On the Electrical Resistivity of Bismuth at the Temperature of Liquid Air
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"On the Electrical Resistivity of Bismuth at the Temperature of Liquid Air." By JAMES DEWAR, LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, and J. A. FLEMING, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London. Received May 19,—Read June 4, 1896.

In the course of last year we published some observations (see 'Phil. Mag.,' September, 1895, p. 303)* on the electrical resistance of bismuth at the temperatures of liquid and solid air, in which the resistivity of certain samples of bismuth was measured at various temperatures down to the temperature at which air solidifies. These observations showed some anomalous results. In the case of two samples of bismuth used by us, and prepared by different chemical means, it was found that the resistivity reached a minimum value at a temperature of about $-80°$, and that after that point further cooling increased the electrical resistivity of these samples of the metal. In the case of another sample of commercial bismuth, the resistivity curve was a curve of double curvature. These results, together with the high absolute value of the resistivity of the samples, caused us to feel a strong conviction that different results would be obtained with bismuth prepared by an electrolytic method. Some observers, particularly M. van Aubel, who have investigated the electrical properties of bismuth, have expressed the opinion that bismuth cannot be prepared in a state of perfect purity by any chemical means. Finding the chemical methods of doubtful utility, we accordingly solicited the assistance of Messrs. Hartmann and Braun, who have devoted a large amount of attention to the preparation of pure electrolytic bismuth for the purposes of constructing spirals of bismuth for measuring the strength of magnetic fields. They kindly prepared for us at our request a considerable quantity of bismuth by an electrolytic method, which examination showed to be exceedingly pure, and this metal was pressed into a uniform wire with a diameter of about half a millimetre. This electrolytic bismuth is very soft, and in the form of wire can be bent without difficulty. Resistance coils were accordingly constructed of this wire, of a form suitable for use when measured in liquid air and at low temperatures. In the case of one resistance coil, which may be denoted as electrolytic bismuth No. 1, the length of the wire employed was 80·85 cm.; the diameter of this wire was carefully measured with a microscopic

* "The Variation in the Electrical Resistance of Bismuth when cooled to the Temperature of Solid Air," Dewar and Fleming, 'Phil. Mag.,' September, 1895, p. 303.

micrometer in twenty to thirty places, these diameters having very nearly equal values, and a mean value of 0·05245 cm. The bismuth wire so prepared was mounted on a suitable holder, and its resistance was taken at several different temperatures and in liquid air, the temperatures being in all cases measured by our standard platinum thermometer P_1.*

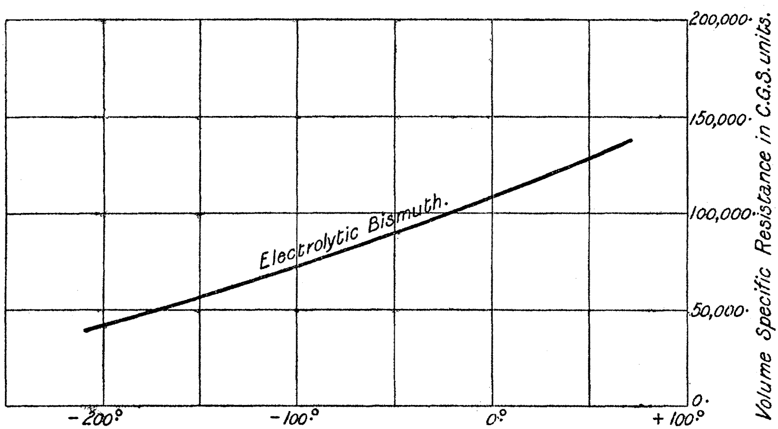
The results of these measurements were as follows:—

Resistivity of Electrolytic Bismuth. No. I.

Temperature in platinum degrees.	Observed resistance in ohms.	Resistivity in C.G.S. units per cubic centimetre.	Remarks.
+60°·5	4·9857	133250	At ordinary temperature.
+19°	4·3464	116180	" "
−61°·2	3·1275	83590	In ether cooled with solid carbonic acid.
−202°·2	1·5256	40780	In liquid air.

The curve of resistivity plotted from these data is shown in fig. 1, and in the table the value of the resistivity of bismuth in C.G.S. units per cubic centimetre is given above. These values of the resistivity show that in the case of this pure electrolytic bismuth

FIG. 1.



* For details of this thermometer, see Dewar and Fleming on the "Thermo-electric Powers of Metals and Alloys at the Boiling Point of Liquid Air," 'Phil. Mag.,' July, 1895, p. 100.

there is no tendency of the resistivity curve to a minimum value. Down to the lowest temperatures reached in these experiments, the resistivity of bismuth continues to decrease in a perfectly regular manner, and in such a way as to show that it would be no exception, in all probability, to the ordinary law, that resistivity of pure metals vanishes at the absolute zero of temperature. On comparing the results of these measurements with those in the former experiments made with chemically prepared bismuth, it is seen that the electrolytic bismuth used by us has a very much lower resistivity at 0° C., viz., 108,000 units, and it has a lower value than that given by Matthiessen for pure bismuth, which is 129,700. We have, then, an additional indication that the bismuth used by us in the experiments in 1895 must have contained sufficient, though slight, impurity to markedly alter its resistivity, and to change entirely the character of the resistivity curve. With this electrolytic bismuth we have repeated the experiments which we made last year, on the variation of the electrical resistance of bismuth when placed transversely to the direction of the force in a magnetic field, and when cooled to the temperature of liquid air. For this purpose we constructed a flat spiral of the electrolytic bismuth, so arranged that its resistances could be measured at ordinary temperatures, and at the temperature of liquid air, by immersing it in a flat vacuum-jacketed test-tube, both when in a powerful magnetic field, and when merely in the terrestrial field. With this electrolytic bismuth we have confirmed the observation which we made last year, with a small sample of electrolytic bismuth, viz., that the effect of a given transverse magnetic field in increasing the resistivity of bismuth is immensely increased by cooling the bismuth to the temperature of liquid air. The figures in the following table will show the actual results obtained in these last experiments:—

Variation of Electrical Resistance of Electrolytic Bismuth in Magnetic Fields of different Strengths.

Temperature in platinum degrees.	Magnetic field strengths in C.G.S. units.			Remarks.
	Zero.	1400 units.	2750 units.	
	Resistance of bismuth coil.			
+20°	ohms. 1·679	ohms. 1·700	ohms. 1·792	At ordinary temperature.
−202°	0·5723	1·4435	2·6801	In liquid air.

It will thus be seen that whereas the immersion of the electrolytic bismuth wire, at ordinary temperatures, transversely in a magnetic field of strength 2,750 C.G.S. units, only increased its resistance by about 6 per cent., the immersion of the same wire in the same magnetic field increased its resistance to more than four and a half times when it was cooled to the temperature of liquid air, and the effect of the cooling with liquid air is more than nullified by the field, so that the bismuth cooled in liquid air and at the same time placed in the field has a resistance of 50 per cent. greater than it was when not cooled and not in the field. We are engaged in extending these observations to stronger fields.

The behaviour of electrolytic bismuth in fields of various strengths and at various temperatures, from 0° C. to 100° C., has been studied by Mr. J. B. Henderson (*see* 'Phil. Mag.,' vol. 38, 1894, p. 488), and he has given a series of curves showing the variation of resistance of bismuth between these temperatures for fields of strength varying from zero to 22,700 C.G.S. units. Our observations at low temperatures are quite consistent with Mr. Henderson's curves. His curves indicate that at lower temperatures the effect of any given field in increasing the resistance of the bismuth becomes more marked.

Pressed to its limit it would appear that pure bismuth, which would in all probability be made a perfect conductor by reducing to the absolute zero of temperature, would be then converted into a non-conductor if at the same time immersed in a magnetic field of sufficient strength. Both M. van Aubel and Mr. Henderson have pointed out that the temperature coefficient of bismuth at any given temperature is quite altered by placing it in a magnetic field, and it will therefore be a matter of great interest to examine the effect of an exceedingly strong magnetic field as bismuth when cooled to the temperature of solid air.

By enclosing a bismuth wire and a platinum thermometer wire in the same mass of paraffin wax we have been able to measure the variation of resistance of the bismuth from the temperature of liquid air up to ordinary temperatures at a number of intermediate points, and to determine the resistance both in a zero magnetic field and in one of known strength, but the results we wish to reserve until we have had the opportunity of repeating them with stronger magnetic fields.