THOMSON EFFECT IN BISMUTH-TIN ALLOYS.

By A. E. Caswell.

In two previous papers[1] the author described two methods of determining the Peltier E.M.F. by compensation and gave the results of a series of experiments in which the Peltier E.M.F. and thermo-electric power were determined for several pure metals and also alloys of bismuth and tin. More recent experiments in which the thermo-electric powers and the conductivities of new specimens of the bismuth-tin alloys were determined, are now reported on in a joint paper, "Conductivities and Thermo-electric Powers of Bismuth-tin Alloys," by Cecil A. McKay and the author.

It occurred to the author that for theoretical reasons it was desirable to have data on the same specimens for the Peltier, Seebeck and Thomson effects, and for electrical conductivity. With that object in mind the author proceeded to modify the apparatus used for the Peltier and Seebeck effects so as to be able to measure the Thomson effect as well.

The method used in measuring the Peltier E.M.F. was to have the junctions of the dissimilar metals (one always being copper) in two Dewar flasks containing coal oil and to send a measured current through them. Owing to the Peltier effect the temperature of one junction with its surroundings rises in temperature faster than the other. By means of a small heating-coil a sufficient amount of heat was added to the flask in which heat was absorbed, owing to the Peltier effect, to maintain the two flasks at the same temperature. A modification of this method consisted in supplying the heat in the junction itself by means of the resistance of the metal which with copper formed the junction, and sending more current through one junction than through the other.

The same principle has been applied in the measurement of the Thomson effect. The general method is here outlined and some of the precautions which must be observed pointed out. The mechanical details as worked out at present are far from perfect but suffice to show that the method is entirely feasible. The results of some experiments on the bismuth-tin alloys are included.

The apparatus is described in the author's paper entitled "Tests of

[1] Phys. Rev., Ser. I., XXXIII., pp. 379–402, Nov., 1911, and Phys. Rev., N. S., VII., pp. 269–277, Feb., 1916.

Thermo-electric Formulæ Based on Bismuth and Bismuth-tin Alloys," to which reference has already been made. The only difference is that new test specimens were cast. The preparation of these is outlined in the paper by Mr. McKay and the author.

The scheme of electrical connections for the Thomson effect alone is shown in Fig. 1. *AB* and *CD* are two test specimens of the same metal,

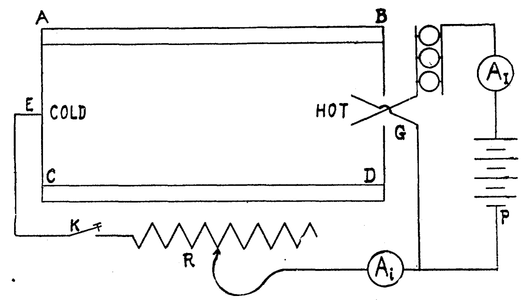

Fig. 1.

connected together at one end and at the other end connected to two poles of the six-pole reversing switch *G*. The switch *G* is in series with a lamp-bank, ammeter and source of current, as shown. The current passing through this ammeter is designated by the letter *I*. A shunt circuit containing another ammeter, the resistance *R* and the key *K* is connected between *E* and the pole *P* of the current source. This shunt circuit is then in parallel with one of the specimens. As these have resistances of the order of 0.1 ohm, any variations of the resistance between *E* and *P* due to variations in *R* have an inappreciable effect upon the value of *I*. One pair of junctions, say *A* and *C*, is kept in melting ice, and the other in boiling water, the water being kept at the boiling-point by sending current through one of the small heating-coils used in determining the Peltier effect. With the key *K* open, a current is sent through the circuit so that the current flows, say, from *B* to *A* and from *C* to *D*. If the Thomson effect is positive, then more heat will be developed in *AB* than can be accounted for by the Joule heating effect, and less in *CD*. If, then, some of the current through *AB* is shunted through *R*, the current *I* being kept constant, the Joule heating can be reduced in *AB*, but not in *CD*, until the Thomson effect is exactly compensated. Assuming the current to flow as already suggested, if *P* is the positive pole of the source of current and the "specific heat of electricity" is positive, compensation is effected by closing the key *K*, and making suitable adjustment of the resistance *R*. If *P* is the negative pole, or if the "specific heat of electricity" is negative, the current through the test pieces must be commuted by means of the switch *G*.

Let I = current through the generator,
i = current through R, and $I' = I - i$,
t and t' = the respective temperature gradients in degrees per unit length of bar,
r and r' = respective resistances of unit length of bar,
and σ = the absolute value of the Thomson effect.

Then

$$I^2r - I\sigma t = I'^2r' + I'\sigma t',$$

whence

$$\sigma = \frac{I^2r - I'^2r'}{It + I't'}. \tag{1}$$

If $r = r'$, and $t = t'$, this equation reduces to $\sigma = ir/t$.

In operation it was found impracticable to obtain exact equilibrium, and so the method followed has been to determine the difference in temperature existing between corresponding points on the two bars, first, when no current was flowing through the bars, secondly, when the same current, I, was flowing through them, and lastly, when some of the current was shunted through the resistance R. Let the difference in temperature be T_1 degrees in the first case, T_2 in the second, and T_3 in the third, and let $(T_3 - T_1)/(T_2 - T_1) = 1 - x$, x being the fraction of the proper compensation which is actually effected, then

$$I^2(r' - r) + \sigma I(t + t') = k(T_2 - T_1),$$

where k is a constant, and

$$I'^2r' + I'\sigma t' - I^2r + I\sigma t = k(T_3 - T_1),$$

whence

$$\sigma = \frac{(2I - i)ir' - xI^2(r' - r)}{xI(t + t') - it'}. \tag{2}$$

Equation (2) has been used throughout the computations.

Previous experimenters, who have used somewhat similar methods, have determined the temperatures at different points on the bars, the temperature gradients and the temperature changes, by means of thermo-elements separated from the metal by thin strips of mica or other insulator. It seemed to the author that the thermo-elements would respond rather slowly to changes in the temperature of the bars and, consequently, might tend to give inaccurate results. To obviate this difficulty, one junction of a thermo-couple was soldered to a small spring, by means of which it was held in contact with a test specimen, and the other junction was placed in a Dewar flask which was filled with water. During the course of an experiment the temperature of the water in the flask rose slightly, but since the temperature was read at frequent intervals the temperature at any instant was known. Three junctions were used on each bar, as is shown in Fig. 2. Copper-constantan couples were used. It was thought that three points on each bar might be sufficient to determine the temperature gradient, but this was found not to be the case, and so it was necessary to perform at least two experiments on each pair of specimens, placing the junctions of the thermo-couples at different points on the bars in the different cases.

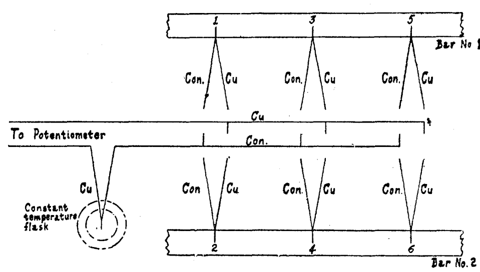

Fig. 2.

Whenever circumstances permit the resumption of the experiments, which must be laid aside for some time owing to the war, the author proposes to use at least ten thermo-couples with five junctions on each bar. These will be rigidly attached to a board covered with a thick layer of felt and hinged to the apparatus in such a way that it can be quickly and easily clamped down onto the bars. In this way it is believed that radiation and convection and conduction losses to the surroundings can be practically entirely eliminated and uniformly good contact between the bars and the thermo-couples will be insured. The steady state in the bars will then depend absolutely upon the end temperatures and the rate of production of heat in them by the electric current. This board will replace the present felt pad which is laid over the bars and held down by weights.

The thermo-couples were connected to a potentiometer and differences in temperature between the various points on the bars and the water in the Dewar flask thereby determined. These readings together with the temperature readings of the water in the flask furnished all the necessary temperature data. It was found that about 25 minutes must elapse before a steady temperature state is set up in the bars after changes in the experimental conditions, such as, starting the current through the bars. Readings were made in the order: 1, 2, 3, 4, 5, 6, 1, 2, 3, 4, 5, 6 (see Fig. 2) and whenever any reading in the second set differed from the corresponding one in the first, the values used were found by interpolation.

Two difficulties have been encountered with the apparatus in use, which have necessitated the rejection of some of the experimental results. The first was that the springs used did not always insure a good contact. This was particularly true in the case of the pure bismuth, the springs being so stiff they chipped the metal. The second was that a small amount of steam escaped from the hot flask through the openings around the test bars, because these were made large enough to permit the bars to slip through easily. This steam condensed on the bars and between the layers of felt and consequently disturbed the thermal equilibrium of the bars. Both these defects can, however, be remedied to a large extent; but in view of the dedication by the university of its staff and other resources to enterprises bearing directly upon the war and the improbability of an early resumption of the experiments, it seems best to make a preliminary report at this time.

The results given in the following table are, with the exception of those for bismuth, the mean of four or more determinations and are, we believe, approximately correct. In the case of the pure bismuth the value given is the mean of but two determinations, and the author would not attach too much weight to it. All the values given here are considerably in excess of those given by Laws.[1] This may be due in part

Table I.

Percentage of Tin in Alloy.	Thomson Effect in Microvolts per Degree Centigrade.
0 (Pure Bi)	58
1.00	676
2.00	537
3.72	207
6.36	137

to slight differences in the composition of the specimens, but probably is more largely due to the differences in the experimental procedure. The author believes that the direct contact between the thermo-couples and the bars is likely to yield more trustworthy results than those obtained when any insulating material, however thin, intervenes. He also believes that the experimental conditions of the method here outlined can be made at least as satisfactory, if not more so, as any other method yet proposed. These results have been calculated from the temperature determinations made with the potentiometer, and the conductivities of the same specimens as determined by McKay and the author. The value of σ was determined for temperatures ranging from

[1] Laws, Phil. Mag., 6, 7, pp. 560–578, 1904.

27.7° C. to 89.2° C., but since they did not indicate any systematic temperature variation, the results given are the means of all the determinations, the mean temperature of all the determinations being 43.5° C. The probable error is in the neighborhood of 50 microvolts per degree Centigrade. In these experiments the value of the current I varied from 3.0 to 3.1 amperes, and that of i from 0.139 to 0.790 amperes. The value of x ranged from 0.252 to 2.81.

The results are shown graphically in Fig. 3.

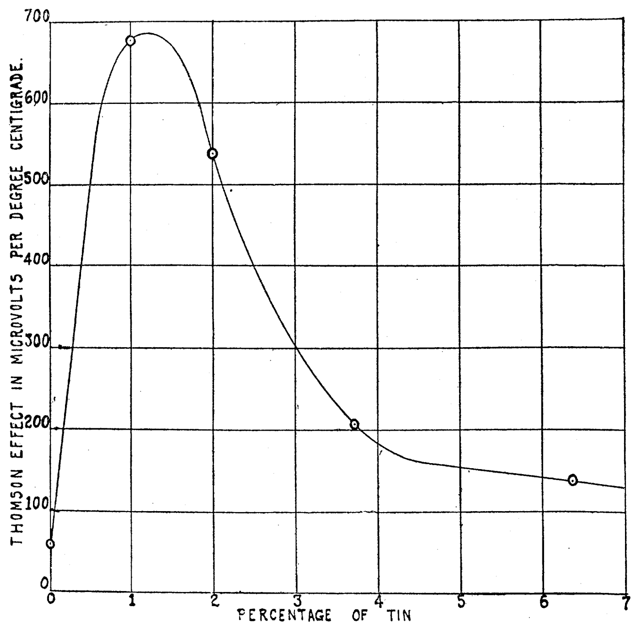

Fig. 3.

SUMMARY.

A method of measuring the Thomson effect by compensation in test specimens designed for the measurement of other thermo-electric effects (also by compensation) is here outlined. One is thus enabled to determine these properties of metals *using the same specimens for all determinations*, and not specimens similar to each other but which may differ considerably in these properties.

The apparatus used is open to improvement in a number of ways and when so improved should make the measurement of the Thomson effect a comparatively simple operation. It is quite possible that a fairly sensitive D'Arsonval galvanometer might be substituted for the potentiometer with advantage.

With bars of homogeneous material and uniform cross-section the mathematical computations become quite simple, since, except in the cases of those substances having abnormally high Thomson effects, the resistances of unit lengths of the bars and the temperature gradients in the bars will be the same for both bars of the same material. In this case the equation for the Thomson effect reduces to the form

$$\sigma = \frac{(2I - i)ir}{(2xI - i)t}.$$

The results obtained indicate a remarkable increase in the Thomson effect when very small amounts of tin are added to pure bismuth. As the percentage of tin is increased beyond about one or two per cent. the value of the Thomson effect decreases.

In conclusion the author wishes to express his appreciation of the help and suggestions of Prof. W. P. Boynton and Mr. Cecil A. McKay.

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