THE EFFECT OF HIGH TEMPERATURES ON THE CHANGE OF RESISTANCE OF BISMUTH IN A MAGNETIC FIELD.

By Frank B. Jewett.

IN a series of experiments carried on at Ryerson Physical Laboratory, University of Chicago, during the winter of 1899–1900, some interesting results were obtained regarding the effect of high temperatures on the change of resistance of bismuth wire in a magnetic field. The experiments were originally undertaken simply to determine the allowable temperature variations in the ordinary form of commercial spiral, as used in measuring field strengths. As the results soon showed, however, that at the higher temperatures the change of resistance curve varied greatly from its mean temperature form, the experiments were carried on much beyond the originally set limits. A few of the results, together with a short description of the method employed in forming the spirals, are appended in the following article.

The commercial spiral as prepared by Hartman & Braun, consists simply of a flat, non-inductive coil of comparatively fine wire having a resistance of from 12 to 20 ohms. The manner of making the wire would seem to point to a crystallographic formation such that any direction through the coil is one of mean resistance; this was the assumption though no microscopic examination of a wire section was made.

At the time of the experiments the impossibility of procuring bismuth wire made the employment of a quick and simple process for its manufacture necessary. After a number of trials the following scheme was adopted as giving more satisfactory results than the ordinary mode of casting in capillary tubes. Two long pieces of cast iron were first planed smooth and fitted with machine screws for clamping them firmly together; shallow, slightly trapezoidal grooves were then planed in one of the pieces and a reservoir cut in one end (Fig. 1); the grooves were highly polished in order to facilitate the removal of the castings. These latter were formed by standing the mould, heated almost to redness, upon an iron plate and pouring molten bismuth into the upper or reservoir end. Since bismuth is malleable at about 200° C. the cap plate was taken off the mould while still quite hot and the castings removed. The wires thus formed, while of the desired length, were neither of the right shape nor cross section to be easily worked; to reduce the amount of metal, the strips were clamped between pieces of

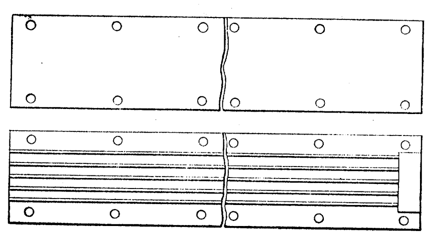

Fig. 1.

heavy sheet brass and the whole filed down the requisite amount. This filing breaks up the crystalline continuity and renders the metal extremely friable; recrystallization is accomplished by transferring the now more or less square filament to a metal plate whose temperature is slightly above the melting point of bismuth. This process serves a double end, for not only does it recrystallize the metal, but at the same time the surface tension causes the wire to assume a form of almost circular cross section. Care must be exercised lest the plate be too hot, in which instance the surface tension causes the wire to break and collect in globules. With the aid of a hot plate the wire formed as above can be readily worked into any desired shape. The spiral once formed the only remaining difficulty is in fastening on the terminal wires — for low temperatures this can be readily accomplished by the use of ordinary soft solder, but as such a joint is in reality simply a piece of fusible metal, other methods must be employed when the temperature is to be above 90° C. After many fruitless attempts pure bismuth was found to answer better than any other solder, although its application is somewhat difficult. To facilitate handling and at the same time protect the spiral from chance injury it was enclosed in a shallow fiber capsule with screw top.

In order to obtain consistent results, it is of prime importance that the bismuth employed be as pure as possible, slight admixtures of foreign metals causing great variations in behavior under identical conditions. In the following work the castings were made from metal electrolytically deposited from an acid nitrate solution with a rod of Kohlbaum's C. P. for an anode. The variations in the behavior of specimens A and B (Tables I. and II.) are probably due to the fact that the wires of which the two spirals were constructed had considerably different diameters, and as is well known, the size of the crystals vary with the dimensions of the casting, when the latter is not made under pressure.

For keeping the spiral at any desired temperature, a bath of heavy mineral oil was used; the box containing the oil was of brass, furnished with insets at the sides to permit of the close adjustment of the pole pieces. The heating was accomplished by means of Bunsen burners and fairly constant and uniform temperatures were maintained by means of an electrically driven propeller. The magnet used was one designed to give a uniform field of 35,000 C.G.S. units over a considerable area for pole pieces 3 mm. apart.

Discussion of the Results. — In making the determinations the process was simply to bring the spiral to the desired temperature, and after constant conditions had been attained, to measure the resistance in fields of various strengths. A condensed outline of the results is given in Tables I. and II. and the corresponding curves are plotted in Figs. 2 and 3 — Table I. and Fig. 2 refer to specimen A — Table II. and Fig. 3 to specimen B. In plotting the curves, abscissæ were taken to represent field strengths in C.G.S. units and ordinates to represent percentage changes of resistance — $\frac{R - Ro}{Ro}$, where R is the resistance of the spiral at any temperature in field H and Ro is the resistance at the same temperature outside the magnetic field.

Upon examining the plates it will be noticed that in every case, with the possible exception of the one for 24°, the curves seem to consist of two straight lines representing regions of uniform variation, connected by a more or less extended curve denoting a region of non-uniform variation — in each case also the percentage change is greater in the second half of the curve. As the temperature of

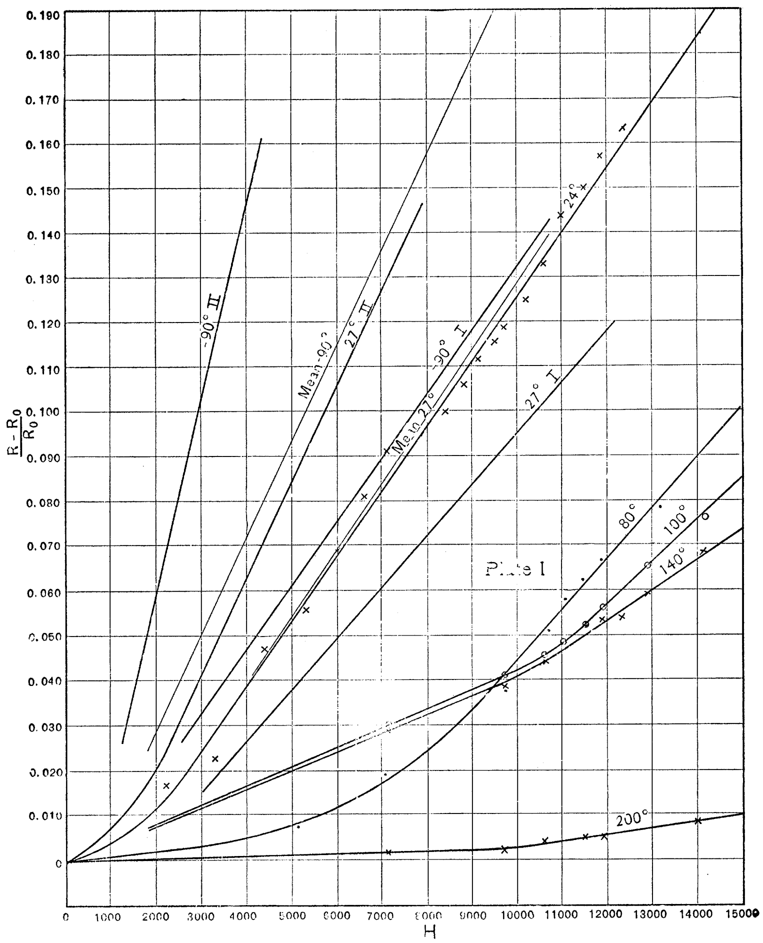

Fig. 2.

the spiral is raised this variable portion seems to travel toward the region of denser magnetic flux.

Even more striking is the apparent existence of fairly well defined temperatures of subsidiary minimum and maximum variation in the region below $H = 10{,}000$. For spiral B the number of readings was too small to give anything but a general idea as to the location of these points; in the case of A, however, if the readings for vari-

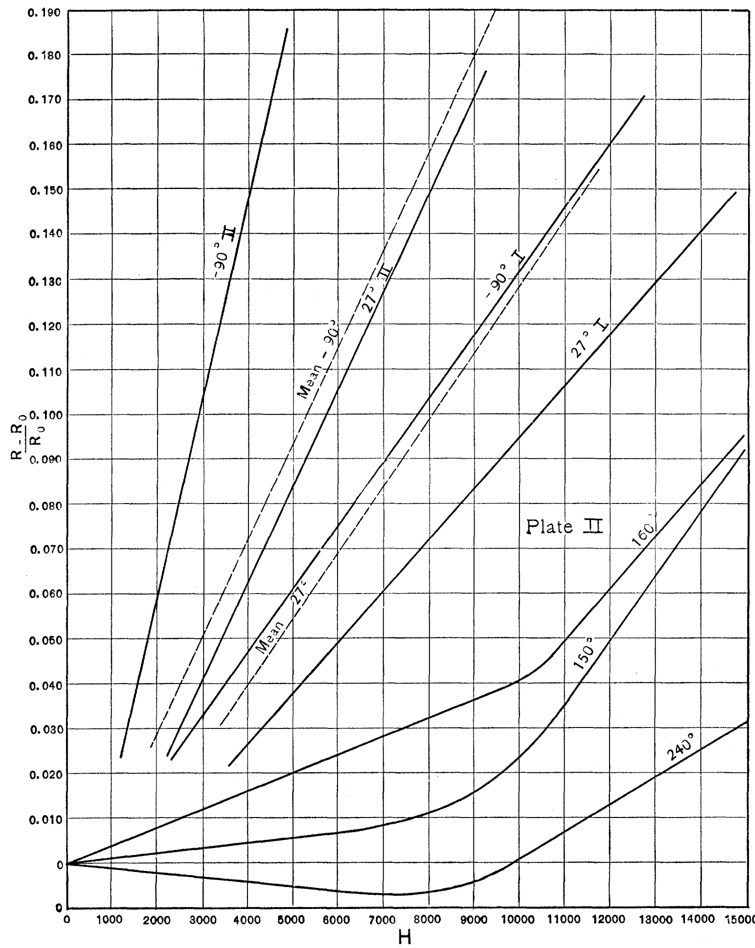

Fig. 3.

ous values of H are plotted with $\frac{R - Ro}{Ro}$ as ordinates and temperatures as abscissæ (Fig. 4), it is seen that the point of minimum variation is in the neighborhood of 80°, while the succeeding maximum occurs somewhere between 100° and 115°. Beyond this point further increase in temperature causes a continuous diminution in the percentage change of R with respect to H. It is also evident that the greatest variation occurs for $H = 6{,}000$ and that the minimum disappears at about $H = 9{,}600$.

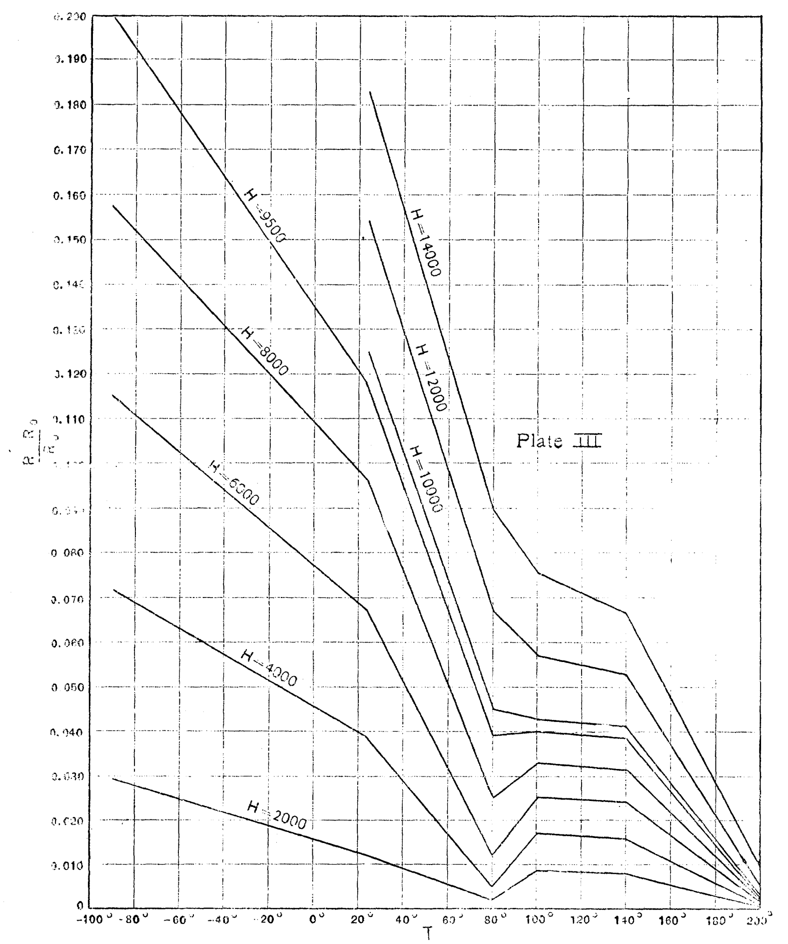

Fig. 4.

While not plotted the corresponding curves for specimen B would apparently be quite similar — so far at least as regards the point of maximum field influence; the point of minimum disappearance for this specimen is somewhere near $H = 18{,}000$.

In both Figs. 3 and 4 are plotted curves showing the variation of resistance for $27°$ and $-90°$; these curves are from a few readings taken by Dr. E. Van Everdingen, Jr.,[1] while experimenting on the Hall effect in crystalline bismuth plates at very low temperatures. The curves marked I. were from readings taken with the direction of maximum resistance in the rod coinciding with the lines of force. Curves II. have this direction perpendicular to the lines. In both plates the mean of the two curves are shown by the dashed lines and the proximity of the mean for $27°$ to the curve for $24°$ would seem to indicate that the previously stated assumption regarding the direction of mean resistance in the spiral was justifiable. The values of $\frac{R - Ro}{Ro}$ for $-90°$ in Fig. 4 are those of the mean curve for that temperature.

While the curve for spiral B at $240°$ shows a negative value for $\frac{R - Ro}{Ro}$ between $H = 0$ and $H = 10{,}000$, it is doubtful if much reliance can be placed on it, as two or three sets of readings on A at neighboring temperatures above and below this point, showed that at about $245°$ the metal loses entirely the property of change of resistance in a magnetic field. This is what would be expected since bismuth loses its crystalline structure at about 245–$250°$. (In this connection it is interesting to note that with thin plates of non-crystalline bismuth, formed by means of the cathode stream, no evidence of any magnetic effect on the resistance was observable even at field strengths as high as 27,000.)

It is to be regretted that a larger number of readings at shorter temperature intervals was not made, but as at the time none of the results were plotted, the peculiar inversion effect was inadvertently overlooked. In case the experiments were to be repeated it would seem advisable to discard the cast spiral form entirely and use slender rods cut from electrolytically deposited plates, as was done by Dr. Van Everdingen; this would permit of determinations being made for both positions of the axis of maximum resistance.

[1] E. Van Everdingen, Jr., Verslagen van de Afdeeling Watnurkunde der Kon. Akademie van Wetenschappen te Amsterdam, Oct. 28 and Dec. 30, 1899.

TABLE I.

Temp.	H	R	$\frac{R-Ro}{Ro}$	Temp.	H	R	$\frac{R-Ro}{Ro}$
24.0	0	1.322	0	100	0	1.358	0
24.0	2,200	1.345	0.017	100	7,100	1.399	0.030
24.0	3,300	1.353	0.023	100	9,700	1.414	0.041
24.0	4,400	1.385	0.047	100	10,600	1.420	0.045
24.0	5,300	1.397	0.056	100	11,000	1.424	0.048
23.5	6,000	1.414	0.069	100	11,500	1.429	0.052
23.5	6,600	1.430	0.081	100	11,900	1.434	0.056
24.0	7,100	1.443	0.091				
24.0	8,400	1.454	0.100	140	0	1.383	0
24.0	8,800	1.463	0.106	140	7,100	1.423	0.029
24.0	9,100	1.469	0.112	139.5	9,700	1.436	0.038
24.0	9,500	1.476	0.116	140	10,600	1.445	0.044
24.0	9,700	1.480	0.119	140	11,000	1.452	0.049
24.0	10,200	1.488	0.125	140	11,500	1.455	0.052
24 0	10,600	1.498	0.133	140.5	11,900	1.456	0.053
24.0	11,000	1.512	0.144	139.5	12,300	1.458	0.054
24.0	11,500	1.521	0.150				
24.0	11,900	1.530	0.157	200	0	1.353	0
24.0	12,400	1.537	0.163	200	7,100	1.356	0.0022
				199.5	9,700	1.356	0.0022
79.5	0	1.334	0	201	10,600	1.358	0.0037
80.5	7,100	1.360	0.019	199.5	11,000	1.360	0.0052
80.0	9,700	1.386	0.038	200	11,500	1.360	0.0052
80.0	10,600	1.401	0.050	200	11,900	1.360	0.0052
80.0	11,000	1.410	0.057				
79.5	11,500	1.417	0.062				
79.5	11,900	1.422	0.066				

TABLE II.

Temp	H	R	$\frac{R-Ro}{Ro}$	Temp.	H	R	$\frac{R-Ro}{Ro}$
148	0	1.288	0	240	0	1.227	0
148	8,200	1.303	0.012	240.5	7,100	1.218	−0.007
147	9,700	1.320	0.025	240	9,700	1.225	−0.001
149.5	10,600	1.320	0.025	239.5	10,600	1.250	0.019
149	11,300	1.340	0.040	239	11,500	1.255	0.022
149.5	12,300	1.400	0.087(?)	241	11,500	1.250	0.019
				241	11,900	1.240	0.012
160	0	1.297	0				
160	7,100	1.335	0.029				
160	9,700	1.348	0.039				
159	10,600	1.355	0.044				
158.5	11,000	1.364	0.051				
160	11,500	1.372	0.057				
160	11,900	1.373	0.058				

In conclusion I wish to express my appreciation of the interest shown throughout the work by Professors Michelson and Stratton, and to thank Professor Stratton for many suggestions given. My thanks are also due to Dr. Earhart for help rendered in the preliminary readings.

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