THE LONGITUDINAL THERMOMAGNETIC POTENTIAL-DIFFERENCE.

By Alpheus W. Smith.

If a plate in which there is a longitudinal flow of heat is brought into a transverse magnetic field so that the lines of force are perpendicular to the plane of the plate, it is found that there is a difference of potential set up between any two points at a given distance apart along the plate. This difference of potential is superposed on the thermoelectromotive force which exists in the plate and may serve to increase or to decrease it. Following the usual practice this effect will be considered positive when the potential-gradient established by the magnetic action is in the same direction as the temperature-gradient along the plate. The coefficient of this effect is given by the equation,

$$e = LH\frac{\partial t}{\partial x}l$$

or approximately

$$L = \frac{e}{H(t_1 - t_2)},$$

where e is the difference of potential in absolute units called forth by the magnetic action; H is the magnetic field in absolute units; and $t_1 - t_2$ is the difference of temperature between the two points on the plate at which the lead wires to the galvanometer are soldered, and l the distance between these points.

Zahn[1] has made observations on the way in which this effect in bismuth depends on the temperature. For a magnetic field of 6,290 absolute units he found L to be 0.134 at 28.7° C. and 0.111 at 24.1° C. From these observations he concludes that this effect in bismuth increases with rising temperature. It seemed desirable to study more fully the influence of temperature on this effect in bismuth.

The bismuth plates to be investigated were cast by pouring the molten bismuth into a lavite mould. These plates were about 3 cm. long, 1.4 cm. wide and 0.2 cm. thick. The apparatus for producing the temperature-gradient in the plates was essentially the same as that used by the author[2] in the study of the transverse thermomagnetic effect in nickel

[1] Ann. der Phys., 14, p. 914 (1904).

[2] Phys. Rev., 33, p. 295 (1911).

and cobalt at different temperatures. For the details of the apparatus reference is made to Fig. 1 of that paper. In the present experiments, however, slots were cut in the ends of the rods which were opposite to each other and into these slots the plates to be investigated were inserted. The plates were then clamped to the copper rods by means of screws. To each end of the plate on its longitudinal axis was clamped a copper-advance thermal junction by means of a screw which pressed the junction firmly against the plate. The copper wires of this junction were connected through a galvanometer to a slide-wire potentiometer by which the thermoelectromotive force between the ends of the plate was compensated. The difference of potential set up by the magnetic field was determined by first measuring the electromotive force between the ends of the plate when there was no magnetic field and then measuring it again when the magnetic field was established. The difference between these two electromotive forces gave the difference of potential called forth by the magnetic field. The observations were then repeated with the magnetic field in the opposite direction. The mean of the potential differences set up by the magnetic field in the two directions was taken as the longitudinal thermomagnetic potential-difference. The magnitude of this difference of potential is not exactly the same for both directions of the magnetic field, because it is impossible to get the copper lead wires exactly on the longitudinal axis of the plate so that the transverse thermomagnetic effect cannot make a contribution to the longitudinal effect. The difference of potential from this transverse thermomagnetic effect increases the longitudinal thermomagnetic potential difference for one direction of the magnetic field and decreases it for the opposite direction of the magnetic field. The mean of the differences of potential observed with the magnetic field in opposite direction eliminates this contribution made by the transverse thermomagnetic effect. The mean of the temperatures at the two ends of the plate was taken as the temperature at which the effect was observed. This procedure is not entirely without objection for the longitudinal thermomagnetic potential-difference is not a linear function of the temperature. Since the difference of temperature between the ends of the plate amounted to only 30° or 40° C. the error introduced by this approximation is not serious. The results of the observations on bismuth are given in Table I. The same observations have been plotted in Fig. 1. It is seen from this curve that this longitudinal effect in bismuth decreases rapidly with rising temperature. The slope of the curve indicates that the effect would vanish at the melting point of bismuth. This result is not in agreeemnt with the observations of Zahn who noted an increase in the effect with rising temperature.

The potential-gradient set up by the magnetic action is in the opposite direction to the temperature-gradient in the plate. According to the usual convention this makes the effect in bismuth negative. The average value of the thermoelectromotive force of this bismuth against copper between 32° C. and 72° C. was 6.26×10^{-5} volts per degree Centigrade difference in temperature. At this temperature a magnetic field of 20,000 C.G.S. units sets up in the plate a longitudinal electromotive force which is equivalent to an increase of about 30 per cent. in the thermoelectromotive force.

Table I.

$t°$ C.	L	$t°$ C.	L
34.5°	0.116	117°	0.051
41.7	0.110	148	0.040
50.5	0.104	151	0.035
64	0.094	203	0.021
101	0.066	215	0.015

From the curve in Fig. 1 the value of L at 53° C. is found to be 0.102. This value as well as the other values in Fig. 1 is for a magnetic field of

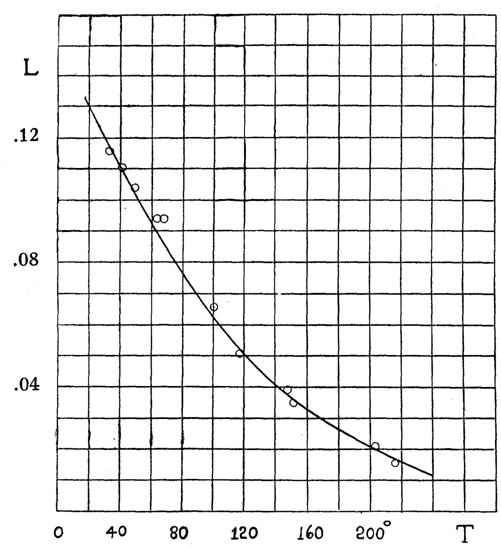

Fig. 1.

9,600 C.G.S. units. For this same temperature and for a magnetic field of 11,000 C.G.S. units Barlow[1] found L to be 0.100,—a value in good

[1] Ann. der Phys., 12, p. 897 (1903).

agreement with that noted above. For a magnetic field of 6,290 C.G.S. units Zahn found L to be 0.111 at 24.1° C. The value of L for this temperature taken from the curve in Fig. 1 is 0.128. Here the agreement is less satisfactory.

Roberts[1] has shown that when graphite is placed in a transverse magnetic field there is a very large change in its electrical resistance. Since the longitudinal thermomagnetic effect is in a way the analogue of the change in the electrical resistance in a magnetic field it seemed that this longitudinal effect in graphite might be large enough to be measured. Two plates of Acheson graphite were made. These plates

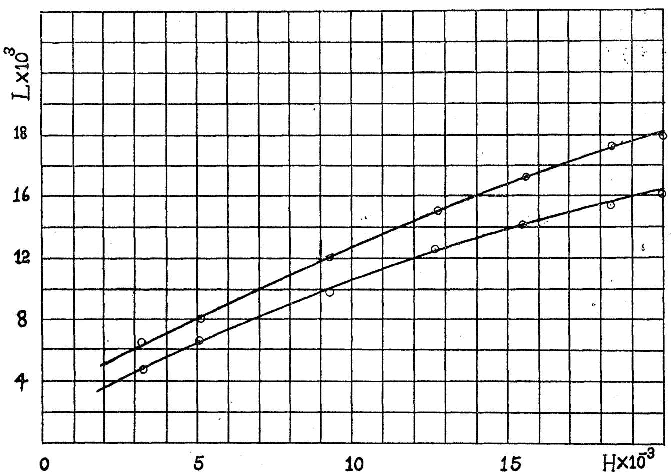

Fig. 2.

were 3.2 cm. long, 1.4 cm. wide and 0.2 cm. thick. The ends were copper-plated and then soldered to copper tubes in the manner described by the author[2] in the study of the Nernst effect in alloys. A description of the apparatus accompanies Fig. 14 of the paper just cited. To the copper-plating on either end of the plate was soldered a copper-advance thermal junction so that the junctions were as nearly as possible on the longitudinal axis of the plate. The temperature-gradient in the plate was established by causing steam at atmospheric pressure to flow through one of the copper tubes and water at room temperature to flow through the other tube. The thermoelectromotive force thus established was compensated on the slide-wire potentiometer when the plate was not in the magnetic field. The potential-difference set up by the magnetic

[1] Phil. Mag. (6), 26, p. 158 (1913).

[2] PHYS. REV., 32, p. 193 (1911).

field was determined by noting the deflections of a d'Arsonval galvanometer. The magnetic field was then reversed and the deflection again noted. The mean of these deflections was taken as a measure of the potential difference set up by the magnetic action. From the figure of merit of the galvanometer the potential-difference was obtained in absolute units. The results of these observations are given in Table II. They have also been plotted in Fig. 2. One end of the plate was at a temperature of about 36° C. and the other end at about 84° C. so that the mean of these temperatures which is 60° C. may be considered the temperature at which the values of the coefficient in Table II. are given. The direction of the effect in graphite is such that the potential-gradient set up by the magnetic field is in the direction of the temperature-gradient in the plate. The effect is therefore positive in graphite. The average thermoelectric height of the graphite against copper between about 36° and 84° C. for Plate I. was 6.17×10^{-6} volts and for Plate II., 5.05×10^{-6} volts. The effect of the magnetic action was to increase somewhat the effective thermoelectromotive force in the plate. The values of L for the two plates differ from each other by about 20 per cent. The reason for this variation is probably to be found in the presence of impurities in the graphite.

Table II.

Plate I.		Plate II.	
H	$L \times 10^4$	H	$L \times 10^4$
3,300	65	3,250	48
5,150	80	5,100	67
9,300	121	9,300	98
12,850	151	12,700	126
15,600	173	15,600	142
18,400	193	18,300	155
20,200	197	20,200	160

Table III. contains the data on monel which is an alloy containing 68 per cent. nickel, 29.5 per cent. copper, 1.5 per cent. iron and 1 per cent. manganese. In Curve I. of Fig. 3 the potential difference in absolute units when there is a temperature-gradient of one degree Centigrade per centimeter in the plate, has been plotted against the magnetic field. In Curve II. the coefficient L has been plotted against the magnetic field. The temperature of one end of the plate was 90° C., that of the other end, 24° C. The mean temperature 57° C. may be taken as the temperature at which the values of L recorded in Table III. were determined. The thermoelectric height of monel against copper between these temperatures is 30.7×10^{-6} volts. In monel the effect is negative so that the potential-difference set up by the magnetic field increases the thermoelectric height of this alloy.

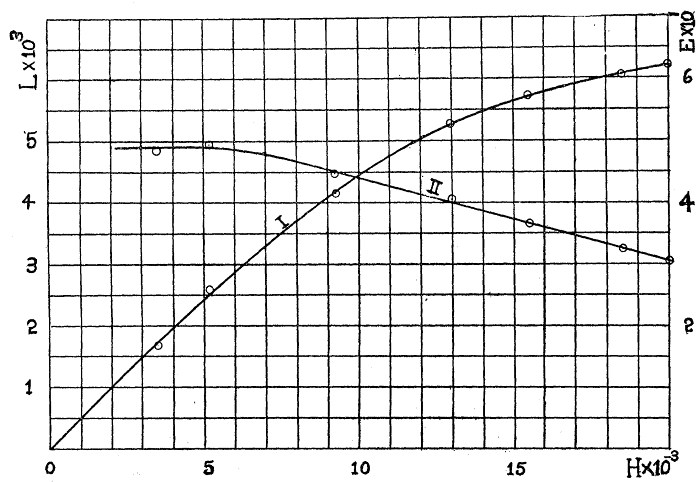

Fig. 3.

TABLE III.

H	$L \times 10^5$	H	$L \times 10^5$
3,500	484	13,000	406
5,200	498	18,500	327
9,300	448	20,000	306

The addition of antimony to bismuth causes the thermoelectric heights to pass through a maximum when the alloy contains about 9 per cent. of antimony. Curve I. of Fig. 4 shows the relation between the thermoelectric height of the alloy and the percentage by weight of antimony in it. In Curve II. of Fig. 4 the coefficient of the longitudinal thermomagnetic potential-difference has been plotted against the percentage by weight of antimony in the alloy. The value of the magnetic field in these observations was 20,200 C.G.S. units. One end of the plate was at about 72° C. and the other end at 22° C. so that the temperature at which the coefficients have been determined is about 46° C. It is seen from this curve that the coefficient of this longitudinal effect has a maximum when the alloy contains about 9 per cent. of antimony. With further addition of antimony to the alloy the coefficient decreases in a manner similar to that in which the thermoelectric heights decrease under similar condition. The two curves are, however, not parallel. The direction of the effect in these alloys is the same as its direction in bismuth.

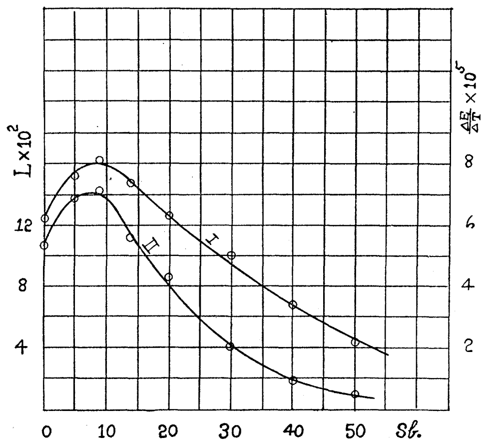

Fig. 4.

Summary.

1. The longitudinal thermomagnetic effect in bismuth decreases with rising temperature and seems to vanish at the melting point of the bismuth.

2. The longitudinal thermomagnetic effect has been determined in graphite and monel. It is positive in the former and negative in the latter.

3. The longitudinal thermomagnetic potential-difference in bismuth-antimony alloys shows a maximum value when the alloy contains about 9 per cent. of antimony.

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