Note on a Determination of the Specific Electrical Resistance of certain Copper-Tin Alloys

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the same group as the copper-tin, is given in his well-known paper * in 1860, and does not show an unbroken line in the horizontal portion. Certain intermediate alloys, in the form of rods, are now being examined by Dr. Lodge, whose results will doubtless clear up the point.

The alloys which occupy the critical points of the induction-balance curve are very interesting. They may be represented by the formulæ SnCu_3 and SnCu_4 respectively; and although they only vary by a single equivalent, or by 6.49 per cent. of copper, their structure and appearance differ widely. The latter, SnCu_4 , is a speculum-metal. It has a large conchoidal fracture and a yellow-grey tint. SnCu_3 , on the other hand, has a blue-grey colour and a coarse surface of interrupted crystalline planes. By successive additions of copper, this alloy seems to pass into the other without any sharp break.

Possibly both alloys are chemical combinations; and the difference of their ordinates probably marks a different allotropic state. For further information on such questions, however, we may look with confidence to Prof. Hughes's beautiful and simple instrument, which will also help us to determine whether the relation between conductivity for heat and electricity is really as exact as it has hitherto been supposed to be.

XXIII. *Note on a Determination of the Specific Electrical Resistance of certain Copper-Tin Alloys.* By OLIVER J. LODGE, D.Sc., Assistant Professor of Physics in University College, London.

ON the 5th of November I received from Mr. Chandler Roberts three rods of certain very brittle copper-tin alloys which he had with some difficulty cast, in order that I might determine their specific resistance per unit of volume by ordinary processes, because the readings which the induction-balance gave for disks of these three metals indicated that their conductivities did not by any means agree with Matthiessen's curve of electric conductivity for copper-tin alloys, though, on the other hand, they did agree with some severely

* Phil. Trans. vol. cl. p. 161.

criticised and discarded experiments of Messrs. Calvert and Johnson on the conductivities of these same alloys for *heat*.

The rods, which are hereafter spoken of as A, B, and C, were about 9 millimetres thick and from 30 to 40 centimetres long. The method which I employed to determine their conductivity was scarcely altered from that which was described by Prof. Foster and myself in this Journal in 1875* ; and the results which I have obtained I believe to be somewhat accurate. It was not worth while to aim at any very *excessive* accuracy, though the method is quite capable of it (by a calibration of the bridge-wire), because the temperature of the alloys was a little indefinite, being simply that of the room.

The three rods were laid end to end in a groove in a long piece of wood so that they just projected above its surface ; and their ends were then screwed up into secure contact with pads of tinfoil between. The resistance of the contacts is not of the slightest consequence, provided it remains constant and is moderately small, all measurements being made within the length of the rod itself.

A bridge-slider was arranged so as to make contact with one of the rods at a point whose position could be read by a millimetre-scale fixed at the proper level. The length of the portion of the rod examined could be ascertained within the tenth of a millimetre ; and the resistance of this portion could also be read with great accuracy. The least satisfactory part of the measurement is the gauging of the diameter of the rod ; for they are not perfectly cylindrical, and the *average* cross section has to be taken. I would have had the rods turned ; only two of them, viz. B and C, are far too brittle to be touched with any tool.

The observation of resistance consisted in placing the slider at a definite point on one of the rods, and feeling about on the bridge-wire with another slider for a point of the same potential. The slider on the rod was then shifted to another part of the same rod and the bridge-slider shifted correspondingly. The shifts on the bridge-wire (German silver) were of course rather small ; but they could be read to the tenth of a millimetre ; and, moreover, the resistances in the circuit were so adjusted that any step along the rods corresponded to a step of 3.62 times

* Foster and Lodge, "On the Flow of Electricity in a Plane.—Part II.," Phil. Mag. December 1875.

the resistance along the bridge-wire. It is needless to say that a weak battery and a reflecting galvanometer were used, and that the contacts were only made momentarily. As an example of the error to be expected I may quote the following.

Two different steps along rod A gave, as the step on the bridge-wire corresponding to the resistance of 1 centimetre length of the rod A, the numbers

·0328 and ·0325 centim.

Two different steps along rod B gave

·0269 and ·0270 centim.

Different steps along rod C, which was a trifle less uniform, gave

·123, ·121, ·1177, ·1173, ·1185, ·1171 centim.

As the step ·1185 was deduced from the entire length of the rod, I have taken this as the mean. The steps which gave ·123 and ·121 were short ones; and their probable error is therefore greater than that of the others. Moreover they were made at the thinner end of the not quite cylindrical rod. As regards the mean cross section of the rods, it was estimated by taking a number of readings of the diameters in all parts of the rods by means of a micrometer-gauge reading to the hundredth of a millimetre.

The mean diameter of rod A was ·879 centim.

„	„	„	B	„	·873	„
„	„	„	C	„	·869	„

The rods had been cast in the same mould; but C had contracted more than the others.

On the 7th of November Mr. Roberts sent me three more rods, which I labelled D, E, F, and then determined their resistance in the same way.

The mean diameter of these rods, which were perfectly strong and might have been drawn into wire, was

D ·880 centim.

E ·862 „

F ·872 „

These had had their surfaces filed after casting.

To get the value of the bridge-wire-readings in absolute measure, a half-ohm coil of German-silver wire at the temperature of the room (*i. e.* of the bridge-wire) was inserted in the place of the rods, and readings taken of the steps corresponding to it. The scale of magnification was of course again observed. Instead of being about 3·6, it was now about $\frac{1}{2}$.

The result of the whole series of measurements may be summed up in the following Table:—

Specific Resistances of the six Copper-Tin Alloys
in square centimetres per second.

A	12960
B	10960
C	47660
D	11830
E	17090
F	15270

I consider these accurate to the second figure, the third figure is probably affected by experimental errors.

If we choose to express the results in terms of conductivity, we have the following:—

Conductivity of a Centimetre Cube of the six Alloys
in B.A. units.

A	77100
B	91200
C	21000
D	84500
E	58500
F	65500

The specific resistance of the alloy C is thus four times that of B or D.

The composition of the alloys by weight, Mr. Roberts informs me, is as follows:—

A	19·2 per cent. of copper	80·8 tin.
B	61·8 " "	38·2 "
C	68·3 " "	31·7 "
D	0·0 " "	100·0 "
E	87·4 " "	12·6 "
F	90·3 " "	9·7 "

Some of these alloys were examined by Matthiessen, viz. A, D, E, and F; and the conductivity of a wire 1 metre long and 1 millimetre thick is stated by him to be, in terms of the B.A. unit,

of the metal A	6·0
" D (pure tin) . .	5·9
" E	4·2
" F	5·9

To reduce these numbers from a wire to a centimetre cube we must multiply them by $\frac{40000}{\pi}$, when they become

for A	76400
„ D	75100
„ E	53500
„ F	75100

of which, therefore, A and E agree tolerably with my measurements on the rods.

Matthiessen also measured the conductivity of pure copper, his number when reduced being

Copper 610000

or about eight times that of pure tin.

The results may be plotted in order to compare them more readily with the readings given by the induction-balance. The abscissæ represent percentages of tin ; the ordinates represent conductivities divided by 1000.

Specific Conductivities of Copper-Tin Alloys.

The continuous broken line joins together my six points of observation. The dotted line is Matthiessen's curve of conductivity on the same scale, viz. absolute measure, with some of his points of observation marked on it; but no alloys between somewhere about E and A seem to have been actually examined by him.

The position of pure copper (from Matthiessen's measurement) cannot be shown in the diagram: the conductivity decreases at such a tremendous rate with the slightest percentage of tin that the ordinate for pure copper is 600 scale-divisions, whereas the greatest height shown in the diagram, that of the point B, is only about 90.

It is unnecessary to call attention to the extraordinary behaviour of the alloy C containing 31·7 per cent. of tin (that is, the alloy SnCu_4), or to point out how easily it might have been supposed to be a distinct metal.

XXIV. *On a Suggestion as to the Constitution of Chlorine, offered by the Dynamical Theory of Gases.* By A. W. RÜCKER, M.A., Professor of Physics in the Yorkshire College, Leeds*.

If a gas of density δ consists of molecules each of which possesses m degrees of freedom, and if also the intermolecular forces are negligible, the specific heats at constant pressure (c_p) and at constant volume (c_v) are connected by the two well-known equations

$$(c_p - c_v)\delta = \cdot 0694, \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\frac{c_p}{c_v} = 1 + \frac{2}{m + e}, \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where e is a quantity which depends upon the potential energy of a molecule. Hence, if c_p is given by experiment, c_v can be calculated from the first of these equations; and then $m + e$ is known from the second.

The accuracy of the value of $m + e$ thus deduced will depend upon that of c_p , and on the legitimacy of the application of the two equations to the gas or vapour under consideration.

* Read November 22nd.