

Date.	Test No.	Original Dimensions.		Length of Specimen under Stress.	Breaking Strength per Square Inch.	Elongation.		Reduction of Area.	Remarks.
		Diam.	Area.			On Specimen.	In two inches.		
1890.			sqr. in.			per ct.	per ct.	per ct.	
Sept. 20	1	·564	·25	10 inches	32 tons	24·0	40·0	64·7	Specimens cut from one bar of Spike Steel, $\frac{3}{4}$ " diameter.
" "	2	·564	·25	8 "	32 "	25·0	39·0	62·8	
" "	3	·564	·25	6 "	32 "	25·0	37·7	61·9	
" "	4	·564	·25	5 "	32 "	26·0	38·0	60·6	
" "	5	·564	·25	2 "	34 "	32·0	32·0	60·0	
" "	1	·564	·25	10 "	40 "	20·5	33·0	57·4	Specimens cut from one bar of Bolt Steel, $\frac{1}{2}$ " diameter.
" "	2	·564	·25	8 "	40 "	20·0	35·0	57·4	
" "	3	·564	·25	6 "	40 "	22·1	34·0	58·1	
" "	4	·564	·25	5 "	40 "	22·4	33·5	56·9	
" "	5	·564	·25	2 "	41 "	30·0	30·0	53·6	

Each of the specimens tested was marked off in inches, and the elongation per cent. taken in the total length and in the two inches at point of fracture, as per above sketch.

## ON THE ORIGIN OF MOSS GOLD.

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[With Plates XVI. – XVII.]

[Read before the Royal Society of N. S. Wales, September 6, 1893.]

IN 1876 I had the privilege to read a paper before this Society "On the Formation of Moss Gold and Silver" (Jour. Roy. Soc. N. S. Wales, 1876, Vol. x., p. 125); since that time the matter has had to be more or less laid aside; but as opportunity offered, the investigation as to the cause of the moss like form of gold met with during the roasting of auriferous mispickel has been proceeded with, and in this note the results are given of additional experiments which appear to afford a solution as to the peculiar forms assumed by the gold, described in the above mentioned paper.



Without going into details, it may be mentioned that the paper referred to contained the results of experiments made with the object of ascertaining the condition in which the gold existed in certain rich specimens of mispickel, obtained from a mine near Orange in New South Wales ; these specimens were roasted in a muffle so as to drive off the arsenic and sulphur, and with the intention of afterwards dissolving away the iron oxide with hydrochloric acid so as to ascertain whether the gold was crystallized ; on removing the specimens from the muffle, exudations of ochre coloured matter were seen on their surfaces. These exudations on closer examination were found to be gold in cauliflower-like aggregations, and under the microscope these were seen to be made up of spicules and spirals of gold [See Plates 16, 17] (afterwards proved to contain some arsenic), the temperature of the muffle was kept between the fusing points of tin and zinc, so as to make quite certain that it was never hot enough to fuse gold. The residual iron oxide never showed any traces of fusion.

For these and other reasons I concluded, in my former paper, that the gold had not been fused ; my later experiments, however, show that although the temperature was insufficient to fuse gold, it was quite high enough to melt the very fusible compound of gold and arsenic, which was either present in the specimens under examination or formed during the roasting.

In the *Mineralogical Magazine* for 1877 and following years, there are several communications from Mr. T. A. R. Readwin upon the formation of moss gold. He is of opinion that metallic growths of gold, silver, electrum and native copper take place at ordinary temperatures, and cites a number of cases of specimens in his cabinets which appear to have "grown" since they have been in his possession. In the case of easily oxidisable sulphides rich in gold, this is probably not impossible.

In the former paper an experiment is given in which gold was fused in a crucible with mispickel under borax ; on roasting the auriferous button moss gold was obtained as from the natural specimens but of much smaller dimensions. The following



additional experiments have been made which more conclusively prove that mispickel, iron pyrites and other sulphides take up gold when fused with it, and in the case of the mispickel give up the gold, on roasting, in moss-like forms.

The following experiments with gold and various sulphides were made in 1877; in each case the sulphide was loosely mixed with the gold (sovereign gold rolled into a thin ribbon and cut up into minute squares) or the gold was only laid on the top and the whole covered with a layer of borax and fused.

Description and weight of sulphide in grammes.	Weight of gold used in grammes.	Percentage of gold used.	Weight of gold separated as a button in gms.	Percentage of gold in regulus.
30 Mispickel ...	3.25	10.80 <sup>(3)</sup>	none	3.60 <sup>(1)</sup>
30 „ ...	1.20	4.00	1.05	not assayed
30 „ ...	.90	3.00	.75 <sup>(5)</sup>	not assayed
25 „ ...	.50	2.00	.3	.80 <sup>(1)</sup>
30 „ ...	.30	1.00	.15 <sup>(6)</sup>	not assayed
30 Iron Pyrites ...	3.25	10.80	none	12.25
25 „ ...	.50	2.00	.39	.44 <sup>(2)</sup>
80 „ ...	1.17	1.46	none	.80 <sup>(4)</sup>
80 Copper Pyrites	1.17	1.46	none	1.00
80 Antimonite ...	1.17	1.46	none	4.42
80 Galena ...	1.17	1.46	none	1.20

<sup>(1)</sup>The regulus of mispickel in each case showed a crystalline structure on fracture, and the fracture under the microscope, was seen to be studded with gold; there was also some moss gold over the surface of the button and in the cavities. On roasting, the mispickel regulus always yielded moss gold.

<sup>(2)</sup>A white brittle button separated during fusion, containing streaks of gold—weight .3 grammes.

<sup>(3)</sup>Precipitated spongy gold was used in this case.

<sup>(4)</sup>Yellow malleable button.

<sup>(5)</sup>Very brittle, intersected with a white crystalline vein.

<sup>(6)</sup>Colour nearly white.

In some cases the percentage of gold found in the product or regulus was greater than that added; this, of course, was due to a part of the original mineral having been removed in the slag or volatilized. Moss gold was only obtained from the regulus of mispickel, none of the other sulphides yielded any.



The above experiments however only show that an artificial mixture of gold and mispickel will yield moss gold.

The next series of experiments was upon the preparation of sulpharsenide and arsenide of gold and the production of moss gold from them.

*Gold, Arsenic and Sulphur.*

*Experiment 1.*—A solution was made of sodium chloraurate and sodium arsenite and hydrogen sulphide passed; the precipitate of the mixed sulphides of arsenic and gold and free sulphur, was dried and roasted, a cauliflower-like residue of gold was left similar to that exuded by auriferous mispickel, which under the microscope was seen to contain a few fine filaments.

*Experiment 2.*—The experiment was repeated with the same result.

*Experiment 3.*—Some of the mixed sulphide of gold and arsenic was compressed into small cylinders, by means of a steel diamond mortar and two of these were carefully roasted at the mouth of the muffle. In both cases the gold was left as a porous mass with sponge like perforations running through it in all directions—with filaments of gold, visible under the microscope.

*Gold and Sulphur.*

*Experiment 4.*—Some experiments were made in 1878, upon gold sulphide obtained by passing hydrogen sulphide through the solution of the sodium chloraurate, this sulphide on roasting yielded ordinary dull brown gold, but in parts it appeared to be more or less crystallized. This experiment was repeated more than once with the like results.

*Experiments with Gold and Arsenic.*

In making the arsenide of gold, in the first experiments in glass tubes, the gold foil was placed in a porcelain boat and the vapour of arsenic driven over it, but it was afterwards found that the boat could be dispensed with. A piece of hard glass three-quarter inch combustion tubing was closed at one end and some metallic



arsenic filled in to about one inch, then a plug of asbestos and upon this the spirals of gold foil were placed, the tube was held in an inclined position in a retort stand and the arsenic volatilized by a bunsen flame, when the air had been displaced by the arsenic vapour the gold was heated to redness by the blowpipe; it quickly began to fuse and to run down upon the asbestos. (The blowpipe flame was quite incapable of fusing the gold by itself in the tube, even when the blast was kept up for an hour or so and the tube softened out of shape, but in the arsenic vapour the gold ran down with great readiness at a dull red heat.) The compound of gold and arsenic formed is very fusible and remains liquid for some little time after removal from the flame and when it has much cooled down; the globules are large and much rounded so that its surface tension is great, like that of the liquid alloy of potassium and sodium, in fact the appearance of the fluid arsenide reminded me very much of that alloy, except that the arsenide is of a yellow colour.

The gold arsenide solidifies suddenly on cooling (superfusion) and sometimes spirts a good deal, the small projected globules attach themselves to the glass tube, but can be readily removed. The cooled mass is often coarsely crystallized on the surface, when it presents a bright lustrous gold colour and appearance, but underneath it is seen to be honeycombed in every direction. In the cavities the microscope shows spirals and spiculæ of gold or of the gold-like arsenide. It is very brittle and breaks readily; inside it is crystalline and may be cavernous, in places there are patches of a bright metallic grey colour. This may be due to the presence of free arsenic or to a grey alloy, but I have not yet had time to determine this. In other cases the resulting compound has the dull ochre colour of moss of precipitated gold.

The alloy first formed by simple fusion seems to greedily absorb more arsenic, *i.e.*, when a piece of arsenic is pushed up against it; the alloy wets the arsenic and on slowly withdrawing the arsenic the alloy follows it like a streak of water, for from one quarter to half an inch. The apparent absorption of the arsenic may be



partly due to the arsenic being volatilized by contact with the fluid alloy. See experiment No. 9.

*Experiment 5.*—In the next experiments for the formation of the gold arsenide, arsenic was filled into a hard glass three-quarter inch tube to the depth of one to one and a half inch and a plug of glass wool placed upon it, the gold plate or foil was next dropped in, followed by another plug of glass wool, the tube was then rendered vacuous, sealed and heated to redness in a combustion furnace. On cooling, the spirals of gold were seen to have fused down into one large globule one-third inch across, scattered about were a number of small globules which were flattened and attached to the glass tubing, extending over two inches of the length of the tube, this scattering seems to have taken place on the solidification of the large globule and was probably due to the expulsion of an excess of arsenic. This experiment was repeated with a similar result; in the next experiment mispickel was used as the source of arsenic. On cupellation the first globule yielded 90.36% of gold and 9.64 of arsenic (by difference). The globule of gold arsenide from the mispickel yielded only 1.82% of arsenic.

It was afterwards found that the combination could be brought about by heating the arsenic and gold, separated by an asbestos plug, in an ordinary small hard glass tube of one-quarter inch bore, in the first trial the alloy melted down into a pear shaped globule, which was very brittle, and crystalline. On cupellation, the loss was equal to 5.54% of arsenic.

*Experiment 6.*—Next .411 g. of pure gold was treated as in the last experiment, on removal from the lamp after I thought it had solidified, the globule still remained fluid, for an air bubble was seen to slowly make its way through the globule, (as in a tube containing mercury) the globule solidified immediately, but the channel caused by the bubble was left. In this channel, minute spicules and spiral filaments of gold (moss gold) were seen when examined under the microscope.



The globule was weighed and found to have taken up 6.16% of arsenic, the amount was really larger but some of the alloy was lost by spirting on solidification. On cupellation of part of this globule the loss was equal to 7.5% of arsenic.

Afterwards larger amounts of gold were converted into arsenide in this way. On introducing cold gold into the arsenic vapour it became coated with a grey deposit of metallic arsenic, but as it became hotter the gold recovered its usual colour and lustre, but as soon as the gold became just red hot it rapidly fused down at the edges, just as when a strip of lead is held in a flame. In dealing with this larger quantity of gold in the large combustion tubing (three-quarter inch diameter) it was found necessary to use a gas blowpipe as a bunsen was not quite sufficient.

*Experiment 7.*—In this case the globule from 1.3627 g. of gold was shaken just as it was about to solidify, the whole suddenly became solid, with strongly marked crystalline surface and of a very bright lustrous gold colour, but cavernous at the base and exceedingly brittle. On cupellation it lost weight equal to 4.61% arsenic.

*Experiment 8.*—On roasting and fusing a portion of the alloy obtained in this experiment in a muffle without cupellation it lost weight = 3.29% of arsenic, although it showed, when fractured, grey specks of either arsenic or a grey alloy.

*Experiment 9.*—In this case after a globule of the arsenide had been formed, fresh supplies of arsenic were pushed down against the molten alloy (the supply of arsenic vapour from the bottom of the tube being still kept up) when it was apparently rapidly absorbed by the fluid alloy, the alloy “wetted” the plate of arsenic at once, and when the plate was drawn slowly backwards followed it as a streak (like water) to about one-third inch in distance.

As the quantity of arsenic increased the alloy became less fluid and less brilliant in lustre; whether much more arsenic was really absorbed and whether the arsenic was only volatilized by contact with the fluid alloy is difficult to tell. On solidifying, the alloy



seems to expel arsenic vapour and this condenses on the inside of the tube, but it is difficult to watch the operation because, the atmosphere of arsenic vapour used for producing the alloy also condenses on the sides of the tube soon after its removal from the lamp.

This specimen on cooling was of a dull brown colour just like the moss gold from mispickel, very hollow and blown out into a secondary globule on one side, the cavities contained spicules and spirals of moss gold.

It was very brittle and on cutting it with a sharp chisel more or less powder was produced, the fracture was coarsely crystalline and of a dull gold colour, which under the microscope was seen to be intermingled with grey. On cupellation it lost weight = 3.2% of arsenic.

*Experiment 10.*—In this case a weight of 7.3674 g. of fine gold was alloyed with arsenic; on the gold first fusing down or “burning” in the arsenic vapour a very fusible alloy was formed, but this like the last became less fusible as more arsenic (solid) was pushed into it (the arsenic had been previously sublimed in glass tubes for this purpose) and on cooling it lost its metallic lustre, became covered with cauliflower-like growths and spirted a good deal; the cavities contained the usual spicules and spirals of moss gold. On cupellation the loss was equal to only 2.8% of arsenic.

*Experiment 11.*—This arsenide was of the colour and lustre of freshly cast bronze. Loss = 5.9% As. on cupellation.

*Experiment 12.*—Also of a bronze colour. Loss = 4.9% of As.

*Experiment 13.*—Of a bright gold colour and matt lustre; this had formed directly in contact with the arsenic and had solidified on the arsenic itself—the alloy was pitted in places and had a very strong resemblance to a nugget. Its fracture showed a few grey streaks mixed with the gold, on cupellation it lost weight = 9.9% arsenic.

*Experiment 14.*—The moss gold obtained by roasting the auriferous mispickel from the New Reform Mine, Lucknow, was cupelled with lead when 2.3668 grammes lost .057 or 1.98%.



From the foregoing experiments it will be seen that the amount of arsenic taken up by the gold varies very much : thus the alloy from Experiment 5 (from arsenic and gold) lost 9·64% arsenic, and from mispickel and gold 1·82% of arsenic.

Experiment 6 (from arsenic and gold) lost 7·5% of arsenic

„	7	„	„	„	5·61%	„
„	8	„	„	„	3·29%	„
„	9	„	„	„	3·2%	„
„	10	„	„	„	2·8%	„
„	11	„	„	„	5·9%	„
„	12	„	„	„	4·9%	„
„	13	„	„	„	9·9%	„
„	14	„	„	„	1·98%	„

The lowest containing only about 2% and the highest nearly 10% of arsenic.

While the arsenic is hot it feels sticky when touched with an iron wire and the fragments cohere to a certain extent.

The excess of arsenic left in the lower part of the tube as well as the sublimed arsenic shows well developed crystals.

*Experiment 15.*—Precipitated gold was mixed with powdered purified arsenic in about equal bulks, and compressed into small cylinders by means of a diamond mortar and then roasted slowly in a muffle ; the gold was left as a porous cylinder, but with excrescences of moss gold in places and lining the cavities.

*Experiment 16.*—Moss gold was also obtained by roasting a cylinder composed of mispickel 1 g. and ·75 g. of precipitated gold.

*Experiment 17.*—Gold ·75 g. arsenic ·5 g. and sulphur ·5 g. were compressed, on roasting, it at once fused down into an irregular cake with a very cavernous and spongy structure ; the surface was like that of moss gold and under the microscope the usual spicules and spirals were seen. The cupel used as a support was stained of a purple tint and this penetrated to nearly one-eighth of an inch deep, just as if the gold had been in solution.



*Experiment 18.*—To ascertain if finely divided gold would burn in arsenic vapour, I introduced some gold leaf; it combined in much the same way as the foil, but more quickly.

*Experiment 19.*—Gold leaf introduced into the vapour of sulphur was apparently unchanged.

*Experiment 20.*—Thin sheet gold, thinner than that used for making the gold arsenide was heated in a piece of combustion tubing for nearly an hour, with the hottest flame obtainable with the blowpipe lamp used for making the experiments on gold and arsenic, but without fusing it or causing any signs of fusion to appear on its edges, hence there is no possibility of the gold having been fused in previous cases, *i.e.*, its fusion was due to the formation of a fusible compound with the arsenic. This test was repeated with the same result in both cases.

*Experiment 21.*—Some precipitated gold was made into an amalgam and roasted at a low temperature in the front part of a gas muffle, the gold was left as an ochre coloured lustreless cauliflower-like mass; under the microscope, however, it is seen to have the usual colour and lustre of metallic gold; the innumerable bright points which reflect the light being too small to be seen by the unassisted eye; the general appearance is much like that of the excrescences of gold from roasted auriferous mispickel; but the spiral and moss like growths are almost absent, although a number of hair like filaments of gold are seen in the cavities and recesses of the mass.

When the pieces of amalgam were roasted at a high temperature they fused and coalesced, the appearance was rougher from the boiling and more rapid expulsion of the mercury, but the number of capillary growths and filaments was not increased. Doubtless most or all of the compounds of gold with volatile elements would yield moss gold on roasting.

Compounds of gold and arsenic do not appear to be mentioned in modern English works of reference upon chemistry. In Aiken's Dictionary of Chemistry and Mineralogy, p. 537, London



1807, there is an account of Hatchett's experiments upon them from Phil. Trans. 1803, as follows :—

“If a small crucible containing gold be inserted in a larger one containing arsenic and an inverted crucible be luted on by way of a cover and the apparatus be heated strongly in a wind furnace, the arsenic will be raised in vapour, and the gold being fused in the arsenicated atmosphere, will combine with a small portion of it. The alloy hence resulting is of a grey colour, a coarse granular fracture, and very brittle.

“A heat equal to that of melting gold is by no means necessary to effect this combination, for if a plate of gold is merely brought to a full red heat in an atmosphere loaded with arsenic, the latter will unite superficially with the gold, and the alloy hence resulting being very fusive, will trickle in drops from the plate, till the whole of it is thus arsenicated. The alloy is scarcely decomposable by mere heat, and at a high temperature the arsenic that is driven off, carries a considerable proportion of gold with it.”

An abstract of the above appears in Gmelin's Handbook of Chemistry, Vol. vi., p. 238, London 1852, after which such compounds are ignored by more modern English writers, except a bare statement in Watt's Dictionary of Chemistry Vol. i., 1872, that gold combines with arsenic.

In Brough Smyth's Gold Fields and Mineral Districts of Victoria, Melbourne 1869, there is a statement that a quantity of arsenical gold was found by some Chinamen in the rubbish from disused roasting kilns at Stawell in Victoria, this was examined by Mr. Newbery, who stated that the gold had probably taken up the arsenic (when the latter was in a state of vapour) during the roasting of arsenical ores, as native arsenides of gold were unknown in Victoria.

A. Deschamps (Comptes Rendus lxxxvi., 1022-3 and 1065-6), states that  $\text{Au}_3\text{As}$  is formed as a dark red powder when metallic arsenic is placed in a solution of gold chloride. By fusion with



potassium cyanide a yellow metallic button of  $\text{Au}_4\text{As}_3$ , sp. gr. 16.2, is obtained.

The above references were made after I had completed the experiments given in this paper, and they are quoted merely as of historical interest.

As a result of the foregoing experiments and observations I conclude that the peculiar form of the moss gold is due to the formation of a fusible compound with arsenic, which behaves in much the same way as fused bituminous coal—to which I referred in my first paper (Jour. Roy. Soc. N.S.W., Vol. x., 1876, p. 125) as follows:—"The general appearance of these peculiar cauliflower-like excrescences of gold would at first sight tend to give one the impression that they had been formed in somewhat the same way as the blebs and excrescences often observed on coke, which are so familiar to us in a fire made of the so-called bituminous coal, *i.e.*, caking coal, in which we constantly see portions of the coal fuse and swell up into fantastic blebs and bladders until the imprisoned gas breaks through the outer thin skin and inflames with a brilliant light. After the more combustible portions have been volatilized and consumed a hard clinkery and more or less cauliflower-like excrescence is left." In the cavities of such cinder we may often see spicules and acicular threads of coke.

In that paper I came to the conclusion that the moss like forms of gold could not be due to fusion, because the experiments were conducted at temperatures far below the fusing point of gold or mispickel, but my later investigations show that the moss gold is due to the fusion of the very fusible gold arsenide and to the escape of arsenic from it, blowing it up into excrescences, spicules and spiral threads, and that the crystallised appearance in places is due to the ready crystallization of the alloy on solidification.

In the auriferous mispickel the gold appears to be in the free condition, but to be converted into gold arsenide during the roasting, and it is from this gold arsenide that the moss gold is produced.

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Liversidge, Archibald. 1893. "On the origin of moss gold." *Journal and proceedings of the Royal Society of New South Wales* 27, 287–298.

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