent agent, while he is further on record as being a member of the Franklin Institute. The journal published by this body, *The Journal of the Franklin Institute and Mechanics' Register*, contained from time to time short articles taken from the London and other trade and technical journals, and in the years 1840 to 1842 it included a number of references to the earlier Elkington patents



GALVANISM.

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N. B. Any person wishing information in this beautiful Art, can obtain it of the subscriber for a moderate compensation.

SUMNER SMITH.

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on immersion gilding as well as to the work of De la Rive in Geneva on gold plating. There is, however, no reference during this period to the final Elkington patent that was vital to the successful electrodeposition of gold. Possibly, as a patent agent, Smith was in correspondence with a fellow agent in London, but by whatever means he obtained the information—and no doubt his interest was aroused by the earlier disclosures —he was moved to insert in the *Hartford Times* in November 1842 the advertisement reproduced here.

L.B.H.