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CHEMISTRY

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John

A STUDY OF THE MAGNETIC SUSCEPTIBILITY

OF SOME BINARY ALLOYS.

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INTRODUCTION.

It is a well known fact that a moving charge of electricity produces a magnetic field and a moving magnet induces an electric current, consequently the modern theory of the atom makes it likely that an investigation of the magnetic properties of elements, mixtures or compounds, might lead to interesting and valuable results connected with the structure of the atom and the origin of the magnetic properties of the atom.

The following account is a description of work done in a study of one of the magnetic properties, namely the magnetic susceptibility, of certain binary alloys.

When a body is placed in a magnetic field it either concentrates or disperses the magnetic lines of force. The intensity of magnetisation is proportional to the strength of the field.

$$I = k H,$$

where

I is the intensity of magnetisation or the magnetic moment per cc,

H is the field strength or force per unit pole,

k is the magnetic susceptibility or coefficient of magnetisation.

Therefore, $k = \frac{I}{H}$,

that is, the ratio of the magnetic moment per cc at any point

within the body to the field H , (provided that the body is of such dimensions that the intensity may be regarded as uniform).

Substances may be placed in three groups according to the manner in which they affect the lines of force of a magnetic field.

(1) The lines of force are concentrated to a great degree.

(2) The lines of force are concentrated to a very small extent.

(3) The lines of force are dispersed slightly.

Members of class 1 are the ferro-magnetic substances, i.e. iron, cobalt, nickel and certain of their alloys and compounds. All other metals and alloys belong to class 2, paramagnetic substances, or class 3, diamagnetic substances. The metals included in the first group are also paramagnetic, but the value of k for these elements is very much greater than the value for any other element.

For paramagnetic substances $k > 0$, and for diamagnetic substances $k < 0$.

The fact that certain bodies are attracted or repelled when placed near a magnet was first noted by Brugmans¹, in 1778, when he observed the action of a magnet on a very small piece of bismuth.

Becquerel observed a similar action in the case of antimony about the year 1827.²

In 1845, Faraday³ published some work which showed that a sufficiently strong magnetic field has an action on practically all substances and these substances are either paramagnetic or diamagnetic.

The nature of the magnetism possessed by a body, whether solid, liquid or gas, has been determined in a variety of ways. In the case of solids the action of a magnetic pole on a small amount of material can be observed, or the position taken up by a rod, placed horizontally between the poles of an electro-magnet, noted. This second method has been applied to liquids, the liquid being placed in a tube suspended between the poles.

Gases, contained in a spherical glass envelope, can be suspended between the poles of an electro-magnet and the gas allowed to rise or fall. Faraday added a little hydrochloric acid to the gas. Above the apparatus, he placed open tubes of ammonia. As the gas rose, the path taken by it could be observed as ammonium chloride fumes were formed.

These experiments show the nature of the magnetism compared with air which is paramagnetic on account of the oxygen it contains.

In the quantitative study of magnetic properties, the value of k is obtained by methods which depend on the force exerted on the body examined when placed in a varying magnetic field.

For a very small quantity of a substance,

$$pg = kvH \frac{\partial H}{\partial x}$$

where p = the force in grams

H = the field strength in C.G.S. units

v = volume in ccs.

g = 981 C.G.S. units.

x = the variation along the axis of symmetry
of the field.

If the substance is in the form of a rod,

$$pg = \frac{1}{2} SkH^2$$

$$\text{i.e. } k = \frac{2pg}{SH^2}$$

p , g , H and k have the same significance as in the
first formula.

S is the area of cross section of the rod.

The first formula was used by Curie, Curie and Chéneveau
and Meslin.⁴

The second formula was used by others notably Stefan Meyer.⁵

Eccquerol,² in 1850, suspended a small horizontal rod
between the poles of an electro-magnet and from the torsion
produced he determined the angle made by the rod with the
lines of force. By observing the action of different
substances in a field of the same intensity, the torsion of
the wire gave a measure of the value of k .

Boltzmann⁶ deduced formulae by which the action of a coil on a magnetic field gave values of k .

Ettingshausen⁷ then measured the force with which a coil repelled a diamagnetic rod placed inside and near one of the ends of the coil. From this he was able to calculate k .

Rowland and Jacques⁸ measured the time of oscillation of a rod of a feebly magnetic substance in a magnetic field and obtained values for k . Toepler⁹ employed a method of comparing the magnetic properties of different bodies by measuring the induced currents produced in these bodies as they moved across a magnetic field. Using this method, with Ettingshausen¹⁰, he made a series of measurements and, amongst other things, found values for equal weights of iron and bismuth.

In 1895, Curie⁴, using the first formula given on page 4, devised an apparatus for the measurement of k . Two electro-magnets were placed near one another at a certain angle. Curie worked out the distribution of the field along the axis of symmetry and at the point of maximum force the body was examined. The body under observation was contained in a glass tube suspended from the arm of a torsion balance. The movement of the arm was measured by the reflection of a beam of light by a mirror attached above the balance arm, on to a convenient scale.

In 1903, P. Curie and C. Chéneveau⁴, constructed another balance in which the electro-magnets were replaced by one annular magnet. This balance is described fully in the section on measurements.

The foregoing methods have all been applied to liquids and gases. Curie⁴ studied compressed gases in the tube attached to the arm of his torsion balance.

Schuhmeister¹¹ used Rowland and Jacques⁸ method to measure the time of oscillation of a tube, filled with liquid, in a magnetic field.

Borgmann¹² used a ballistic method for liquids. In 1885, Wiedemann¹³ obtained relative values of k by measuring the force exerted on tubes of liquid by an electro-magnet. The torsion of the wire supporting the tube and liquid gave a measure of k .

Schuhmeister¹¹ improved Wiedemann's method and, by having his liquid in a spherical envelope, he obtained absolute values for k .

A differential method has also been commonly used for liquids and gases. The magnetic susceptibility of a body was obtained in air and vacuo and then in the liquid or gas examined.

The results of these investigations, that is up to about 1903, have given values of k for most of the elements and a great many compounds. It has often been difficult to compare results because some were made with sticks of material, some with powder and some in solution.

By plotting atomic weights as abscissae and atomic volumes as ordinates, a curve with well defined maxima and minima is formed and Stefan Meyer⁵ showed that paramagnetic substances fall on the descending curve and diamagnetic on the ascending curve.

Becquerel², Tyndall, Reich¹⁴ and others showed that k is independent of the field H . This was supported later by Wiedemann¹³, Etingshausen⁷, Curie⁴, Stefan Meyer⁵ and others but this is not true of the ferromagnetic metals iron, cobalt and nickel.

Other investigators found a relation between k and H in some cases. Honda¹⁵, for example, did so in his study of 43 of the elements. It was shown to be due to the presence of traces of iron and, for iron free specimens, he proved k to be absolutely independent of H .

The relation between magnetic susceptibility and temperature was studied by Faraday³, Plücker¹⁶, Matteucci¹⁷ and others who showed that as the temperature increases both para and diamagnetism decreases.

Wiedemann¹³, in the case of iron, nickel, cobalt and manganese salts, found that k varies inversely as the absolute temperature.

Curie⁴ indicated that for diamagnetic bodies k is independent of temperature except in the case of antimony and bismuth, while for paramagnetic bodies k varies inversely as the absolute temperature.

Honda¹⁵ carried out a similar research but he was unable to confirm Curie's results.

Urbain¹⁸ has shown that, for a large number of binary mixtures examined by him, the value of the susceptibility depends directly on the amount of each constituent present, that is, the property is strictly additive.

Stefan Meyer⁵ gave the following rules as the result of his investigations:-

- (1) Two diamagnetic elements always produce a diamagnetic compound.
- (2) Two paramagnetic elements usually produce a paramagnetic compound.

The investigation of the magnetic susceptibility of alloys was stimulated by the discovery, in 1903, of the Heusler¹⁹ alloys. Manganese alloys, containing no ferro-magnetic metals, were found to be strongly magnetic. The addition of aluminium, tin, arsenic, antimony and bismuth to manganese-copper containing 30 per cent manganese produced a great increase in magnetic properties.

Sir Robert Hadfield's work²⁰, in 1917, on certain manganese steels, showed that the addition of carbon, tungsten, manganese, silicon, chromium, copper and nickel to certain steels, altered the magnetic properties considerably.

e.g. (a) the influence of manganese and carbon on steels of constant manganese content is shown in the following table.

Ratio carbon to manganese.	$k \times 10^6$
0.01	78
0.076	19
0.083	+17
0.1	-17

(b) Influence of nickel

Ratio carbon to manganese	Nickel	$k \times 10^6$
0.15	2.57	23
0.14	9.0	35
0.15	14.55	52
0.12	19.0	67

(c) Influence of silicon, at high temperature.

Ratio carbon to manganese.	Silicon.	$k \times 10^6$
0.010	-	76
0.015	6.15	240,000

The amount of work done on the magnetic susceptibility of alloys is small compared with the investigations of other physical properties such as hardness, density, thermal behaviour and electrical conductivity.

The following research was therefore undertaken with a view to finding out if this particular physical property bears any relation to other properties or throws light on the conditions prevailing within the atom.

PREPARATION OF THE ALLOYS.

Owing to the fact that the ordinary chemical laboratory has the means of obtaining high temperatures to a limited extent only, it was advisable to consider the range of temperature needed for the formation of various alloys. An electric resistance furnace, giving a temperature of 1100° - 1200°C was available and consequently the alloy systems examined are all fusible at a temperature below 1200°C .

The plan of work consisted in the examination of systems of two metals which should be completely miscible in the liquid condition in all proportions and which should melt below the limit attainable by the available apparatus, viz. 1200°C .

- (a) Mixtures of two paramagnetic metals
- (b) " " " diamagnetic metals
- (c) " " one paramagnetic and one diamagnetic metal.

An examination of the freezing-point curves given in Landolt-Börnstein's *Physikalisch-Chemische Tabellen*, 1923 Edition, page 527 et seq., led to the choice of the following binary systems for investigation -

- (a) Aluminium - Tin.
- (b) Silver - Lead
- Gold - Lead
-
- Gold - Cadmium.

(c) Bismuth - Tin

Lead - Tin

Gold - Tin

Cadmium - Tin.

Materials. Pure lead (assay), tin, bismuth, cadmium and aluminium were supplied by Kahlbaum. The lead, supplied in sticks, was granulated by melting and shock-cooling in water. The tin was already in granular form. The aluminium, in blocks, and cadmium in sticks, were cut up and washed with dilute hydrochloric acid and water. Bismuth, in sticks, was broken up in an agate mortar.

Pure silver from Johnson and Matthey was used. This was cut into small squares, washed with dilute hydrochloric acid, distilled water and dried. The dried pieces were scraped with a sharpened glass rod.

Fine gold, in granulated form, was obtained from Johnson and Matthey.

(a) Silver-Lead Alloys.

Melting Point range²³, Pb 327°C. Ag 962°C with minimum at 300°C.²¹
Nine alloys were made i.e. 10 per cent lead. 90 per cent silver; 20 per cent lead, 80 per cent silver and so on expressed in weight per cent.

In each case the weight of mixture taken was about 15 grams.

The alloys containing 10-60 per cent silver were made as follows:-

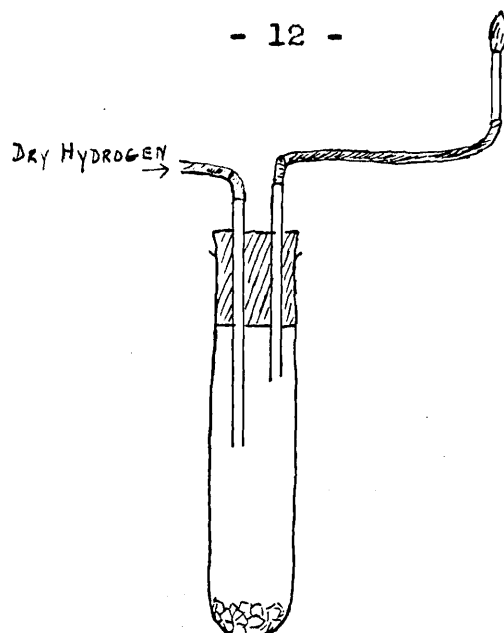


Fig 1.

The metals were placed in a silica test-tube fitted with a rubber cork carrying two pieces of glass tubing. One of these was attached to an apparatus giving dry hydrogen, (the hydrogen from a Kipp was washed in water and dried with concentrated sulphuric acid) and the other to a tube at the end of which the hydrogen could be burned. In this atmosphere of hydrogen the metals were heated over a bunsen burner until molten. The mixture was kept molten for 10 to 15 minutes and the tube well agitated.

It was decided that the alloy in the form of a cylinder would be most convenient for measuring. A mould of fine plaster of Paris was made with cylindrical holes .4 cms in diameter so that the rods formed could pass easily into a measuring tube.

The molten mixture of metals was poured into one of the cavities of the mould.

2. The alloys containing 70 to 90 per cent silver were made in an electric furnace.

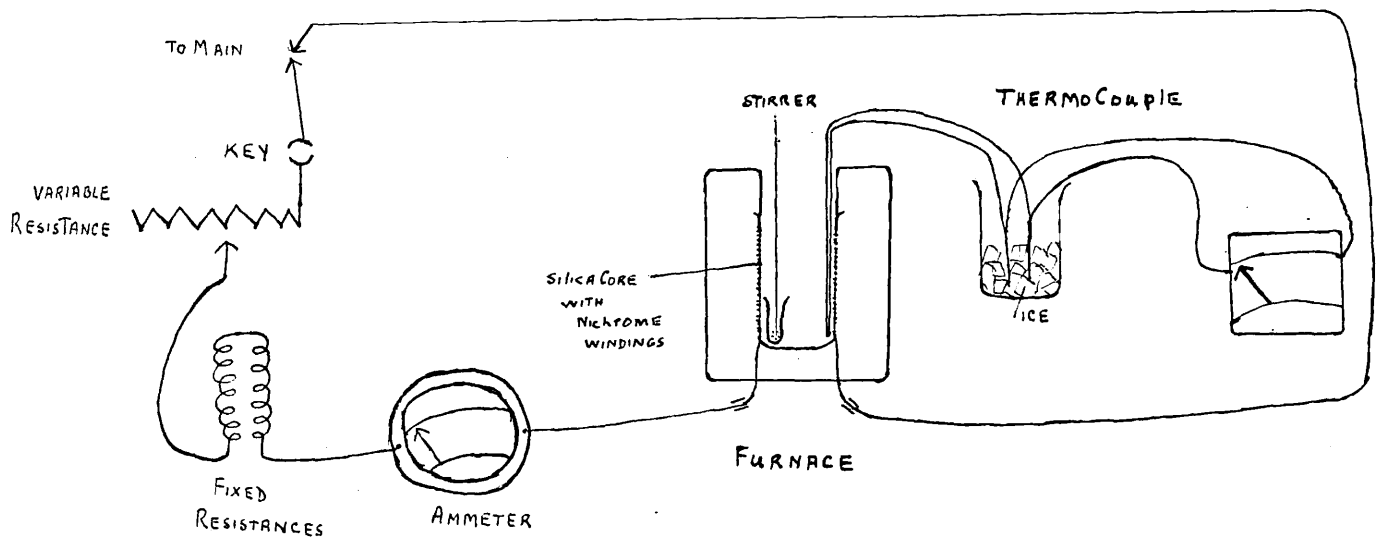


Fig 2.

A nichrome wound resistance furnace was connected up as shown above and fed with a current of 9-10 amperes when a temperature between 1100° and 1200°C was maintained. Lower temperatures than 1200°C were obtained by placing additional resistances in the circuit.

The metals, in a silica test tube, were placed inside the furnace and when molten, the mixture was stirred for several minutes with a silica rod. It was then cast in moulds.

All these alloys were silvery in colour. The 80 and 90 per cent silver alloys had the appearance of pure silver but were somewhat brittle.

Lead reacted with the silica tubes and formed a fusible slag which floated on the molten alloy but remained in the tube when the alloy was poured. The only inconvenience caused by the formation of lead silicate lay in the fact that the tubes were soon destroyed.

(b) Gold-Lead Alloys.

Range of melting point²⁴, Au 1064°C, Pb 326°C, minimum point at 215°C.²²

Alloys containing 5, 10, 20, 30, 40, 50, 60, 70, 80 and 90 weight per cent gold were made in the following way:-

18 grams of gold and 18 grams of lead were taken in a silica tube. This tube was heated in an electric furnace at a temperature about 700°C. When the mixture became molten it stirred well with a silica rod and poured into a mould. A rod of alloy about an inch long was set aside. Half the residue was weighed and the requisite amount of lead added to make a 40 per cent gold alloy. This mixture was treated as above and the residue used to obtain a 30 per cent gold alloy and so on down to 5 per cent gold. The temperature of the furnace was raised to about 1150°C.

The other half of the 50 per cent gold residue was weighed and gold added to make a 60 per cent gold alloy. The residue from this was used for a 70 per cent gold alloy and so on up to 90 per cent gold.

It was found difficult to keep the 90 per cent gold alloy molten. A little lead was added in order to make the mixture sufficiently molten to flow into the mould.

The alloys from 5 to 60 per cent gold were dull and resembled lead. The 70 per cent gold alloy showed a very faint yellow tinge and the 90 per cent gold alloy was very like pure gold but much harder.

(c) Lead-Tin Alloys.

Melting point range²⁵, Pb. 326°C, Sn 232°C, minimum at 181°C.²³

Nine alloys were made by method (1) described for the silver-lead alloys.

All these were bright silvery alloys.

(d) Bismuth-Tin Alloys.

Melting point range²⁷, Bi 267.5°C, Sn 232°C, minimum 98.5°C.²⁴

Nine alloys were made exactly as in the case of the lead-tin alloys.

The alloys rich in bismuth were bright and very brittle.

Those rich in tin were dull and less brittle.

(e) Aluminium-Tin Alloys.

Melting point range²⁸, Al 657°C, Sn 232°C, no maximum or minimum.²⁵

Nine alloys were made in the electric furnace which was maintained at about 800°C.

The mixtures of metals were easily melted, mixed and poured into a mould.

All were bright silvery alloys. These alloys were examined for silicon but no trace could be found consequently the fear that the molten ^{ALUMINIUM} silicea might have reduced some of the silica was unfounded.

(f) Gold-Tin Alloys.

Melting Point range,²⁶ Au 1064°C, Sn 232°C, minimum 217°C.²³

Nine alloys were made beginning with the 50 per cent alloy and using the successive residues with more tin or gold as in the case of the gold-lead alloys.

The 10-30 per cent gold alloys were of a dullish silver colour. The 40 per cent gold alloy had a faint yellow tinge but, on the whole, was bright and silvery. Alloys of 50-70 per cent gold looked very like silver and the 80 and 90 per cent gold alloys had the appearance of pale gold.

(g) Cadmium-Tin Alloys.

Melting point range²⁹, Cd 320°C, Sn 232°C, minimum at 176°C.²⁷

Nine alloys were made in an electric furnace maintained at about 600°C. Some oxidation of cadmium took place, brown fumes were evolved and the alloys were difficult to pour.

The rods were washed carefully and examined to see that no oxidised material remained attached to the rod.

These were all bright silvery alloys.

(h) Cadmium-Gold Alloys.

Melting point range³⁰, Cd 320°C, Au 1064°C, minimum 303°C.²⁸

6 grams of a 50 per cent alloy were made, the furnace having a temperature of about 800°C. The residue was used to form alloys less rich in gold by the addition of weighed amounts of cadmium. The temperature of the furnace was then raised to about 1150°C and a 60 per cent gold alloy prepared. The residue was used to make the alloys richer in gold.

All these alloys, owing to the oxidation of cadmium, were difficult to pour.

The alloys containing 10 to 30 per cent gold were silvery in colour. The 40 to 70 per cent gold alloys had a yellow tinge; 80 per cent gold alloy was more markedly yellow and the 90 per cent gold alloy looked like pure gold.

Preparation of the Rods of Pure Metal.

Silver. Pieces of silver were placed over an opening in a mould and heated with a blowpipe. As the silver melted, it flowed into the cavity and a rod was thus formed.

Gold. Pieces of gold were placed over a cavity in a mould and heated with the oxyhydrogen flame.

In the case of lead and tin, the metal was melted in a silica crucible and cast in a mould. Rods of aluminium, bismuth and cadmium were obtained by turning the Kahlbaum material to the required diameter.

Preparation of portion of specimen for measurement.

In all cases the cylinders of alloys were treated as follows:- a portion about half a centimetre long was cut with a razor from the centre of each cylinder and small pieces from either side of this portion were analysed. The small rod thus obtained was found, in the first case, to measure .65 centimetres long and .36 centimetres in diameter and all other rods were cut to this size.

When the results of the analysis showed that the composition of the ends of the rod did not differ by more than 0.2 per cent, the centre piece was prepared for measurement by being washed in dilute hydrochloric acid, distilled water and dried. The composition of the rod was taken as the mean of that of the two ends.

The cylinders of pure metals were cut to size and washed in the same way. The main object of washing with dilute hydrochloric acid was to remove particles of iron which had possibly been left during the cutting of the alloy. This precaution has been previously shown by Hadfield and Chéneveau²⁹ to be very necessary.

Analysis of Alloys.

(a) The tin in all the systems containing tin, except that of gold-tin, was determined as tin dioxide by the method described in Scott, Standard Methods of Chemical Analysis, page 442.

(b) The noble metal in all the systems containing either gold or silver was estimated by cupellation, the amount of the base metal being obtained by difference.

The silver-lead alloys cupelled readily and it was not necessary to use any additional lead.

The gold-lead alloys required a much higher temperature and a little lead was needed to complete the cupellation of the 90 per cent gold alloy.

In the case of the gold-tin alloys, the tin dioxide produced delayed the cupellation. It was found necessary to use larger cupels and to add a considerable quantity of assay lead in order to obtain satisfactory results.

The gold-cadmium alloys presented no difficulty as the volatile cadmium oxide was soon removed.

Results of Analysis.

(a) Tin estimated as dioxide.

I. Lead-Tin Alloys.

Alloy.	Percentage Tin		Mean Percentage tin in rod.	Atoms per cent.	
	1.	2.		Lead.	Tin.
A.	96.93	96.75	96.84	1.85	98.15
B.	84.96	84.76	84.86	9.49	90.51
C.	81.46	81.50	81.48	11.55	88.45
D.	73.25	73.01	73.13	17.53	82.47
E.	52.49	52.71	52.60	34.11	65.89
F.	43.99	43.77	43.88	42.36	57.64
G.	36.19	35.97	36.08	50.44	49.56
H.	20.51	20.37	20.44	67.76	32.24
I.	13.53	13.67	13.60	78.50	21.50

II. Bismuth-Tin Alloys.

Alloy.	Percentage Tin.		Mean Percentage Tin in rod.	Atoms per cent.	
	1.	2.		Bismuth	Tin.
A.	7.74	7.94	7.84	87.05	12.95
B.	17.69	17.51	17.60	72.82	27.18
C.	30.42	30.15	30.28	56.85	43.15
D.	42.76	42.71	42.73	43.40	56.60
E.	49.91	50.17	50.04	36.35	63.65
F.	57.97	58.02	57.99	29.29	70.71
G.	68.13	68.01	68.07	21.17	78.83
H.	82.56	82.26	82.41	10.87	89.13
I.	93.50	93.75	93.62	3.75	96.25

III. Aluminium-Tin Alloys.

Alloy.	Percentage Tin.		Mean Percentage tin in rod.	Atoms per cent.	
	1.	2.		Aluminium.	Tin.
A.	96.19	96.29	96.24	30.58	69.42
B.	83.01	83.33	83.17	47.06	52.94
C.	76.20	76.06	76.13	57.23	42.77
D.	65.75	65.68	65.71	69.70	30.30
E.	49.49	49.61	49.55	81.76	18.24
F.	41.74	41.98	41.86	86.37	13.63
G.	31.47	31.79	31.63	90.47	9.53
H.	19.82	20.09	19.95	94.67	5.33
I.	11.67	11.95	11.81	96.95	3.05

IV. Cadmium-Tin Alloys.

Alloy.	Percentage 1.	Tin. 2.	Mean Percentage tin in rod.	Atoms per cent. Cadmium.	Tin.
A.	90.01	89.90	89.95	10.56	89.44
B.	74.66	74.87	74.76	26.34	73.66
C.	62.09	62.21	62.15	39.19	60.81
D.	51.92	51.84	51.88	49.53	50.47
E.	45.74	45.88	45.81	55.63	44.37
F.	20.81	21.07	20.94	80.00	20.00
G.	15.49	15.53	15.51	85.23	14.77
H.	9.61	9.35	9.48	91.00	9.00
I.	1.39	1.61	1.50	98.58	1.42

Alloys analysed by cupellation.

I. Silver-Lead Alloys.

Alloy.	Weight Percentage Silver.		Mean Percentage silver in rod.	Atoms per cent Silver. Lead.	
	1.	2.			
A.	9.69	9.55	9.62	16.96	83.04
B.	14.48	14.72	14.60	24.71	75.29
C.	20.89	20.65	20.72	33.41	66.59
D.	29.99	30.31	30.15	45.31	54.69
E.	40.27	40.01	40.14	56.27	43.73
F.	52.42	52.31	52.36	67.84	32.16
G.	61.09	61.31	61.20	75.16	24.84
H.	70.86	70.73	70.79	82.30	17.70
I.	84.86	84.92	84.89	91.52	8.48
J.	96.26	96.54	96.40	98.20	1.80

II. Gold-Lead Alloys.

Alloy.	Weight Percentage Gold.		Mean Percentage gold in rod.	Atoms per cent.	
	1.	2.		Gold.	Lead.
A.	6.01	6.00	6.005	6.29	93.71
B.	11.51	11.27	11.39	11.90	88.10
C.	20.38	20.39	20.385	21.20	78.80
D.	28.00	28.07	28.04	29.04	70.96
E.	41.45	41.47	41.46	42.65	57.35
F.	47.33	47.42	47.38	48.61	51.39
G.	57.97	58.21	58.09	59.28	40.72
H.	68.05	67.92	67.98	69.04	30.96
I.	81.38	81.47	81.42	82.15	17.85
J.	83.20	83.44	83.32	83.97	16.03
K.	89.06	88.78	88.92	89.39	10.61

III. Gold-Tin Alloys.

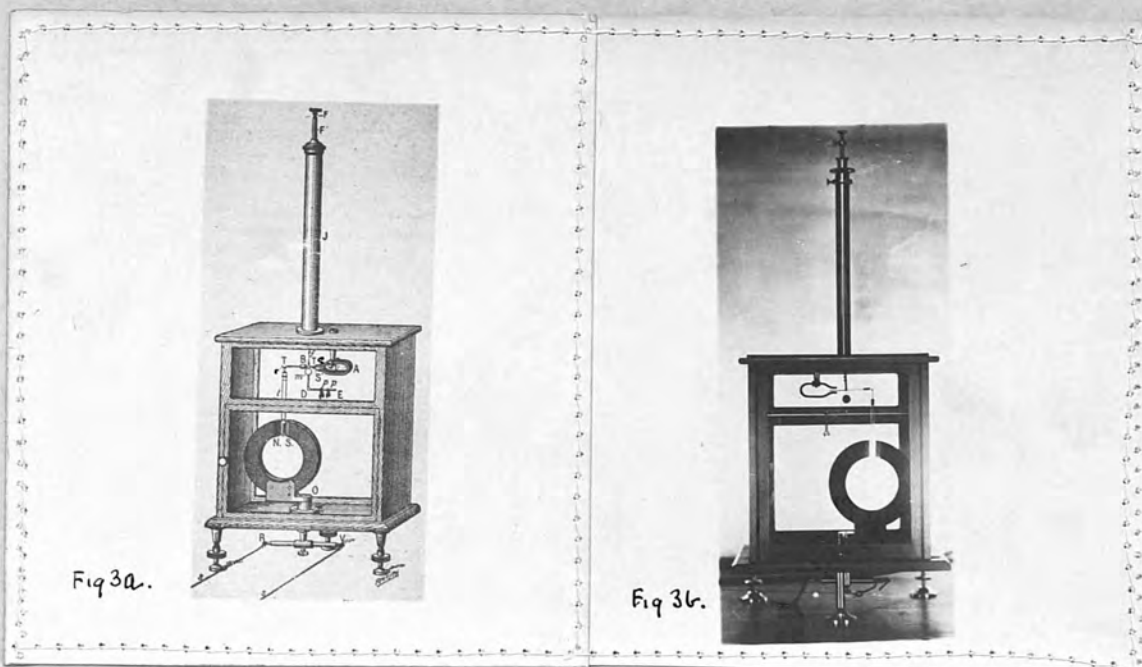
Alloy.	Weight Percentage Gold.		Mean Percentage gold in rod.	Atoms per cent	
	1.	2.		Gold.	Tin.
A.	9.05	8.95	9.00	5.63	94.37
B.	17.31	17.39	17.35	11.31	88.69
C.	26.19	26.41	26.30	17.72	82.28
D.	38.77	38.67	38.72	27.60	72.40
E.	47.26	47.42	47.34	35.17	64.83
F.	58.82	58.88	58.85	46.34	53.66
G.	67.81	67.41	67.60	55.73	44.27
H.	79.56	79.43	79.49	70.03	29.97
I.	89.75	89.80	89.77	84.14	15.86

IV. Gold-Cadmium Alloys.

Alloy.	Weight Percentage Gold.		Mean Percentage gold in rod.	Atoms per cent.	
	1.	2.		Gold.	Cadmium.
A.	10.84	11.09	10.96	6.57	93.43
B.	18.51	18.54	18.53	11.76	88.24
C.	32.23	31.95	32.09	21.25	78.75
D.	39.75	39.66	39.70	27.32	72.68
E.	49.81	49.96	49.88	36.00	64.00
F.	55.68	55.70	55.69	41.77	58.23
G.	66.59	66.77	66.68	54.15	45.85
H.	72.93	73.12	73.02	60.70	39.30
I.	87.22	87.22	87.22	79.38	20.62

Measurement of Magnetic Susceptibility.

The measurements were made by means of the magnetic balance of P. Curie and C. Chéneveau⁴ and the method consisted in comparing the susceptibility of the alloy in question with that of distilled water. The value adopted for water was $- 0.79 \times 10^{-6}$ as given by Curie⁴.



The instrument is a torsion balance with which the attraction or repulsion of a permanent magnet on a weighed quantity of a feebly magnetic substance can be measured.

TT', figs. 3a and b, is the copper arm of the torsion balance. At one end is a hook carrying a glass tube, t, containing the substance under examination and at the other is a flat piece of copper, C, which passes between the poles

of a small damping magnet, A. The oscillations of the arm are thus damped by the induced currents which are set up in C as it moves.

Below C, and parallel to it, is a piece of copper attached to the centre of TT' and bent at right angles at D. The tube, t, can be arranged symmetrically between the poles of the permanent horseshoe magnet NS by adjusting the weight B, which slides along TT', and a rider on DE.

The arm is supported by a fine platinum wire. In the original form of the balance the suspension was a platinum wire twisted to form a loop at each end.

One end was attached to a hook on the brass head, F, fixed at the top of the hollow brass cylinder J. The other end was attached to a hook carried on a piece of copper fixed vertically on TT' at f. The sensitiveness of the balance is obviously altered by using wires of different diameters and material.

The magnet, NS, can be displaced horizontally, between two fixed positions, by rotation around the axis O. The movement of the torsion wire is observed on a scale, graduated in millimetres, about two metres away, the light of a lamp fixed below the scale being reflected from the concave mirror m.

Theory of the Magnetic Balance.

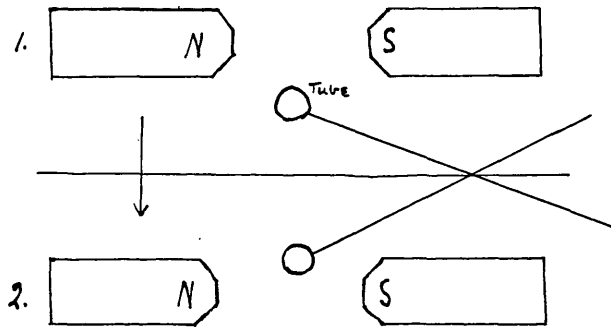


Fig 4.

The substance to be tested is attached to the arm of the torsion balance. The annular magnet can be moved horizontally so that its direction of motion is at right angles to the line joining the poles. The substance is thus brought into a stronger and stronger field.

When the tube lies between the poles of the magnet the deflection of the beam of the torsion balance is zero. The deflection increases as the magnet moves away and becomes a maximum when the magnet is in position, 1, Fig. 4.

As the magnet moves back to its mean position the deflection decreases and becomes zero again when the tube and magnet are parallel. If the magnet is moved still further, a deflection in the opposite direction is observed and this

becomes a maximum again when the magnet is in its other extreme position, 2, Fig. 4.

The two positions are fixed by stops against which the support of the magnet rests when it is in either of the maximum positions.

The deflections are taken as positive or negative, the sign depending on whether there is an attraction or repulsion.

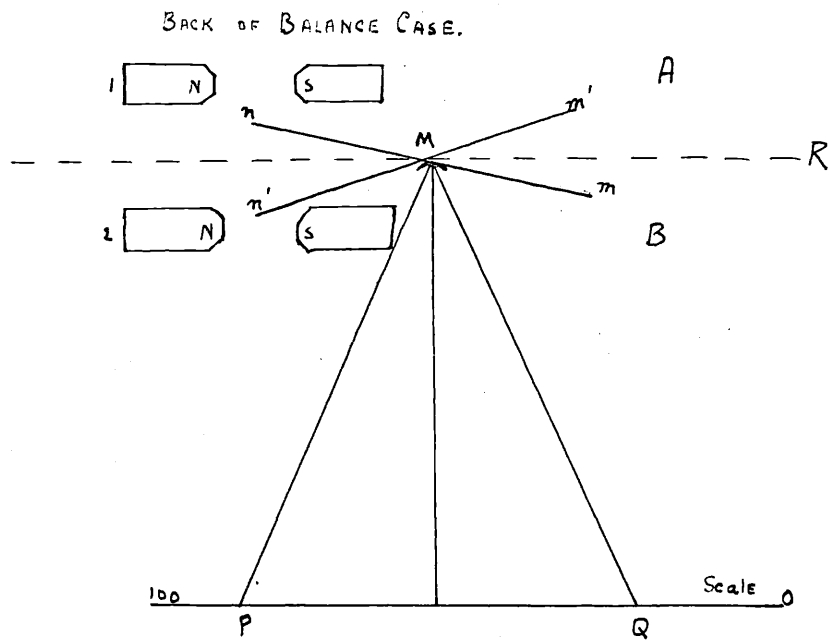
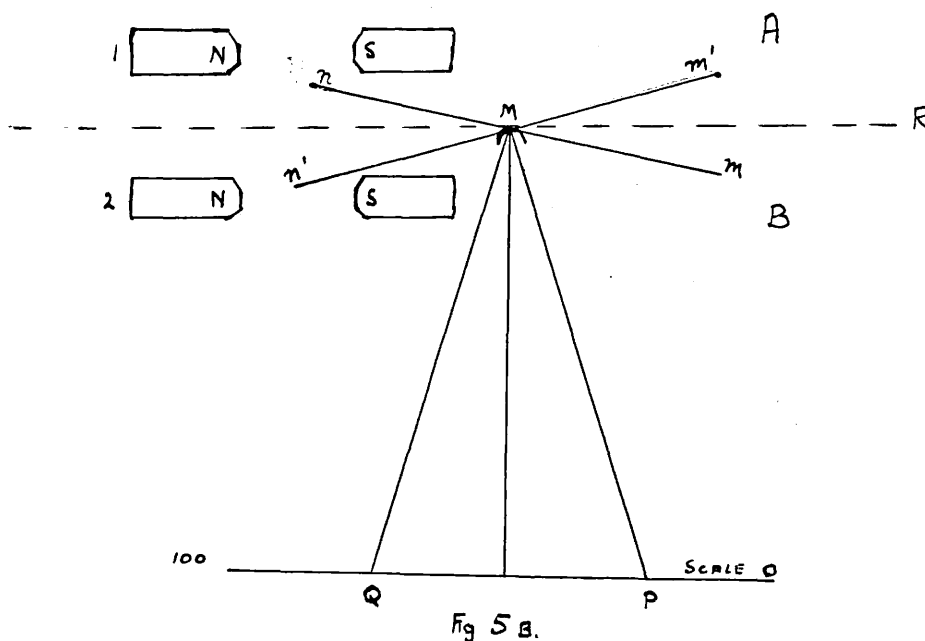


Fig 5A.

If A is the position of the magnet when at the back of the balance case, B the extreme position towards the front of the balance case and R the position of rest of the unloaded balance beam, the conditions for paramagnetic substances are shown in Fig. 5A. When the magnet is in the position A, there is an attraction and the balance arm lies as nm, therefore the light reflected from the mirror M illuminates the scale at P. When the magnet is in the B position, the balance arm

is at $n'm'$ and the spot of light is seen at Q.

Therefore, if the A reading is larger than the B, the substance is paramagnetic.



The conditions for diamagnetic substances are shown in Fig.5B.

When the magnet is in the position A, there is a repulsion and the balance arm lies as nm and the light on the scale is observed at P.

When the magnet is in the B position, the balance arm lies as $m'n'$ and the light on the scale is seen at Q. So that, if the A reading is less than the B reading the substance is diamagnetic.

The difference in the maximum deflections is observed for an empty tube, for the tube containing a mass of substance m , and the tube containing a known weight of

distilled water. The water fills the tube to the same height as the substance under investigation and so lies similarly in the magnetic field.

If Δ = difference of the readings in position A and B
for a substance mass m ,

Δ' = difference for water mass m' ,

Δ'' = difference for the empty tube,

then $\frac{k}{k'} = \frac{\Delta - \Delta''}{\Delta' - \Delta''} \cdot \frac{m'}{m} = r$ where k is the coefficient of magnetisation of the substance examined and k' that of water.

k' was taken as -0.79×10^{-6} , the value being that given by Curie⁴ as the best value for use when water is used as a comparison substance.

This formula is only approximate and does not take into consideration the magnetism of the air in the apparatus.

The corrected formula gives

$$\frac{k}{k'} = r \left[1 + .041 \left(\frac{1}{rD} + 1 \right) \right]$$

where D = the density of the substance.

The magnet used had a field of about 640 gauss.

All measurements were made at temperatures between 16° and 23°C .

Study of the magnetic susceptibility of the pure metals and alloys prepared.

The balance was arranged on a bench fitted with rubber shock-absorbers to minimise the effect of external vibrations. The material was enclosed in a glass tube shown in fig. 6.

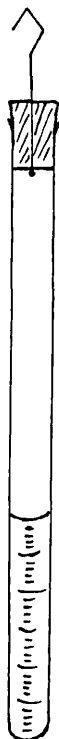


Fig 6.

The tube, 8 cms. long and of an internal diameter of 0.5 cms. was graduated from its base to about half its length. A cork carrying a copper hook fitted the open end of the tube. The length of hook was arranged so that the material in the tube lay at the centre of the field when the tube was suspended from the balance beam.

Some difficulty was experienced in taking readings with the balance in its original form. When the tube was allowed to come to rest, the magnet being in the A or B position, the light on the scale was not stationary but a gradual creep was observed.

Other suspensions, both phosphor-bronze and platinum, were tested and, since the creep remained, it was thought that the method of attaching the suspension to the beam and torsion head was unsatisfactory as the hooks could easily move with respect

to one another. The hook on the torsion balance was replaced by the arrangement shown in the diagram

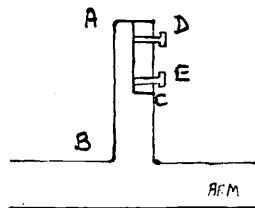


Fig 7.

A cylindrical piece of copper AB was attached to the balance beam. The copper was cut down the centre from A to C. The end of the suspension was wrapped in lead foil and fixed firmly between the copper sections by tightening the screws D and E.

A similar device was used to attach the other end of the suspension to the brass head fixed at the top of the hollow cylinder in which the wire hung.

Although this suspension diminished the amount of creep it did not eliminate it entirely.

It was then suggested that the creep might be due to a strain in the suspension itself.

When fine wires are drawn, strains may be set up between successive layers of the material. Some platinum wires were therefore annealed.

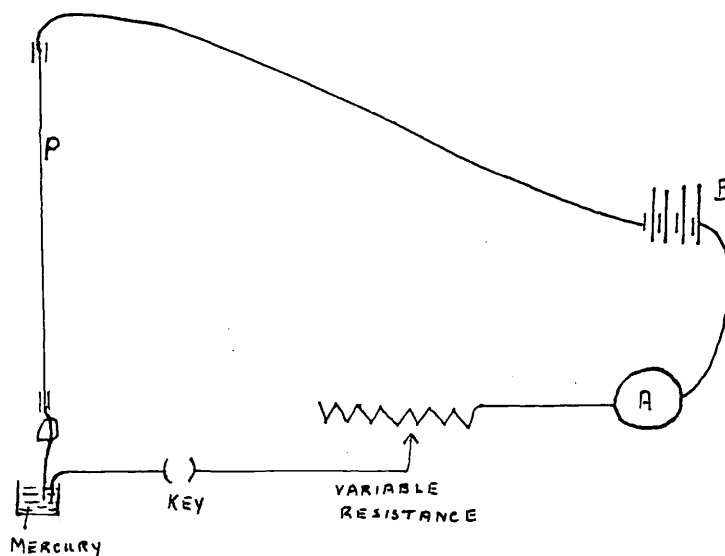


Fig 8.

The wire P was mounted in two binding screws. At one end a 20 gram weight was attached and connected to a wire passing into a cup of mercury. The other end was connected to some accumulators and a circuit completed through an ammeter, a rheostat and a key as shown in Fig. 8.

Beginning with a large resistance in R, the circuit was closed and the current increased gradually until the wire was as hot as the fingers could bear. The current was then doubled and kept steady. After half an hour, it was reduced gradually (the reduction of temperature taking about half an hour more) to zero and the wire allowed to become cold.

It was noticed that, during the heating, the wire untwisted itself - thus substantiating the presence of strain in the unannealed wire.

Annealed specimens of platinum wire of 0.05 and 0.10 millimetres diameter were mounted in the magnetic balance and tested.

It was found that the 0.05 mm. wire was too sensitive to the influence of the damping magnet and therefore not readily usable for the present purpose. The 0.10 mm. platinum wire gave no creep but as the deflections were very small it was difficult to read the differences accurately if the tube was allowed to come to rest and also a great deal of time was wasted in waiting for the oscillations to cease.

An oscillation method was therefore adopted. The permanent magnet was placed in the A position and the damping magnet moved, by a brass head on the top of the balance case, to a position fixed by a mark on the balance case.

The arm of the torsion balance then oscillated rapidly and, after 10 minutes or so, the oscillations died down sufficiently for the movement to be easily observed by the light on the scale.

Five successive turning points were taken, i.e. twice on one side and three times on the other and a mean calculated. This was repeated five times and a mean of the five values taken as the position of rest of the tube under those conditions. The magnet was then moved to the B position and the readings repeated. This method proved to be entirely satisfactory and gave results which were reproducible and, in the case of the metals, values of k which were in substantial agreement with previous work. In this way the difference could be measured to within 0.01 of a centimetre on a scale 2 metres away from the reflecting mirror.

Details of one set of Measurements.

The doors of the balance case were kept closed to avoid draughts and alterations in temperature. A thermometer was placed in the balance case and read from time to time. The keeper of the permanent magnet was placed in a certain position away from the balance and kept there while all the measurements were being made.

A clean weighed tube was suspended from the arm of the torsion balance and the rider moved until the tube hung symmetrically between the poles of the magnet. The light reflected on the scale was adjusted near the centre of the scale. The annular magnet was then moved to the A position and the arm allowed to oscillate.

Turning points in this and the B position were observed, as already described, and the difference calculated. The tube was then removed and a known weight of pure metal or alloy inserted. The tube was suspended and adjusted exactly as before and readings repeated.

The volume occupied by the pure metal or alloy was noted and the tube filled with distilled water to that volume. The tube plus water was weighed and the difference for the tube containing water observed.

Results obtained for Gold.

Tube, weight 3.2501 grams.

Temperature 20.5°C.

Turning points A Position.

Turning points B Position.

	32.95	19.25	
16.95			29.80
	32.70	19.45	
17.25			29.60
	32.40	19.70	
	<u>24.884</u>		<u>24.583</u>
17.45			29.40
	32.20	19.85	
17.60			29.25
	32.05	20.00	
17.85			29.10
	<u>24.879</u>		<u>24.587</u>
	31.80	20.15	
18.05			28.95
	31.65	20.30	
18.25			28.55
	31.45	20.45	
	<u>24.891</u>		<u>24.587</u>
18.45			28.70
	31.25	20.55	
18.65			28.55
	31.05	20.65	
18.85			28.45
	<u>24.900</u>		<u>24.583</u>
	30.90	20.75	
19.00			28.35
	30.75	20.85	
19.10			28.25
	30.55	21.00	
	<u>24.891</u>		<u>24.583</u>
	MEAN = <u>24.889</u>		MEAN = <u>24.585</u>
			Difference = +.30.

Gold.

Weight 1.3768 grams.

Turning Points A Position.

Turning Points B Position.

	34.55	16.30	30.30
11.35	34.30	16.40	30.10
11.65	34.05	16.60	<u>23.316</u>
<u>22.900</u>		16.80	29.95
11.95	33.75	16.95	29.70
12.20	33.45		<u>23.312</u>
12.50		17.10	29.40
<u>22.906</u>	33.20	17.30	29.25
12.75	32.90	17.40	<u>23.296</u>
13.00	32.65		29.10
<u>22.888</u>		17.60	28.95
13.30	32.40	17.75	28.75
13.50	32.15		<u>23.304</u>
13.70	31.85	17.90	28.65
<u>22.887</u>		18.00	28.50
14.05	31.60	18.15	<u>23.296</u>
14.30	31.40		
<u>22.896</u>			
MEAN = <u>22.895</u>			MEAN = <u>23.305</u>

Difference = +.41.

Tube plus water.

Weight tube + water = 3.3679 grams

" water = .1178 "

Turning points A Position.

Turning points B Position.

13.30		16.10	
	35.20		32.70
13.60		16.30	
	34.85		32.50
13.90		16.50	
		<u>24.450</u>	
<u>24.312</u>			32.30
	34.60	16.75	
14.15			32.05
	34.30	16.95	
14.45			31.85
	34.05	<u>24.458</u>	
<u>24.308</u>		17.15	
14.70			31.70
	33.80	17.30	
14.95			31.50
	33.50	17.50	
15.20		<u>24.458</u>	
<u>24.300</u>			31.30
	33.30	17.70	
15.50			31.10
	33.00	17.90	
15.70		<u>24.450</u>	30.90
	32.80		
<u>24.316</u>		18.10	
15.95			30.75
	32.55	18.20	
16.20			30.60
	32.35	18.40	
16.40		<u>24.454</u>	
<u>24.316</u>			
MEAN = <u>24.310</u>			MEAN = <u>24.454</u>
		Difference = -.14	

$$\begin{aligned}k \text{ (approx)} &= \frac{\Delta' - \Delta''}{\Delta' - \Delta''} \cdot \frac{m'}{m} \cdot k' \quad (\text{see Page 33}) \\&= \frac{-0.41 - 0.30}{-0.14 - 0.30} \cdot \frac{0.1178}{1.3768} \cdot -0.79 \times 10^{-6} \\&= \frac{-0.71}{-0.44} \cdot \frac{0.1178}{1.3768} \cdot -0.79 \times 10^{-6} \\&= -0.11 \times 10^{-6}\end{aligned}$$

$$\begin{aligned}k \text{ (corrected)} &= -0.11 \times 10^{-6} \left[1 + 0.041 \left(\frac{-0.79}{-0.11 \times 19.27} + 1 \right) \right] \\&= -0.119 \times 10^{-6}\end{aligned}$$

The density of gold = 19.268.²¹

Results for Silver-Lead Series.

Material	wt. in grams	Differences.			wt. water in grams	*Density	Temp ^o C.	k × 10 ⁶
		Empty Tube	Material	Water				
LEAD	.7210	+ .39	+ .29	+ .28	.1235	11.38	19	- .131
Alloy A	.7405	..	+ .29	..	..	11.22	..	- .128
" B	.8607	..	+ .24	..	..	11.18	..	- .141
" C	.7340	..	+ .29	..	..	11.10	..	- .113
" D	.5894	..	+ .31	..	..	11.07	19.5	- .128
" E	.6634	..	+ .33	..	..	11.00	19	- .086
" F	.7171	..	+ .62	..	..	10.92	..	+ .299
" G	.6767	..	+ 1.88	..	..	10.85	..	+ 2.02
" H	.5605	..	+ 2.09	..	..	10.70	..	+ 2.23
" I	.6970	..	+ 1.37	..	..	10.63	..	+ 1.30
" J	.7210	..	+ .74	..	..	10.51	..	+ .44
Silver	.7210	+ .31	+ .08	+ .03	.1447	10.47	..	- .138

*Density values given by Maey.²¹

Pb

Ag

CURVE 1.

LEAD - SILVER

+2

+1.5

+1

+0.5

0

-0.5

-1

-1.5

-2

Pb

Ag

$K \times 10^6$

20

40

60

80

WEIGHT PER CENT



Results for Gold-Lead Series.

Material	wt. in grams	Differences.			wt. water in grams	*Density	Temp ^o C.	k × 10 ⁶
		Empty Tube	Material	Water				
Lead	.7210	+ .39	+ .29	+ .28	.1235	11.38	19	- .131
Alloy A	.9706	+ .03	- .73	- .04	.1252	11.68	21	- 1.16
" B	.7763	..	- .45	..	..	12.02	..	- .91
" C	1.0598	-	- .45	..	..	12.52	21.5	- .67
" D	.9143	..	- .26	..	..	13.00	..	- .47
" E	1.2330	..	+ .14	-	..	13.92	..	+ .20
" F	.9286	+ .30	- .12	+ .09	.1284	14.38	22.5	- .23
" G	.8995	..	- .27	..	..	15.08	21.8	- .33
" H	1.2473	..	- .21	..	..	15.78	22	- .21
" I	1.2892	..	- .45	..	..	17.22	..	- .29
" J	1.1731	..	- .44	..	..	17.42	22.2	- .33
" K	1.3045	..	- .41	..	..	17.98	..	- .05
Gold	1.3768	..	- .41	- .14	.1778	19.27	20.5	- .119

*Density values given by Maey.²¹

Pb

Au

CURVE 2
LEAD-GOLD

+1

+0.5

0

-0.5

-1

K x 10⁶

20

40

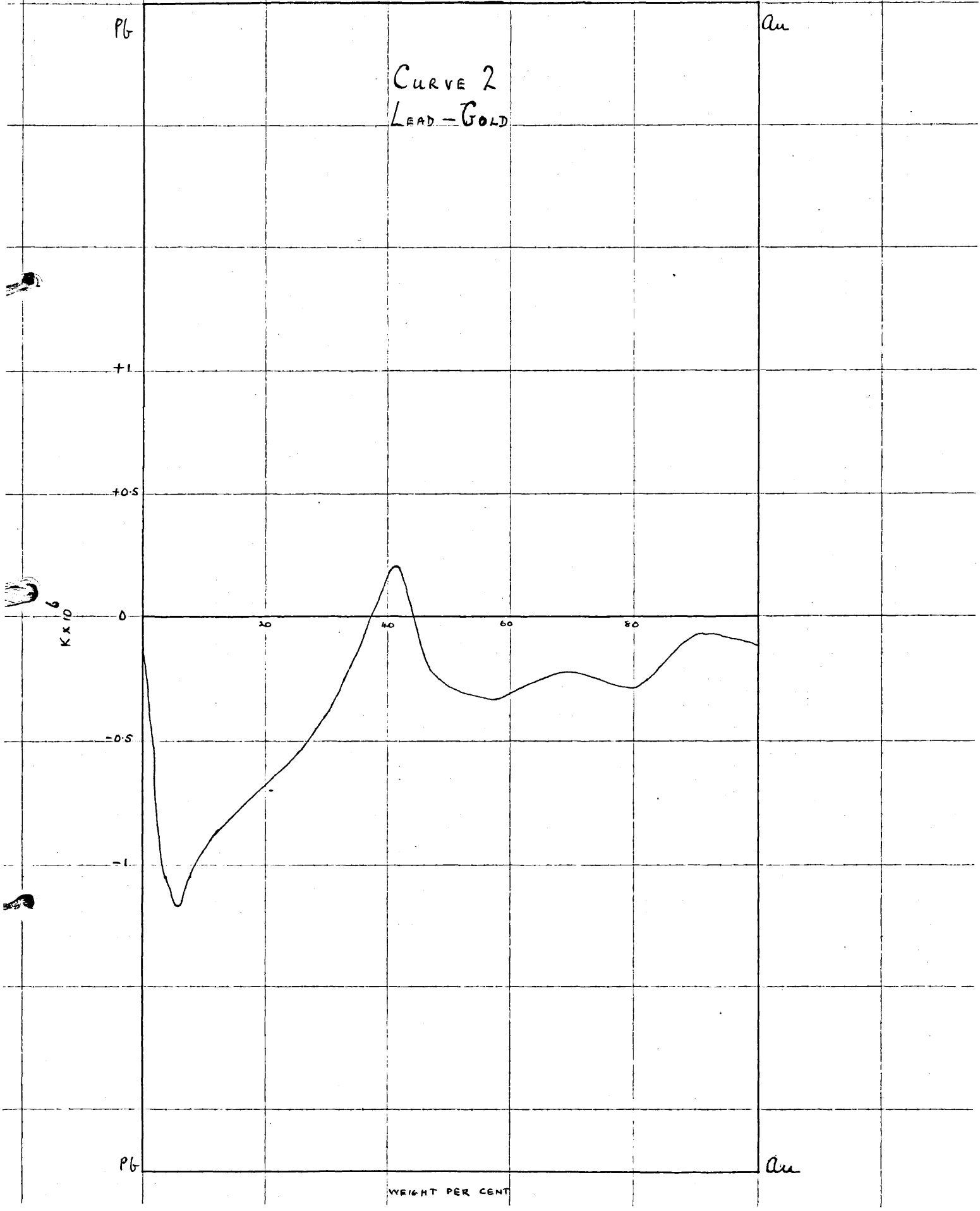
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80

Pb

Au

WEIGHT PER CENT



Results for Lead-Tin Series.

Material	wt. in grams	Differences.			wt. water in grams	*Density	Temp °C	k x 10 ⁶
		Empty Tube	Material.	Water.				
TIN	.5812	- .12	+ .02	- .46	.1123	7.29	20	+ .051
Alloy A	.5613	+ .24	+ .41	- .33	.1196	7.36	22	+ .050
" B	.4800	..	+ .30	..	..	7.70	..	+ .018
" C	.5325	..	+ .30	..	..	7.78	..	+ .016
" D	.6188	..	+ .25	..	..	8.05	..	+ .003
" E	.6497	..	+ .13	..	..	8.80	..	- .031
" F	.5568	..	+ .08	..	..	9.13	..	- .051
" G	.6633	..	+ .05	..	..	9.45	..	- .063
" H	.7418	..	- .16	..	..	10.15	..	- .10
" I	.6878	..	- .17	..	..	10.51	..	- .11
Lead	.7210	+ .39	+ .29	+ .28	.1235	11.38	19	- .131

*Density values given by Maey.²¹

Pb

Sn

CURVE 3

LEAD-TIN

+1

+0.5

$K \times 10^6$

0

20

40

60

80

-0.5

-1

Pb

Sn

WEIGHT PER CENT



Results for Gold-Tin Series.

Material	wt. in grams	Differences.			wt. water in grams	*Density	Temp ^o C.	k × 10 ⁶
		Empty Tube	Material	Water				
Tin Tin	.5812	-.12	+ .02	-.46	.1123	7.29	20	+ .051
Alloy A	.5122	+ .07	+ .23	+ .29	.1228	7.74	16	- .150
" B	.6045	"	+ .13	"	"	8.20	"	- .046
" C	.6029	"	+ .20	"	"	8.68	"	- .110
" D	.6301	+ .32	+ .11	+ .19	.1196	9.58	17.5	- .25
" E	.6882	"	- .06	"	"	10.28	"	- .42
" F	.7387	- .55	+ .33	+ .02	.1244	11.34	18.5	- .27
" G	.7997	"	+ .15	"	"	12.50	"	- .16
" H	.9180	"	+ .15	"	"	14.66	"	- .14
" I	.9167	"	+ .17	"	"	16.88	"	- .137
Gold	1.3768	+ .30	- .41	- .14	.1178	19.27	20.5	- .119

*Density values given by Maey.²¹

Sn

Au

CURVE 4
TIN - GOLD

+1

+0.5

K x 10⁶

0

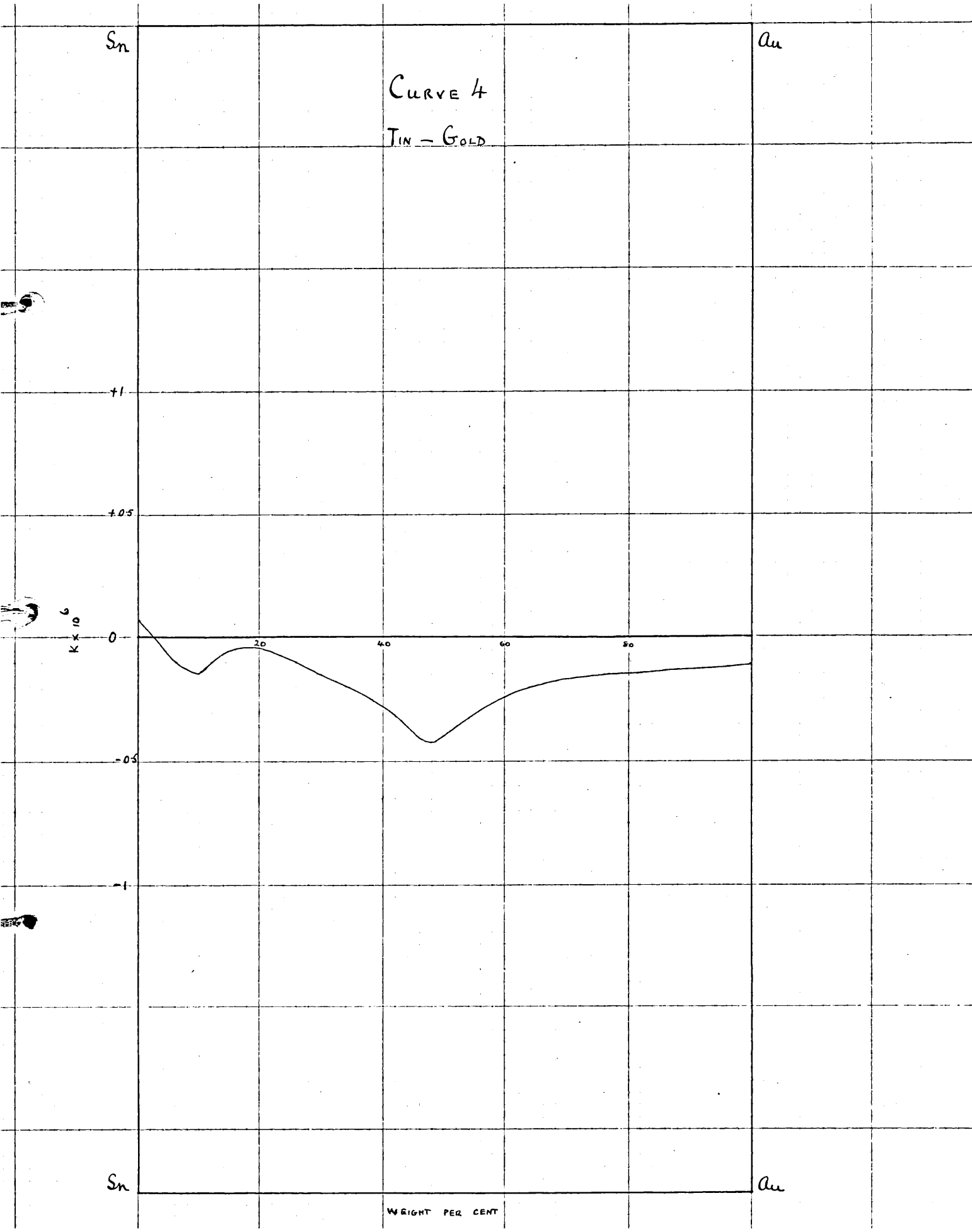
-0.5

-1

Sn

Au

WEIGHT PER CENT



Results for Bismuth-Tin Series.

Material	wt. in grams	Differences.			wt. water in grams	Density	Temp ^o C.	k × 10 ⁶
		Empty Tube.	Material.	Water.				
Bismuth	.6021	+ .39	- .36	+ .29	.1086	9.82	20	- 1.12
Alloy A	.6705	- .12	- .07	- .46	.1123	9.57	..	- .048
" B	.6238	+ .19	+ .11	- .07	.1128	9.28	..	- .049
" C	.6685	..	- .03	..	..	8.91	..	- .118
" D	.6745	..	- .15	..	..	8.57	..	- .181
" E	.5762	..	- .05	..	..	8.40	..	- .15
" F	.5648	..	+ .14	..	..	8.22	..	- .035
" G	.6310	..	+ .11	..	..	7.97	..	- .046
" H	.5201	..	+ .15	..	..	7.64	..	- .035
" I	.5390	..	+ .12	..	..	7.42	..	- .025
Tin	.5812	- .12	+ .02	- .46	.1123	7.29	..	+ .051

*Density values given by Maey. 21

Bi

Sn

CURVE 5

BISMUTH-TIN

+1

+0.5

0

-0.5

-1

$K \times 10^6$

20

40

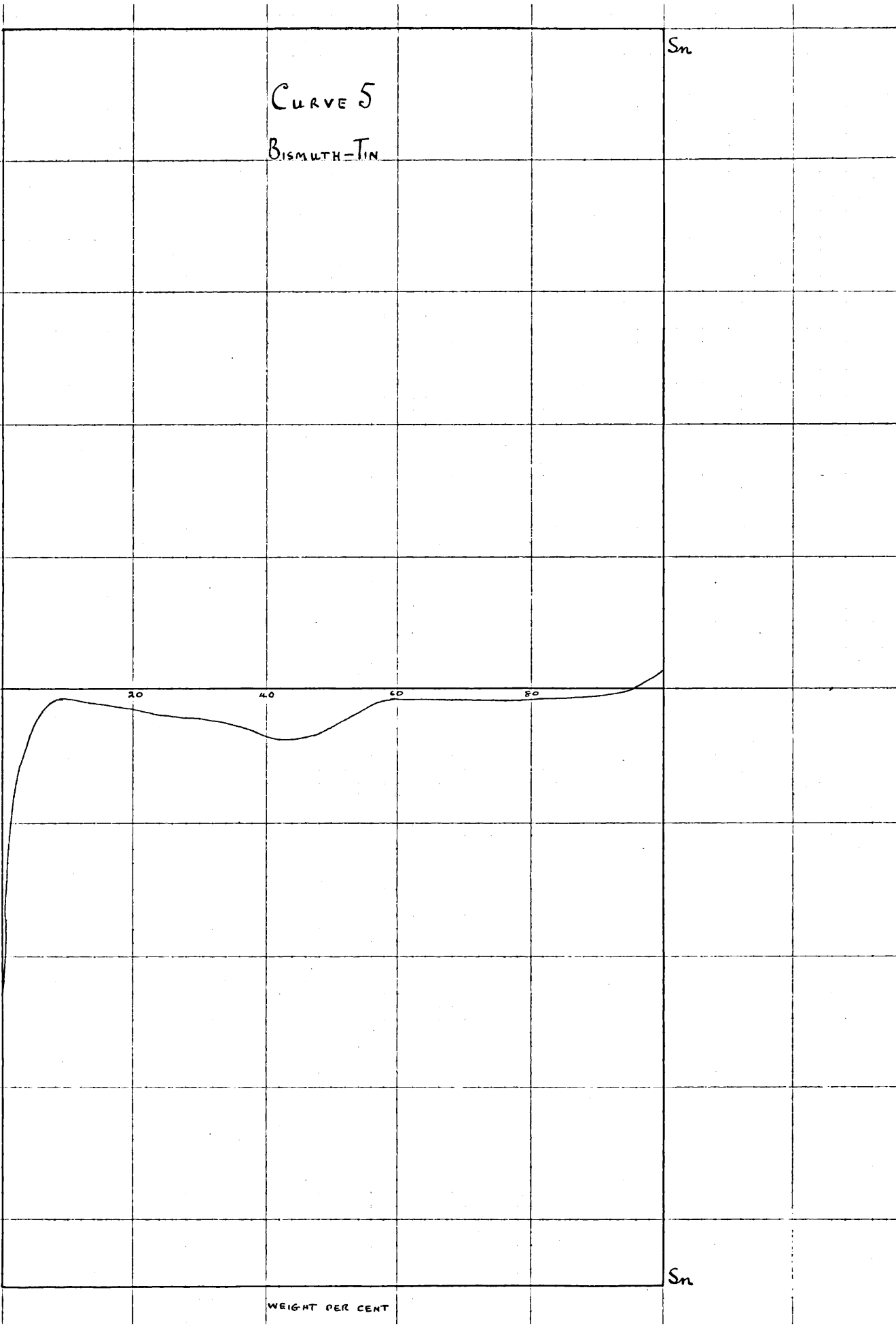
60

80

Bi

Sn

WEIGHT PER CENT



Results for Aluminium-Tin Series.

Material	wt. in grams	Differences.			wt. water in grams	*Density	Temp °C.	k × 10 ⁶
		Empty Tube	Material	Water				
Tin	.5812	-.12	+ .02	-.46	.1123	7.29	20	+ .051
Alloy A	.5023	+ .23	+ .27	+ .28	.1205	6.85	17	-.019
" B	.3280	-.45	-.24	-.24	.1208	5.54	20	-.30
" C	.2815	-.07	-.19	+ .12	.1205	5.08	18	-1.03
" D	.3387	"	-.16	"	"	4.46	"	-.67
" E	.5332	+ .07	+ .53	+ .29	.1228	3.81	"	-.40
" F	.5910	-.45	-.19	-.24	.1201	3.54	20	-.20
" G	.5455	-.07	+ .20	+ .29	.1228	3.22	18	-.031
" H	.5591	-.05	-.06	-.10	.1251	3.00	"	-.05
" I	.2058	+ .17	+ .19	+ .43	.1086	2.85	"	-.043
Aluminium	.2127	+ .02	-.86	+ .61	.1150	2.68	17.5	+ .64

*Density values given by Shepherd. ²²

Al

Sn

CURVE 6

ALUMINIUM-TIN

+1

+0.5

0

-0.5

-1

$K \times 10^6$

20

40

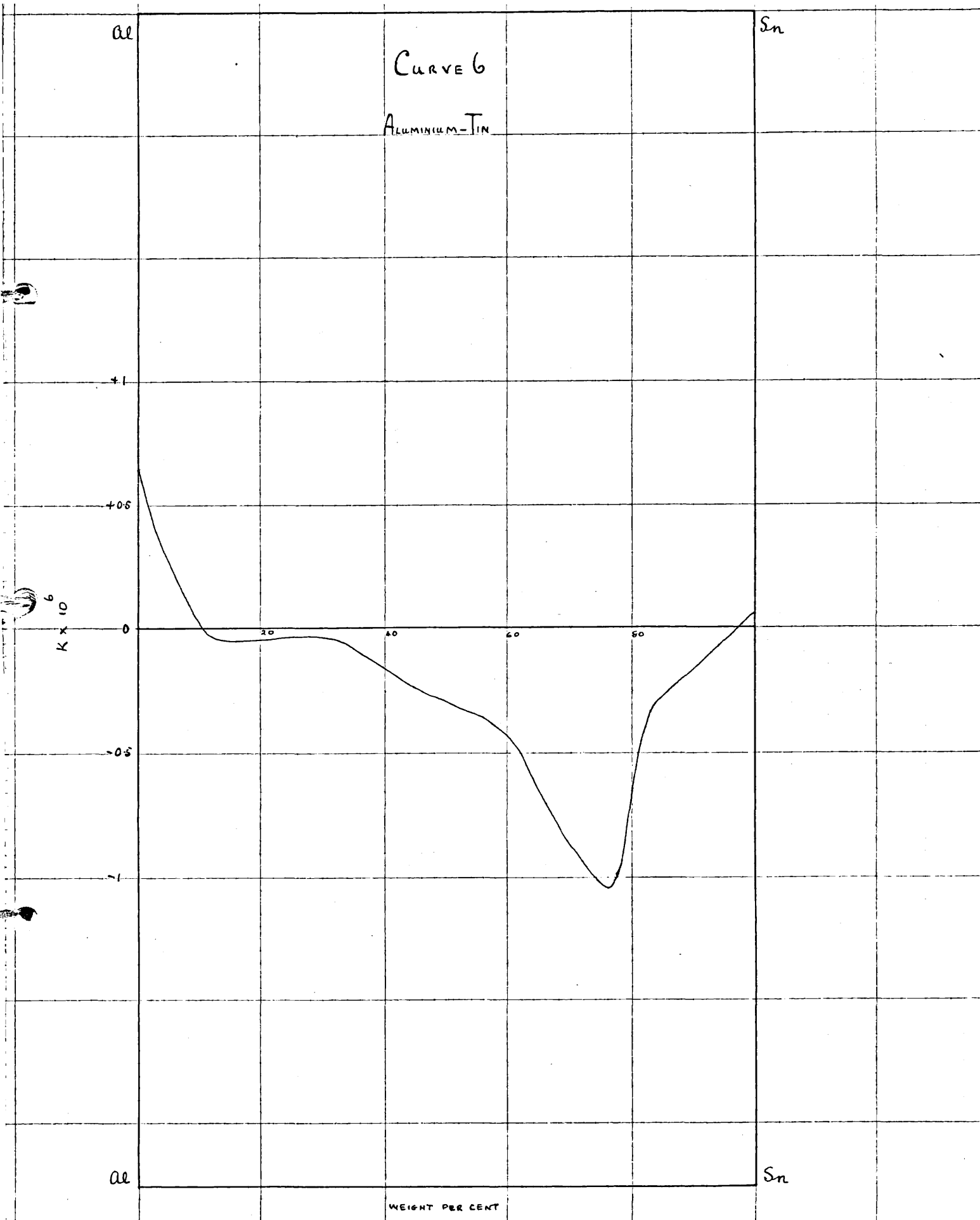
60

80

Al

Sn

WEIGHT PER CENT



Cadmium Tin Series.

Material	wt. in grams	Differences.			wt. water in grams	*Density	Temp °C.	k × 10 ⁸
		Empty Tube	Material	Water				
Tin	.5812	-.12	+ .02	-.46	.1123	7.29	20	+ .051
Alloy A	.5516	+ .27	+ .29	+ .18	.1036	7.40	22	+ .03
" B	.5441	..	+ .28	..	..	7.58	..	+ .013
" C	.5371	..	+ .26	..	-	7.75	..	- .014
" D	.5374	..	+ .26	..	..	7.89	..	- .022
" E	.5947	..	+ .24	..	..	7.94	..	- .049
" F	.5927	..	+ .23	..	..	8.33	..	- .068
" G	.6425	..	+ .19	..	-	8.42	..	- .097
" H	.6320	..	+ .26	..	..	8.50	..	- .019
" I	.6132	..	+ .25	..	..	8.63	..	- .035
Cadmium	.5733	+ .16	- .09	+ .19	.1056	8.67	19	- .118

*Density values given by Maey²¹

Cd

Sn

CURVE 7

CADMIUM-TIN.

+1

+0.5

0

-0.5

-1

$K \times 10^6$

20

40

60

80

Cd

Sn

WEIGHT PER CENT



Cadmium - Gold Series.

Material	wt. in grams	Differences.			wt. water in grams	*Density	Temp ^o C.	k x 10 ⁶
		Empty Tube	Material	Water				
Cadmium	.5433	+ .16	- .09	+ .19	.1056	8.67	19	- .118
Alloy A	.6511	+ .29	+ .41	+ .07	.1107	9.58	23	+ .070
" B	.6574	..	+ .36	..	..	10.11	..	+ .041
" C	.6134	..	+ .367	..	..	11.15	..	+ .050
" D	.6743	..	+ .21	..	..	11.70	..	- .051
" E	.6035	..	+ .19	..	..	12.57	..	- .071
" F	.7483	..	+ .36	..	..	13.13	..	+ .044
" G	1.1314	..	+ .40	..	..	14.50	..	+ .040
" H	.7746	..	+ .37	..	..	15.49	..	+ .042
" I	1.0072	..	+ .24	..	..	17.69	..	- .021
Gold	1.3768	+ .30	- .41	- .14	.1178	19.27	20.5	- .119

*These values were obtained by experiment.

Cd

Au

CURVE 8.

CADMIUM - GOLD.

+1

+0.5

0

-0.5

-1

$K \times 10^6$

20

40

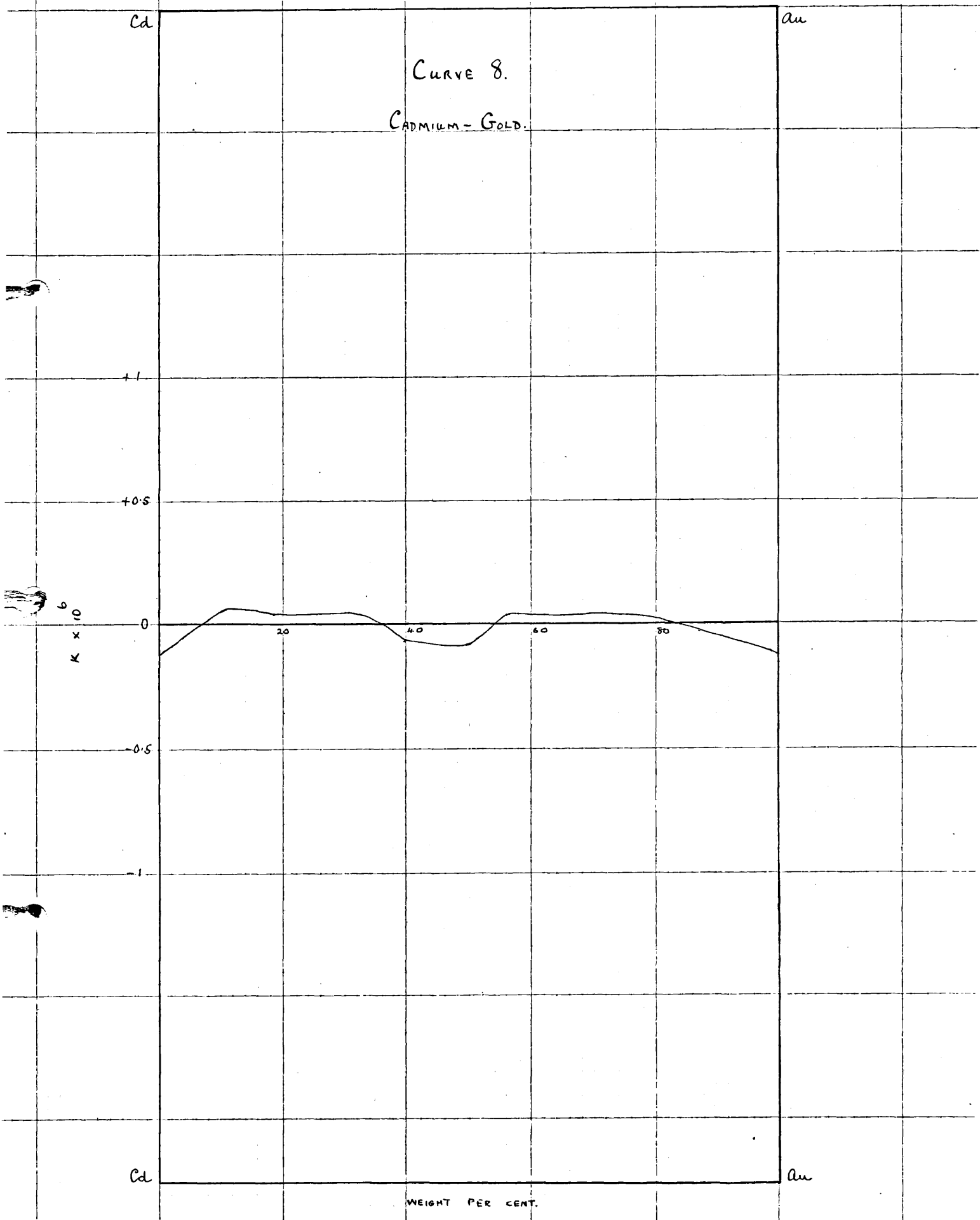
60

80

Cd

Au

WEIGHT PER CENT.



Values for the densities of cadmium-gold alloys could not be found and they were determined.

A microburette was calibrated with mercury, the level of the mercury being read with a cathetometer.

If W is the weight of mercury between two readings

t the temperature of the mercury

then the volume $V = 0.0735(1 + 0.000182t)W$ ccs.

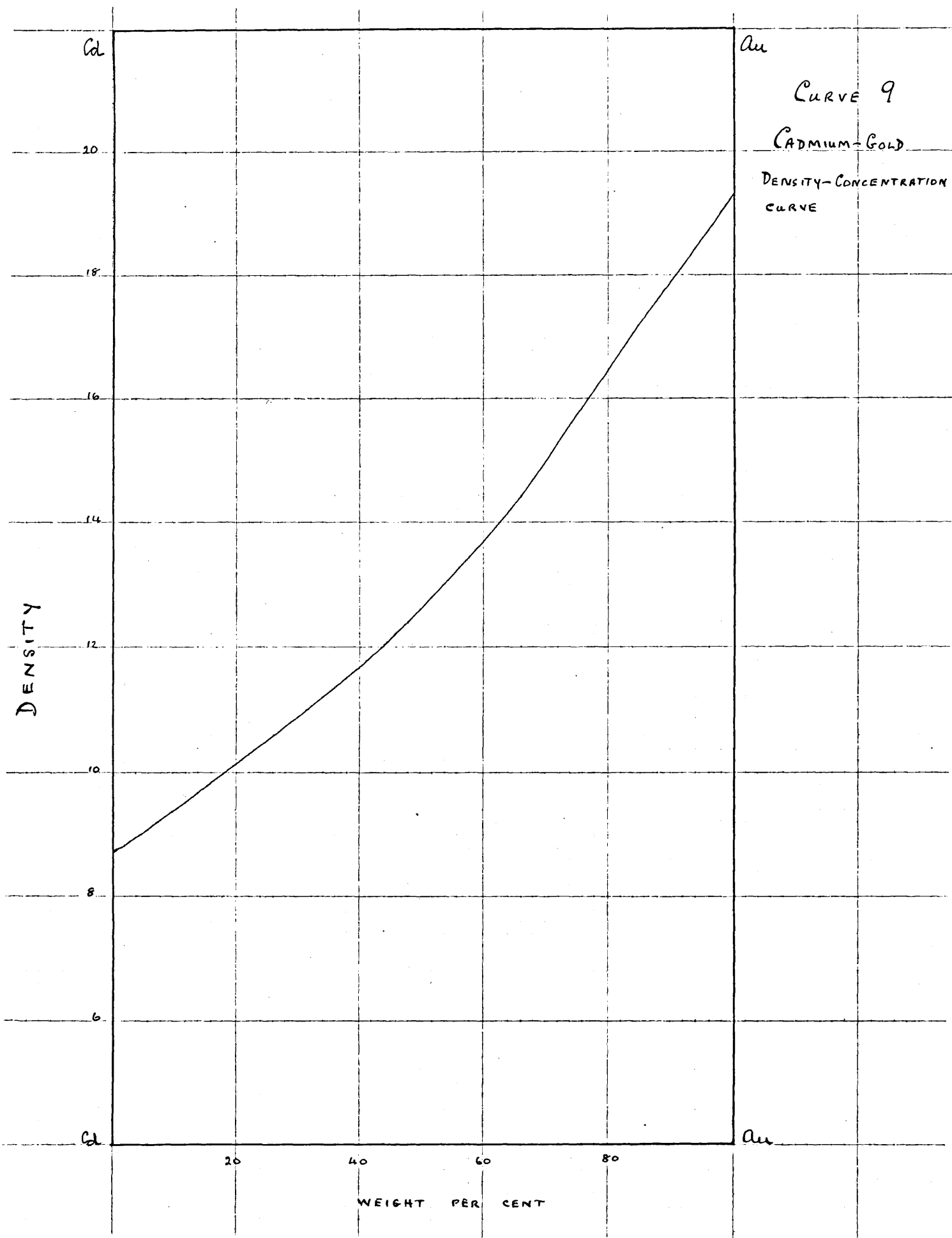
By plotting volumes against successive cathetometer readings a curve, showing the variation in volume of the burette over the range examined, was obtained.

The burette was then filled with water to a level a little above that at which the calibration began. The cathetometer was then used to fix the position of a particular line on the burette so that, if the burette was moved while the alloy was dropped in and the air bubbles removed by tapping, it could be adjusted to its original position before the new height of water was observed.

The alloy, of known weight, was dropped into the burette and all air bubbles were removed by tapping. The burette was then adjusted, if necessary, to the position occupied before the addition of the alloy and the new level of water read through the cathetometer. The difference in the readings was a measure of the volume of the alloy. Noting the exact part of the calibrated range at which this difference was measured, the volume of the alloy was obtained from the calibration curve.

Results.

Alloy.	Cathetometer Readings.		Difference.	Volume from Curve.	Wt. of alloy.	Density.
	1.	2.				
A.	96.09	96.51	.42	.068 cc	.6511 g	9.58
B.	96.51	96.91	.40	.065 "	.6574 "	10.11
C.	96.91	97.22	.31	.055 "	.6134 "	11.15
D.	-	-	-	-	-	-
E.	97.24	97.52	.28	.048 "	.6035 "	12.57
F.	97.52	97.86	.34	.057 "	.7483 "	13.13
G.	97.86	98.32	.46	.078 "	1.1314 "	14.50
H.	98.32	98.61	.29	.050 "	.7746 "	15.49
I.	98.61	98.96	.35	.057 "	1.0072 "	17.67



Discussion of Susceptibility - Concentration Curves.

It appeared to be of interest to examine the magnetic susceptibility with the object of ascertaining, whether or no, there is any similarity between the variation of this property with composition and the variation of other physical properties.

The main object of this comparison was to determine whether the measurement of magnetic susceptibility may furnish a ready means of detecting the formation of compounds and other changes in alloys.

With this object in view, curves have been prepared from existing data, as far as that is available, giving the variation of density, freezing-point and electrical conductivity respectively with composition and these have been compared with the corresponding curve for magnetic susceptibility-composition.

Density - Composition Curves.

In the case of density-composition curves²¹ there is obviously no similarity nor analogy to be found, the density curves are all perfectly smooth and regular whereas the susceptibility curves show both maxima and minima in most cases. (Curves 1, 2, 4, 8).

It is however to be noted that the variation of susceptibility with composition, in some cases, is very much greater than the variation of density.

Thus -

Silver-Lead alloys.	Composition wt.per cent Silver.	$k \times 10^6$	Density.	Percentage Change k.	Change D.
	52.36	+0.299	10.917	+570	-0.659
	61.20	+2.02	10.845		
	70.79	+2.23	10.695	+10.4	-1.383

Magnetic susceptibility thus appears to be very much more sensitive to variations in composition than density and consequently the measurement of susceptibility would be a more delicate means of detecting a small change in composition than the density.

Freezing-Point - Concentration Curves.

(a) Silver-Lead System.

The freezing-point-concentration curve²³ for silver lead (Curve 10) indicates the presence of an entectic at 2.5 grams or 4 atoms per cent silver, but there is no indication of intermetallic compounds.

The corresponding susceptibility curve shows a marked inflection at a little over 50 grams or 65.75 atoms per cent silver and the curve then rises steeply to a maximum at about 70 grams or 81.8 atoms per cent silver. This maximum can hardly represent the presence of a pure intermetallic

compound and, as yet, the reason for the maximum is not apparent. Still in view of Stefan Meyer's conclusions (Page 8) a compound would seem to be indicated.

(b) Gold-Lead System.

In this case, the freezing-point-concentration²⁴ curve indicates the formation of two compounds, i.e. Au₉Pb and AuPb₂ (Curves 11).

The corresponding susceptibility curve shows a minimum at 6 atoms per cent gold and a maximum at 48 atoms per cent gold.

These two points do not represent the presence of inter-metallic compounds but, as the alloys were not annealed, this may be due to the fact that the compounds had not been formed that is, the alloy was in a metastable condition, as it could easily be from the method by which it was prepared.

(c) Lead-Tin System.

On the freezing-point-concentration curve²⁵ an entectic point occurs at 75 atoms per cent tin. There is no indication of the formation of intermetallic compounds. (Curves 12)

The susceptibility-concentration curve is in agreement with this. The curve is smooth and generally obeys the "mixture law", that is, the value of the magnetic susceptibility is directly proportional to the percentage of each constituent present.

Thus

Composition Wt. per cent tin.	$k \times 10^3$ Calculated	Observed.
81.5	+0.0165	+0.018
52.6	-0.0368	-0.031
36.1	-0.0657	-0.063
20.4	-0.0941	-0.10

(d) Gold-Tin System.

Maxima corresponding to the compounds AuSn, AuSn₂ and AuSn₄ are indicated on the freezing-point concentration curve.²⁶ (Curves 13).

The corresponding susceptibility curve forms a minimum at 35 atoms per cent gold and this point corresponds with the composition of a compound AuSn₂, the ratio of atoms per cent being $\frac{1}{1.99}$. Between 10 and 30 grams per cent gold the formation of a maximum, at about 19.5 atoms per cent gold, points to the presence of a compound the ratio of atoms per cent being $\frac{1}{4.1}$, that is, the compound AuSn₄.

The susceptibility curve does not indicate the presence of the compound AuSn and again this is probably due to the fact that the alloys were not annealed. This is supported, in this case, by the fact that in the region at which the ratio of atoms per cent is 1, the mixture law does not hold.

Thus

Atoms per cent Gold.	$k \times 10^6$ Calculated	Observed.
43.34	-0.028	-0.27
55.74	-0.033	-0.16
70.03	-0.068	-0.14

(e) Bismuth-Tin Series.

An entectic point occurs on the freezing-point-concentration curve²⁷ at 43 atoms per cent bismuth but there is no indication of the presence of intermetallic compounds (Curves 14).

The susceptibility-concentration curve shows no formation of compounds. It must be noted, however, that the curve rises steeply towards the paramagnetic region between 100 and 95 grams per cent bismuth and causes the mixture law to be broken over the range rich in bismuth. This is of interest in view of the fact that bismuth is the most strongly diamagnetic element known.

(f) Aluminium-Tin System.

The freezing-point-concentration curve²⁸ shows an entectic point at 99.52 atoms per cent tin but indicates no compound formation (Curves 15). The corresponding susceptibility curve has a marked minimum at about 42 atoms per cent tin. At this point the ratio of atoms per cent of the constituents is $\frac{1}{1.37}$, that is, the ratio is not simple and the point apparently

does not represent a compound but the minimum may resolve itself into the value for a definite intermetallic compound when the particular alloy is annealed.

(g) Cadmium-Tin System.

These metals form an eutectic mixture at 67.6 atoms per cent tin. The freezing-point-concentration curve²⁹ does not indicate the presence of intermetallic compounds.

(Curves 16)

The corresponding susceptibility curve is in agreement with this and is analagous to that of the lead-tin system.

(h) Cadmium-Gold Series.

Compounds Au_4Cd_3 and $AuCd_3$ are deduced from the freezing-point-concentration curve.³⁰ (Curves 17)

The break between 21 and 42 atoms per cent gold, on the susceptibility-concentration curve, occurs at the region of formation of $AuCd_3$.

The form of the curve lends support to the view that, in unannealed alloys, retarded compound formation produces flattened maxima and minima.

Electrical Conductivity - Concentration Curves.

(a) Silver-Lead System.

Mattheissen³¹ has examined silver-lead alloys of from 95.9 to 19.9 atoms per cent lead and, over that range, he found that the electrical conductivity decreased regularly with increasing percentage of lead. Thus, there is no indication of the formation of silver-lead compounds.

The corresponding susceptibility curve indicates no compounds but a maximum is formed at 82 atoms per cent silver, an irregularity which is not reflected in any way by the conductivity curve.

(b) Gold-Lead System.

The conductivity-concentration curve³¹ (Curves 11) shows a change in direction at 84.25 volumes or 75.19 atoms per cent lead. At this point the ratio of atoms per cent is 1 Au:3Pb, that is, a compound AuPb₃ is possibly represented. Such a compound is not indicated by the freezing-point-concentration nor the susceptibility curves. The maximum and minimum of the later do not represent the presence of simple compounds.

(c) Lead-Tin System.

Mattheissen's conductivity-concentration curve³¹ (Curves 12) is perfectly smooth and regular. Thus all three curves - conductivity-concentration, freezing-point-concentration and susceptibility-concentration - for this system are analagous. No intermetallic compounds are indicated and the susceptibility values follow the mixture law throughout.

(d) Gold-Tin System.

In this case the conductivity-concentration curve³¹ (Curves 13) shows two breaks, at 29 and 51 atoms per cent gold respectively. At these points the ratio of gold to tin in atoms per cent is $\frac{1}{2.4}$ and $\frac{1}{1.05}$ respectively. Thus the formation of AuSn is possibly indicated. The corresponding susceptibility curve has been shown to indicate the presence of AuSn₂, AuSn₄ and the divergence from the mixture law at 50 atoms per cent of the pure metals points to the possibility of AuSn being found.

(e) Bismuth-Tin System.

The conductivity-concentration³¹ and susceptibility - concentration curves (Curves 14) are analagous in showing no compound formation and both agree in this way with the freezing-point concentration curve.

There is a similarity, also, in the way in which large variations in electrical conductivity and magnetic susceptibility take place in the alloys rich in bismuth. Thus, the conductivity value falls from 1.03 to 0.245 between 99.86 and 99.36 grams per cent bismuth while the magnetic susceptibility changes from -1×10^{-6} to -0.75×10^{-6} over the same range.

(f) Aluminium-Tin System.

No information as to the electrical conductivity of this system could be found in the literature, consequently no comparison can be made.

(g) Cadmium-Tin Series.

The conductivity-concentration curve³¹ (Curves 16) for these alloys is smooth, that is, no compounds are indicated. The corresponding susceptibility curve is of a similar form and, as in the case of the lead-tin alloys, agrees with that of both freezing-point and electrical conductivity.

(h) Cadmium-Gold System.

Saldau³² has shown that the electrical conductivity-concentration curve (Curves 17) for these alloys contains two maxima at 50 and 75 atoms per cent cadmium respectively. The ratio of the pure metals in atoms per cent at these points is 1 and the 1Au : 3Cd respectively, that is, the compounds AuCd and AuCd₃ are indicated.

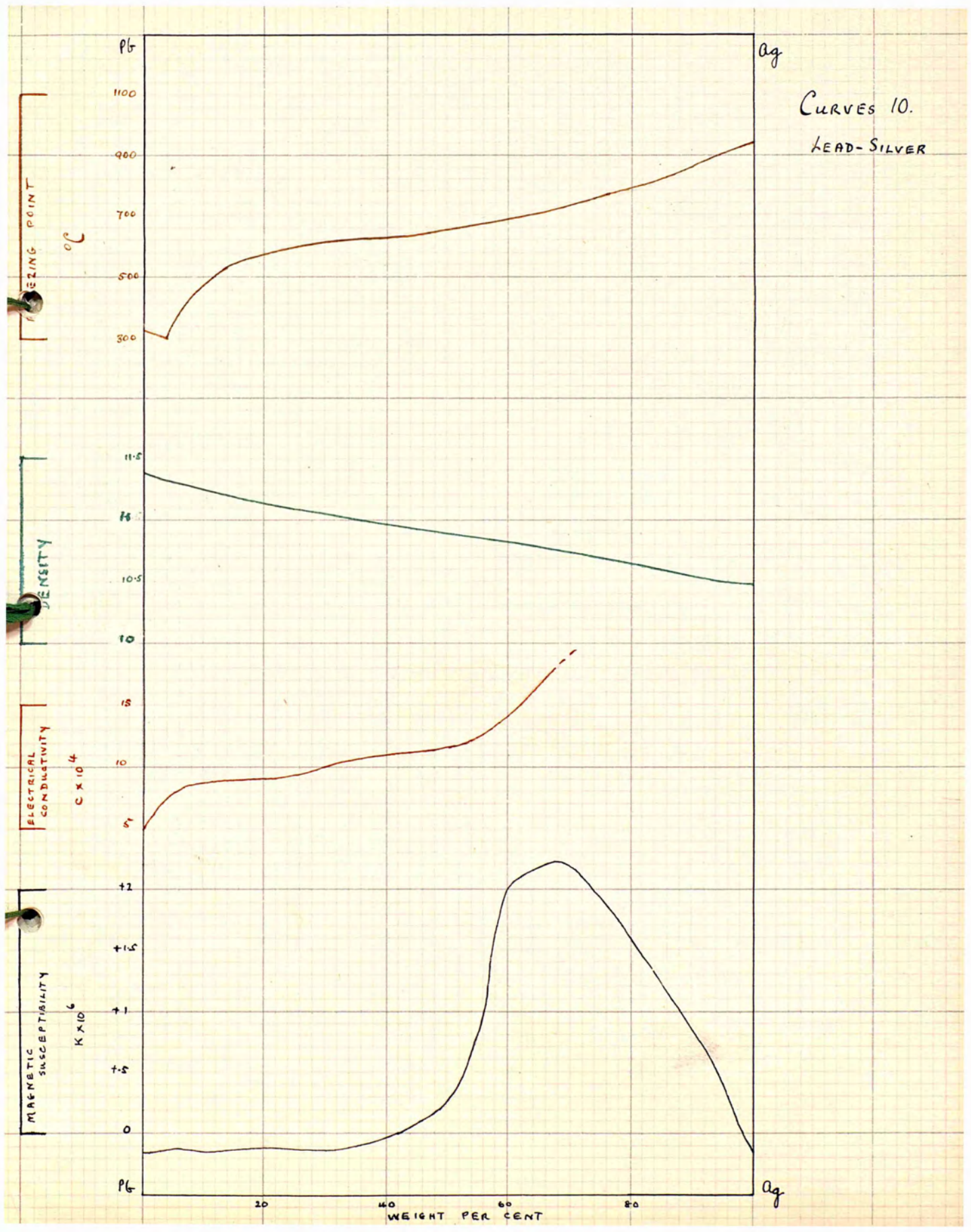
The break between 21 and 42 atoms per cent gold on the corresponding magnetic susceptibility curve occurs over the range of formation of AuCd₃ and, as explained in the comparison with the freezing-point-concentration data, the unannealed alloys form apparently flattened maxima.

It was hoped to be able to include the susceptibility-concentration curve of the copper-lead system since, in both the silver-lead and gold-lead curves a well defined maximum, which possibly does not represent a compound, occurs, and as copper belongs to the same sub-group of the periodic system as silver and gold, it is to be expected that a maximum, which is even more pronounced, should be shown by the alloys of copper and lead.

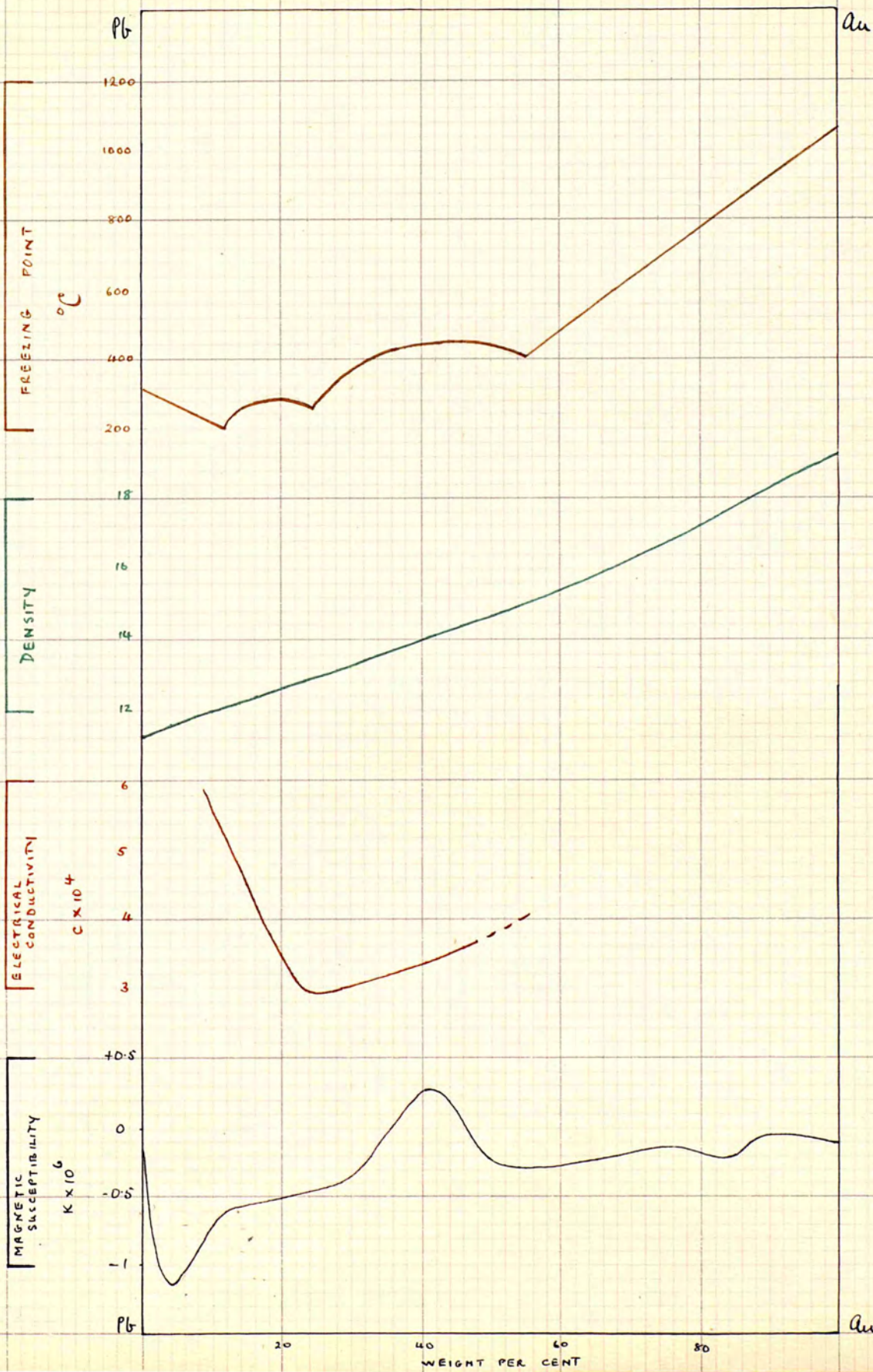
Copper and lead, however, are not miscible in all proportions and the region of immiscibility covers the concentration range where the maxima are found in the other two systems.

Thus a comparison could not be made.

CURVES 10.
LEAD-SILVER

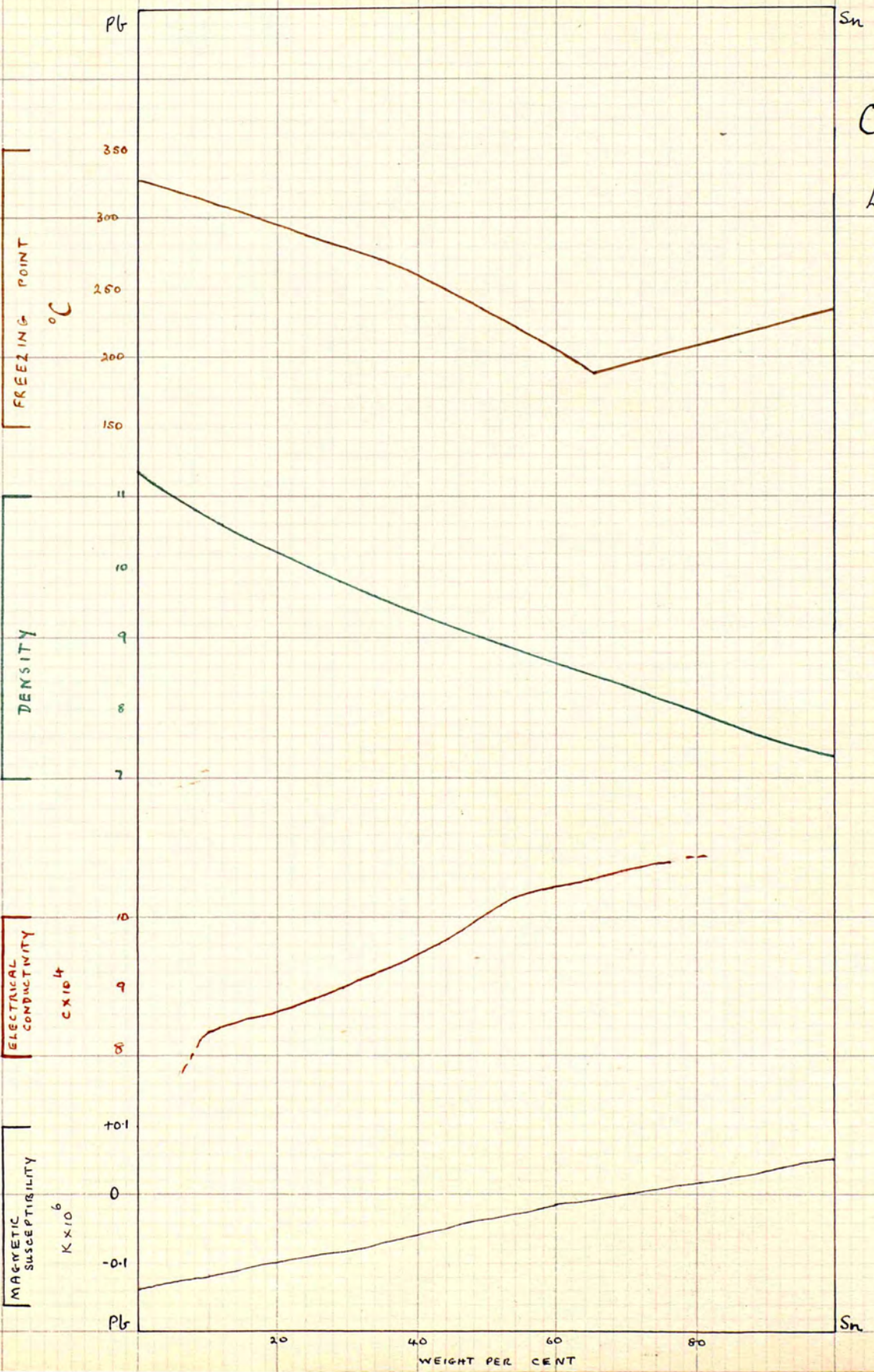


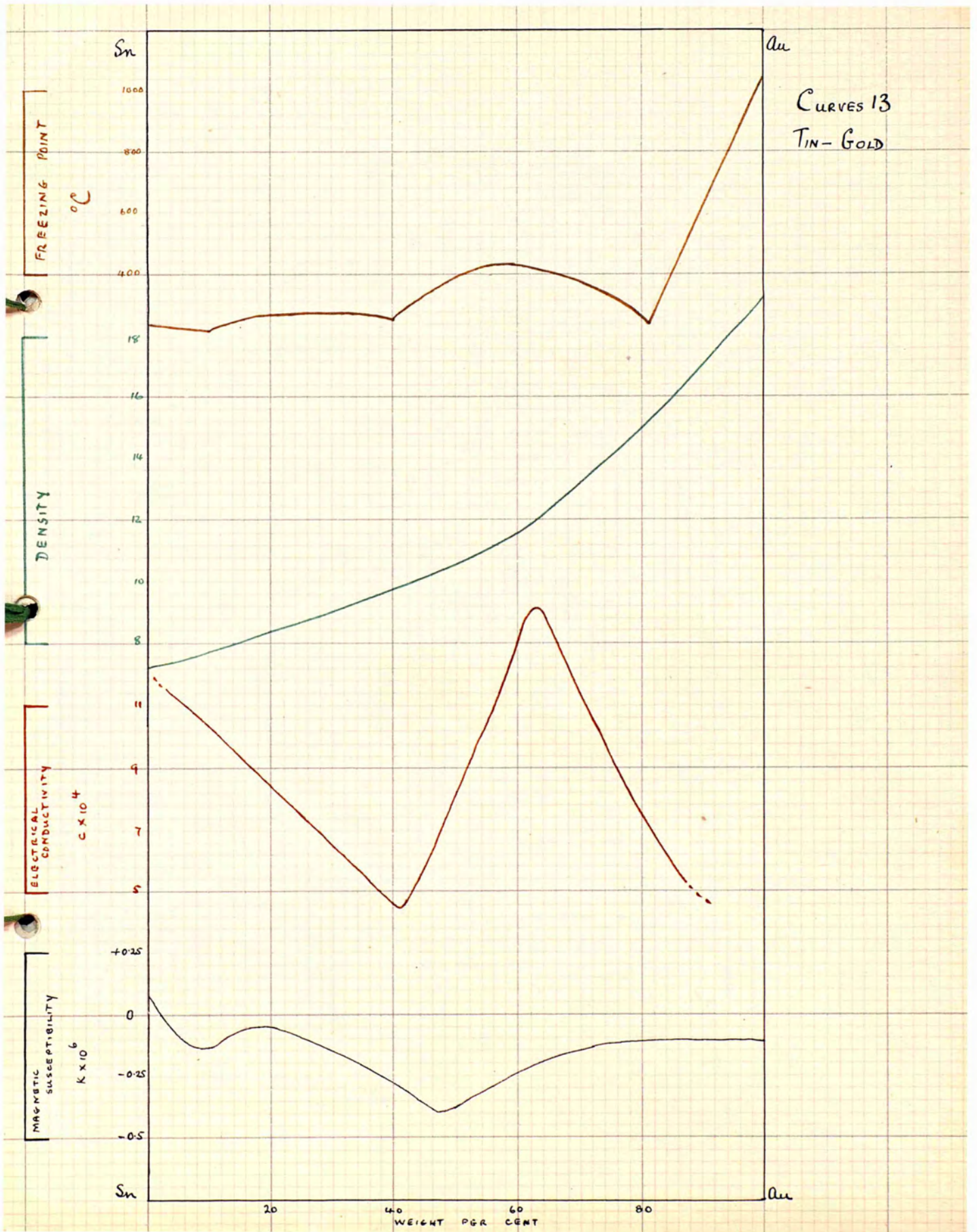
CURVES II.
LEAD-GOLD.



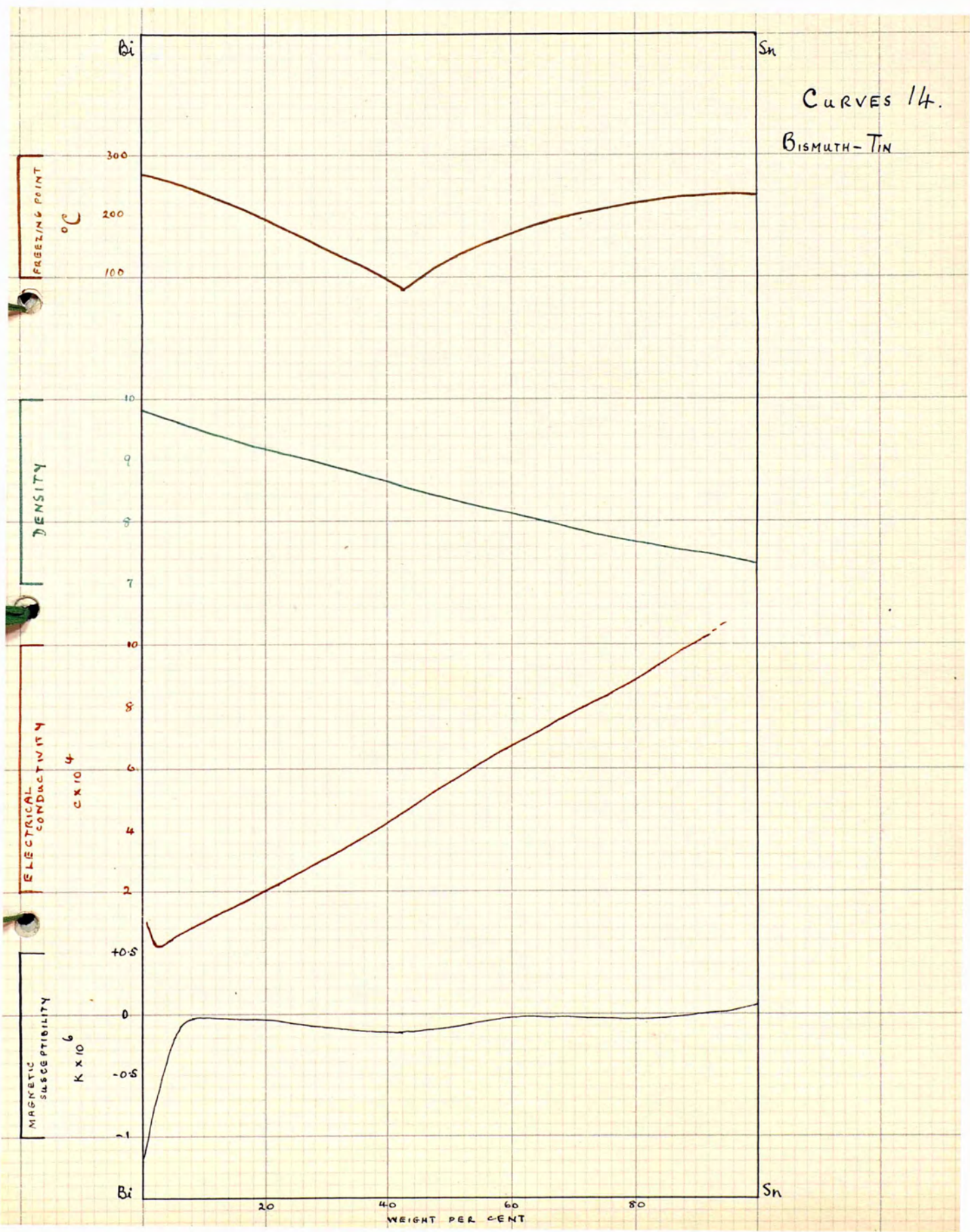
CURVES 12

LEAD-TIN

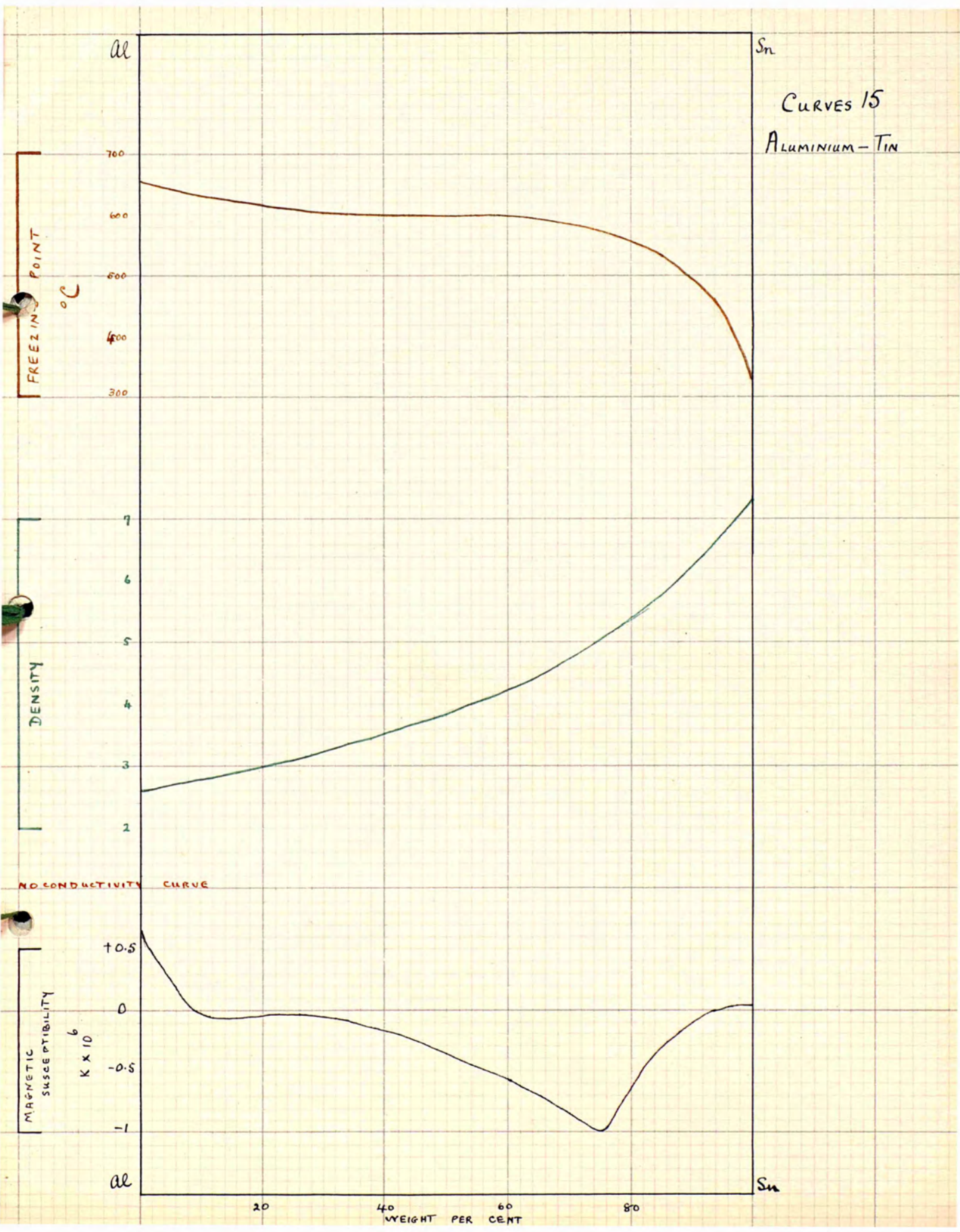




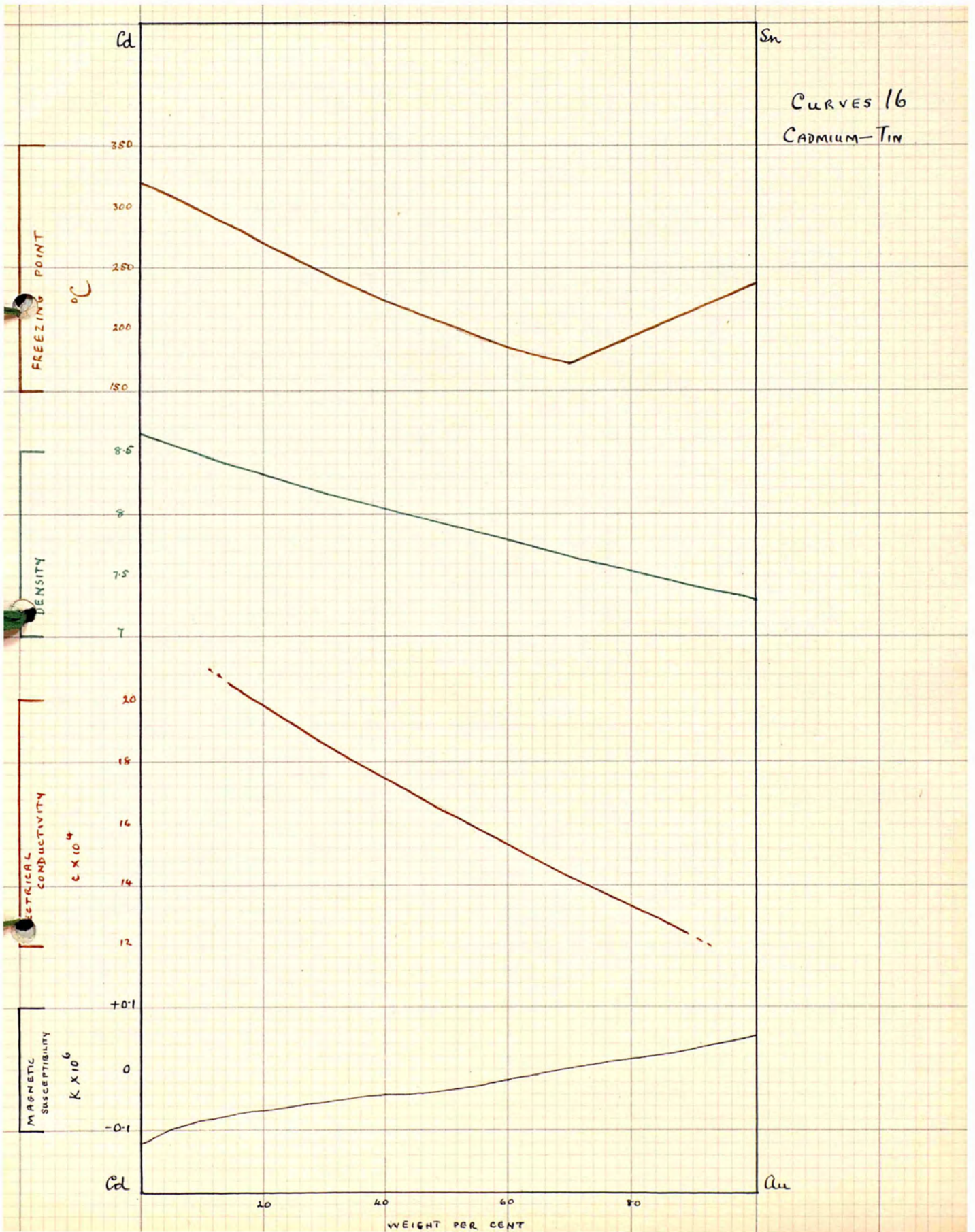
CURVES 14.
BISMUTH-TIN



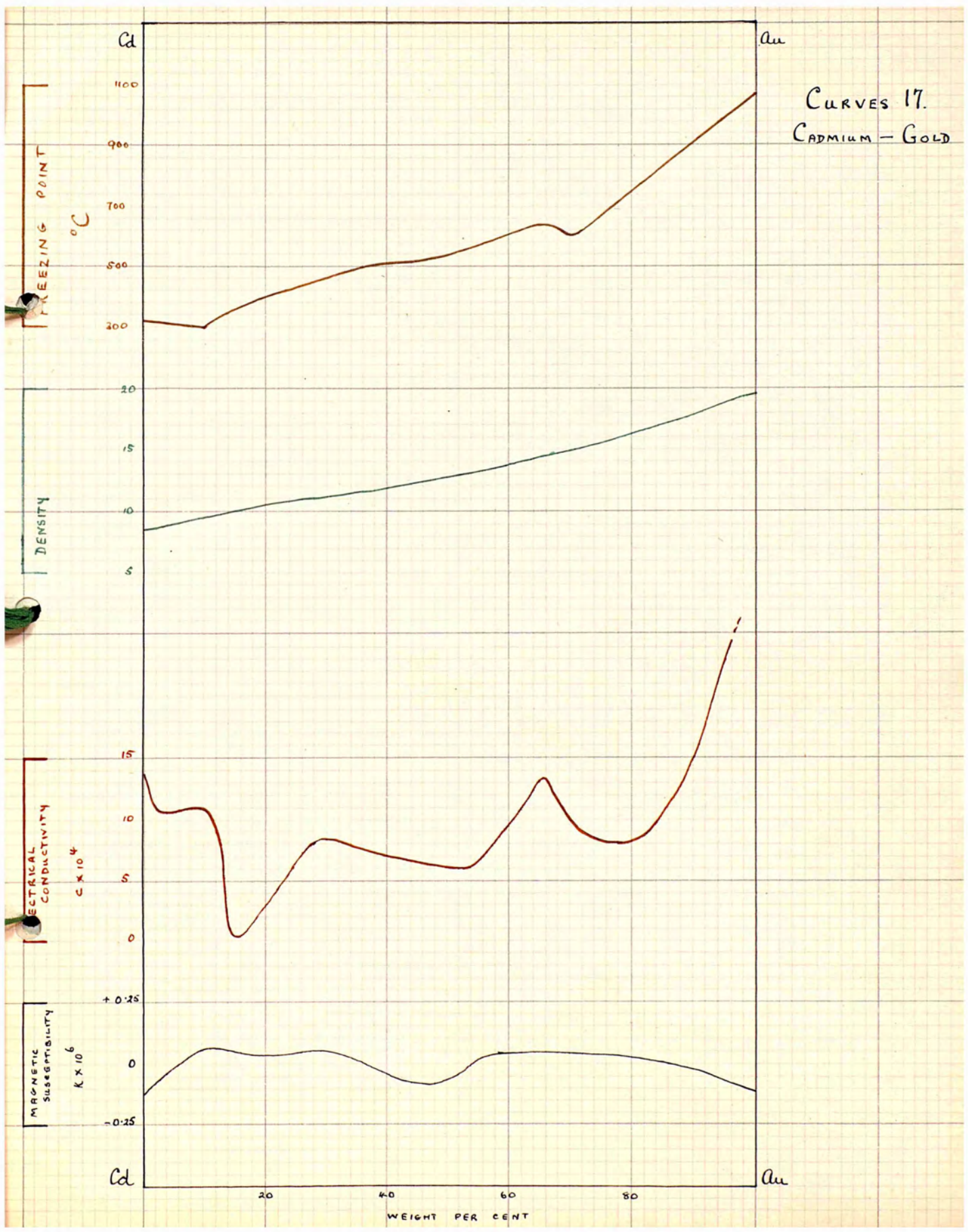
Sn
 CURVES 15
 ALUMINIUM-TIN



CURVES 16
CADMIUM-TIN



CURVES 17.
CADMIUM - GOLD



CONCLUSIONS.

- - - - -

The foregoing comparison of magnetic susceptibility with density, freezing-point and electrical conductivity respectively, leads to the following conclusions:-

1. There is no parallelism between the density and magnetic susceptibility of alloy systems.
2. Magnetic susceptibility is more sensitive to changes in composition than density. In many cases it is also more sensitive than electrical conductivity but variations in freezing point with changing composition are sometimes larger.
3. Some analogy exists between freezing-point and magnetic susceptibility especially in systems giving no compounds, that is, in cases where the mixture law is true.
4. Closer analogy exists between electrical conductivity and magnetic susceptibility both in systems in which compounds are formed and in those containing mixtures only.
This is to be expected in view of the close connection between electrical and magnetic phenomena.
5. The mixture law generally holds in systems in which no compound occurs.

6. The mixture law does not hold in any region indicating compound formation.

The data obtained supports further conclusions, thus -

7. The mass susceptibility of the pure metals examined is
silver -0.133×10^{-6} bismuth -1.12×10^{-6}
gold -0.119×10^{-6} cadmium -0.118×10^{-6}
lead -0.131×10^{-6} aluminium $+0.64 \times 10^{-6}$
tin $+0.051 \times 10^{-6}$
8. Silver-lead, lead-tin, cadmium-tin, bismuth-tin, form no intermetallic compounds.
9. Cadmium-gold form AuCd_3 , and gold-tin the compounds AuSn_2 and AuSn_4 .
10. Two paramagnetic elements, in the case examined namely aluminium-tin, form some diamagnetic alloys.
11. Two diamagnetic elements, as shown in the systems silver-lead, gold-lead, cadmium-gold, form some paramagnetic alloys.
12. One paramagnetic and one diamagnetic metal form alloys whose susceptibility lies between that of the pure metals, as in the lead-tin, cadmium-tin and bismuth-tin systems, except when intermetallic compounds are formed as shown in the gold-tin series.

The above piece of work was suggested to me by Dr. Spencer and he has given me advice with regard to the carrying out of the experiments.

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