THE ELECTRICAL CONDUCTIVITY OF VERTICALLY SUSPENDED WIRES.¹

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UNDER a similar caption, Shelford Bidwell² showed that the electrical resistances of vertically suspended copper and iron wires alter to a small extent with the direction of the current traversing them. He found that the resistance of a copper wire is slightly greater when it is directed upwards than when it flows downwards. On the other hand, a temporarily stretched iron wire, apparently, has a greater resistance for a downward current than for one flowing upwards.

Bidwell closes his interesting paper by saying, "The effects hitherto observed are so small that they might possibly be due to accidental causes, and I publish this account of them with some diffidence." He suggests that "the experiments be repeated with much longer wires, such as might be suspended in the shaft of a coal pit or in a shot tower." So far as the present author knows, no repetition of these experiments was ever carried out by Bidwell or anyone else and it therefore seemed worth while to check up these interesting effects. Bidwell explained this change in resistance from change in direction of current as due to the Peltier heat effect and that the phenomenon was closely allied to some experiments carried out by Wm. Thomson³ in which he studied the Seebeck effect between stretched and unstretched portions of the same material.

Thomson found that if a temporarily stretched iron wire is connected to an unstretched iron wire in series and one of the junctions is heated, a current will flow from the unstretched to the stretched portion through the heated junction, as shown in Fig. 1. For permanently stretched iron wire just the reverse occurs as shown in Fig. 2. In temporarily stretched copper wire the current flowed from the stretched to the unstretched section through the junction at higher temperature. That is, temporarily stretched copper wire behaves as does the permanently stretched iron wire.

In some experiments carried out by Le Roux⁴ along the same lines as

¹ Read by title at the Columbus meeting of the Amer. Phys. Soc., Dec. 27-30, 1915.

² Phil. Mag., Vol. 23, p. 499, 1887.

³ Thomson, Papers, Vol. 2, p. 296.

⁴ Le Roux, Ann. Chim., Phys. (4), 10, p. 226, 1867.

those indicated by Thomson, contradictory results were obtained. According to Tunzelmann¹ this was because the stretching gave different

Fig. 1.

Fig. 2.

results, depending upon whether the tension was large or small. Cohn² found a cyclic effect in increasing and decreasing the tension and doubtless the discrepancy between Thomson's and Le Roux's work may be

found in just this phase of the subject. This seems to have been confirmed by Ewing.³

In a vertically suspended wire, the wire becomes more and more stretched as we ascend, hence an electric current flowing up the wire flows from a less stretched to a more stretched portion and we should have a Peltier heating or cooling depending upon what the Seebeck effect is for the particular material investigated. For a substance in which the Peltier effect gives a heating at the junction when the current flows from an unstretched to a stretched portion there will

Fig. 3.

be a small increase in temperature in a vertically suspended wire if the current flows upward and a slight cooling when the current flows downward. By arranging the vertically suspended wire, as shown in Fig. 3, Bidwell was able to demonstrate this phenomenon.

¹ Tunzelmann, *Phil. Mag.* (5), 5, p. 339.

² E. Cohn, *Wied. Ann.*, 6, p. 385, 1879.

³ Ewing, *Beibl.*, 6, p. 32, 1882.

A wire AB was suspended at its middle point and the two ends connected to a Wheatstone bridge in such a way that the two portions of the wire A and B formed two arms of the bridge. When the current flows from the battery, the major part may be made to flow through A and B by making R_1 and R_2 fairly large. This arrangement also increases the sensitivity of the bridge.

The current as it flows, let us say, up A and down B will cause the temperature of A to rise and of B to lower if it is a specimen of permanently stretched iron wire. In addition there will also be a Joule heating, but if the wire is uniform this change in temperature will be the same in both arms of the bridge and will remain the same no matter which way the current flows. With the Peltier heating effect, however, there will be a difference in the temperature between A and B and this will depend upon the direction of the current through A and B . This difference in temperature due to the Peltier effect will produce a change in resistance and so throw off the balance of the bridge when the current is reversed by means of the commutator, X . This explanation of Bidwell's effect of course led to the suggestion by Bidwell that the experiment be repeated, using much longer wires, for the longer the wires the greater would be the difference in resistance between the two portions of the wire, A and B , which could the more readily be measured on the Wheatstone bridge.

Inasmuch as no mine shaft or tall tower was available and a deep elevator shaft was so drafty that temperatures were hard to control it occurred to the author that the differential resistance might be augmented by loading the wires at regular intervals. This was done by attaching to the vertically suspended wires, A and B , at intervals of 30 cm., blocks of lead weighing 175 grams each. The effects were so positive that it seemed worth while to put the results on record as corroborating the preliminary notice given by Bidwell.

The wires used were *insulated* iron and copper wires. Uninsulated wires gave very discordant results from variations in temperature due to air currents. The insulating material prevented those rapid changes in temperature so that balancing of the bridge was possible. There were two specimens of iron wire; one possessed a permanent stretch from having been stretched for years as a telephone line, while the other wire was only temporarily stretched during the experiment, as was also the case for the copper wire.

The temporarily stretched copper wire had a diameter of 0.104 cm. and was insulated with a double cotton covering. One branch, A , Fig. 3, of the copper wire had a resistance of 0.2055487 ohms when a current

of three amperes flowed upwards, and a resistance of 0.2055162 ohms when the current was reversed. This gave a difference in resistance equal to 0.0000325 ohms. This is equivalent to a 0.016 per cent. change. A change in temperature of 1° C. produces an alteration of about 0.4 per cent. in the resistance of copper; hence the temperature of the copper wire was $1/25^{\circ}$ C. higher with an upward than with a downward current.

Qualitatively, a permanently stretched iron wire behaved the same as the sample of copper just described. It had a diameter of 0.268 cm. and was insulated with rubber and a cotton covering over that. The arm *A* of this wire had a resistance of 0.2095217 ohms when a current of three amperes flowed upwards and a resistance of 0.2095012 ohms when the current was reversed, making a difference of 0.0000206 ohms or about 0.01 per cent. change in resistance. A change in temperature of one degree C. changes iron about 0.5 per cent.; hence this would indicate an alteration in temperature of about $1/50^{\circ}$ C. when the current was reversed in the wire.

Another iron wire which was only temporarily stretched had a diameter of 0.1024 cm. and was insulated as the other sample of iron wire. The arm *A* of this wire had a resistance of 0.9996020 ohms when the current flowed up and a resistance of 0.9997754 ohms when the current was

Fig. 4.

reversed. This sample of wire showed an opposite effect from that of the copper or of the permanently stretched iron wire. This change in resistance amounted to 0.0001734 ohms and would be counted positive if the other two were taken as negative. The percentage change amounts to about 0.017 and since iron changes its resistance per degree about 0.5 per cent. the alteration

in temperature due to the reversal of three amperes amounted to about $1/30^{\circ}$ C.

In order to check up the effects thus found and compare them with the Seebeck effect, the following tests were made. In the edge of a piece of a plank about a meter and a half long, two large nails, *A* and *B*, were driven, Fig. 4. Between these two spikes was suspended a piece of the wire to be tested and so wrapped about the nails that there would be no slipping when a weight was hung on it. The two ends of the wire were then carried to the terminals of a galvanometer, *G*. With a weight of 13.5 kg. hanging on the portion of the wire between the nails a combina-

tion was obtained whereby a stretched portion of the wire was connected to two unstretched sections, the junctions being located at the nails. By applying a Bunsen flame at the junction of the stretched and unstretched portions it was checked out and found that the Seebeck effect was of the character that should correspond to the Peltier effect found in the suspended wires. The character of the Seebeck effect in the three wires experimented upon are shown in Figs. 1 and 2.

It is needless to say that when measuring the resistance of the vertically suspended wires careful tests were made to insure that no spurious

Fig. 5.

thermoelectromotive forces were present to cause a deflection of the galvanometer when the bridge was being balanced on the reversal of current.

Change in resistance of the vertically suspended wires with change in direction of current was measured for different magnitudes of current flowing through the wires. These results are shown in Fig. 5, that for iron being for temporarily stretched iron wire.

If the explanation given by Bidwell is correct and a difference in temperature between *A* and *B* exists then it ought to be detected by various means. This was done and the first method used was to strip off the

insulation from the vertically suspended wires for a distance of about 5 cm. and paint the bare wire with a thin coating of shellac. Around this bared portion of the wire, No. 32 single cotton-covered German silver wire was closely wound in a single layer. Equal coils, C_1 and C_2 , were wound on each vertical wire as shown in Fig. 6. The vertically suspended

Fig. 6.

wires were detached from the bridge and connected in series with ammeter, G , reversing switch, C , and suitable rheostat, R , so that current could be sent up either A or B . The wire, C , connecting the center point of $A-B$, Fig. 1, was also detached from the bridge and the lower end swung free in the air.

Coils, C_1 and C_2 , were then put into the bridge as two arms of the same, see Fig. 6.

If now an electric current is allowed to flow up A and down B in a piece of permanently stretched iron wire, the temperature of A will increase slightly and consequently C_1 , while section B will cool off a small amount, slightly lowering the temperature of C_2 . If the bridge is now balanced and the current in $A-B$ reversed the reverse conditions of temperature will occur in A and B and so spoil the balance of the bridge. The results obtained by this method proved very erratic, but on the whole pointed to a positive result.

Not content with this demonstration, a thermocouple of No. 36 copper and constantan wires was made and the two junctions placed alongside of bared portions of the wires *A* and *B*, care being taken that the junctions were electrically insulated by shellac from the vertically suspended wires (see Fig. 7). Both in using the coils, *C*₁ and *C*₂, and the thermocouple, the current was allowed to flow through *A* and *B* for 5 minutes before any readings were taken. Very positive results were obtained with the thermocouple. There is a difference in temperature of the wire when a current flows up than when down. It was not a sensitive thermocouple which was used. With the galvanometer used in this test I could detect 1/100 of a degree C. without any difficulty.

Fig. 7.

Calibrating the thermocouple, I found a fair degree of agreement between the results obtained by observation and those calculated by the method given by Bidwell. For instance, in the permanently stretched iron wire there was, by observation, with the thermocouple a difference in temperature of about $1/20^{\circ}$ C. between *A* and *B* when 8 amperes flowed through *A* and *B*. When 3 amperes flowed it was calculated, as already shown, a difference of about $1/50^{\circ}$ C. in *A* when current flowed up and when down.

It is to be remembered that a reversal of current in *A* and *B* would not reverse the Joule heating effect, hence it could be eliminated from the final results.

It is hard to draw comparisons between the results obtained for the different wires. The tension for the temporarily stretched iron wire is very much larger per unit cross section than for the permanently stretched one and accounts in part for the larger difference in temperature and

resistance when the current flows in one direction from what it does in the other. Then there is also the difference in physical conditions of the conductors—as well as chemical—to be considered.

This note, then, confirms the work of Bidwell both as to the character of the effect and as to the explanation of it. It has also extended the observations to another specimen of iron wire, and would have been extended to more if insulated specimens could have been obtained. It is a small contribution to that very large subject¹ in which thermoelectric currents are generated between portions of the same material but in one of which permanent or temporary *physical* changes have occurred.

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¹ Wm. Thomson, Phil. Trans., Pt. IV., 1856. Tomlinson, Phil. Mag., Vol. 25, p. 45, 1888. Newall, Phil. Mag., Vol. 25, p. 510, 1888. Smith, PHYS. REV., Vol. 28, pp. 69, 107, 429. Science, Vol. 40, p. 606, 1914.