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XXV. *The Production of Thermoelectric Currents in Wires subjected to Mechanical Strain.* By G. W. VON TUNZELMANN, *Holder of the Clothworkers' Exhibition in Chemistry and Physics at University College, London.*

THE following inquiry was suggested by some observations recorded in a paper of Sir William Thomson's on the Electrodynamic Qualities of Metals, in the 'Philosophical Transactions' for 1856; and the object in view was to investigate the conditions under which thermoelectric currents are produced in a circuit composed of a single metal when one portion of the metallic conductor is subjected to a strain and the junctions of the strained and unstrained portions are maintained at different temperatures.

The experiments were made upon wires of iron, steel, and copper, the copper wire employed having been obtained from Messrs. Johnson, Matthey & Co. as chemically pure.

Two tin cans were obtained open at the top, and pierced at the bottom by necks into which india-rubber corks were inserted; and through slits in these the wires were passed. The wire was fastened by a clamp in the lower can, and was grasped in the upper one by a pair of wire-drawing dogs attached to the shorter arm of a lever, to the longer arm of which was attached the weight by which the strain was produced. In the earlier experiments ordinary weights were used; but ultimately these were rejected, as it was found impossible to apply and remove them in a sufficiently gradual manner to prevent a certain amount of shock, which introduced complications.

In the arrangement finally adopted, there was attached to the longer arm of the lever a tin can open at the top, and having at the bottom a neck fitted with an india-rubber tube, which could be closed by merely bending it up and hitching it in a hook attached to the can for that purpose. The strain on the wire was then produced as gradually as was desired, by pouring in measured quantities of shot; and it could be removed as gradually by letting the shot run out by the india-rubber tube.

The two cans through which the wire passed were filled with water, the water in the upper can being kept at the temperature of 100° C. by means of a gas-burner, while that in the lower can could be kept for a considerable time at a uniform temperature by allowing a current of water, of the same temperature as the place of experiment, to circulate through it.

The extremities of the experimental wire were bent round in a large curve and brought close together; they were then tied to the extremities of two covered copper wires connected, through a four-way key, with a Thomson's galvanometer having a resistance of between one and two ohms. The junctions were then placed side by side separated by thin paper, and wrapped up in cotton-wool, as was done by Thomson in his experiments, to prevent the production of currents by the unequal heating of the two junctions.

Before being used the wires were annealed:—the iron and steel wires by being heated to redness in an iron tube, through which a current of coal-gas was passing to prevent oxidation; the copper wire by being slowly passed through a Bunsen flame, as it was found that the exposure of the copper at a red heat to the current of coal-gas produced an effect similar to that known as over-poling in the process of refining copper, the wire being rendered so brittle as to break with the least strain.

Thomson found in his experiments that when a weight was applied so as to produce a state of strain in a portion of the wire, and the two junctions of strained and unstrained portions were kept at different temperatures, in iron and steel wire a current was produced the direction of which was from the unstrained to the strained portion across the hot junction, while in copper wire the current was in the opposite direction. When the weight was removed the result was in either case a weaker current in the reverse direction.

Some experiments of the same nature have also been made by M. le Roux, and described in the *Annales de Chimie et de Physique*, 4th series, vol. x. p. 201 (1867). He obtained results of the same nature as Thomson—with the notable difference that in iron and steel wires he got a current from strained to unstrained across the hot junction, while in copper wire the current was from unstrained to strained across the

hot junction. On comparing the descriptions of the experiments, it appeared that Thomson had always made his experiments with comparatively small strains, while Le Roux had strained his wires very nearly to the breaking limit. This at once suggested a possible explanation of the apparent discrepancy between their results; and on making the experiments, it was found that as the strain was gradually increased the current was increased, as in Thomson's experiments, but only up to a certain limit. When the strain was increased beyond this limit there was a gradual decrease in the current; and if the strain was very carefully increased, the direction of the current was reversed shortly before the breaking strain was reached.

During the experiments, it was very soon observed that after a weight had been added the current did not remain constant, but gradually diminished; while at the same time there were variations of small period in the strength of the current, which were greater when the weight was added suddenly, and scarcely perceptible when it was very carefully and slowly added by pouring in shot; these variations gradually ceased when the apparatus was not disturbed. A very gentle and gradual addition of weight diminished these variations, which always died away more rapidly when there was a heavy strain on the wire. Clutching the wire in the "dogs" also set up these variations, which were allowed to subside before beginning the experiment. These results suggested that the production of the current might be due to a process of change in the molecular state of the wire; it was found, however, on examination that there was a permanent effect which could not, as far as I can see, be produced in that way, whatever may have caused the temporary effect.

Where the results obtained at different times had not to be compared, the current is generally given in terms of the deflections of the galvanometer; but where such comparison was necessary, the value of the deflections was determined at each experiment in terms of a standard current obtained by sending a current from a Daniell's cell through a definite resistance.

For the sake of brevity, U.S. will be written for "from unstrained to strained across the hot junction:" and the oppo-

site direction of the current will be denoted by S.U. The following letters are used in the description of the experiments:—

- W = tension applied to wire in pounds, = 3 times weight actually applied to lever;
 M = number of measures of shot effective in stretching wire, = 3 times number actually applied to lever;
 Θ = temperature of lower can;
 D = mean deflection of galvanometer;
 C = strength of current in terms of the standard current.

A considerable number of preliminary experiments were made to verify Thomson's results and to determine the best form of apparatus, the arrangement ultimately adopted being that already described. These experiments (which are not described here) gave a general idea of the phenomena to be looked for. The alteration of resistance from strain is not taken into consideration, as H. Tomlinson's experiments, *Proc. Roy. Soc.* 1876 (vol. xxv. p. 451), have shown that it is too small to have an appreciable influence upon the results.

Experiment 1.—An iron wire .46 millim. diameter. $\Theta = 16^\circ$; $W = 31.5$. The result is given in the accompanying Table, the direction of the current being U.S., the first reading being taken immediately after the weight was applied. It will be observed that the current does not reach its full strength immediately upon the application of the weight, but rises rapidly to a maximum, and then gradually falls to a strength at which it remains steady.

Time (minutes).	D.
0	2.5
5	6
10	3
15	2
20	2
25	2

Experiment 2.—A similar wire. $\Theta = 16^\circ$. The readings were taken immediately after the application of the weight. The sign * means that there is a deflection, but too small to be measured.

W.	D.	Direction.
6 *		U.S.
9 5		U.S.
12 3·5		U.S.
15 3		U.S.
18 *		S.U.
21	{ wire broke.	

It will be observed that the direction of the current changes just before the wire breaks.

Some steel wire was now taken ; and as it was found almost impossible by the most careful annealing to get a piece of wire arranged in the apparatus which should give no deflection before the application of the weight, the initial deflection was noted in each case.

Experiment 3.—A steel wire ·81 millim. diameter. $\Theta = 16^\circ$. Initial deflection = 20 S.U. $W = 31\cdot5$. After the application of the weight the deflection reversed its direction to U.S. The result is given in the following Table.

Time (minutes).	D.
2	10
3	12
4	13
5	15
6	18
24	10
25	9
50	9
90	5
130	3

The apparatus was then left for about 90' hours with the weight attached ; Θ being still 16° , there was now a deflection of 15 S.U. The weight was then removed, and the deflection fell rapidly and changed to U.S. The subsequent deflections were as follows:—

Time from removal of strain (minutes).	D. U.S.
1	2
2	3
3	4
4	6
5	7
6	8
14	8
20	10
25	7
30	3

In both cases we observe that the current gradually rises to a maximum and then falls.

Experiment 4.—A steel wire .98 millim. diameter. $\Theta = 15^\circ$. Initial deflection = 10 S.U. On the addition of a weight of 42 lbs., the deflection changed rapidly to 14 U.S., and in about an hour fell to 8 U.S., and in 40 hours to 3 U.S.

Experiment 5.—A steel wire .6 millim. diameter. $\Theta = 13^\circ$. Initial deflection = about 1 U.S. $W = 63$ lbs. Direction of current after application of weight U.S. The weight was now left suspended for about 40 hours; but the apparatus received an accidental jar before the permanent deflection could be ascertained. The weight was then removed, causing a deflection of 8 S.U., gradually increasing to 11, and then decreasing much more slowly than it had increased.

Time from removal of strain (minutes).	D.
3	3.5
6	4.5
9	3.5
12	2.5
15	1.5
18	.87
36	*

The effect of rapidly putting on and taking off the weight a number of times in succession was then tried; and it was found that each time the weight was put on the deflection diminished, while each time that it was taken off the deflection was increased up to a certain limit. The immediate increase produced by taking off the weight was greater than the immediate decrease produced by putting it on; so that on the whole there was a large increase in the current, the deflection being got

up in this way to nearly 30 S.U., falling again very rapidly if the weight were left attached to the wire. Under these circumstances the deflection went down rapidly to zero, changed sign, rose to a maximum, and then again began to diminish, passed through zero in the opposite direction, and so continued to perform excursions in alternate directions, and very rapidly decreasing in extent. When the weight was permanently removed the deflection of the galvanometer died out much more slowly, and the changes of sign were only just perceptible. These phenomena confirm the conclusion to which I was led by the former experiments, that there is, besides the main effect, a transient effect produced by altering the strain on the wire; and this transient effect appears to me to be due to the molecular state of the wire making a partial return after the first shock towards its primary condition, just as the immediate deflection of a spring suddenly stretched by a weight is greater than when it has come to rest in its position of equilibrium. The changes of sign in the current as it gradually comes to its final state after the wire has been violently disturbed, as in the last experiment, as also the fact of there being a permanent as well as a temporary effect, seem to render this hypothesis more probable than that the current is actually produced by a change in the molecular state of the wire.

The phenomena obtained in the last experiment will be rendered more clear by a diagram.

The intervals between taking off and putting on the weight were approximately equal. These are therefore represented by equal distances along the axis OT ; and the strength of the current is set off along the axis OC . Starting from the point O , at the beginning of the experiment, with the weight attached to the wire as it had been left, then at any time the broken line

----- represents the permanent change in the current produced by taking off or putting on the weight;

..... represents the temporary change;

—— represents the resultant strength of the current, being the sum of these two components.

The curve A represents the change in the current when the weight is left permanently attached; and the curve A' represents the change in the current when the weight is permanently removed.

At this stage in the experiments the method of measuring the current-strength in terms of a standard current was adopted.

The battery used as a standard was a "sawdust" Daniell's (Menotti's) cell; and the strength of the current was approximately that produced by 1 volt through 10,000,000 ohms, or 10^{-8} C.G.S. unit. The measurements of the Tables are given in millionths of a C.G.S. unit.

Experiment 6.—A similar steel wire. $\Theta = 16^\circ$. Initial deflection barely perceptible S.U. Weight of 30 lbs. left on about 40 hours.

It was observed that at the time of making the experiment the weight was making small oscillations; and this appeared to be the cause of the deflections making small oscillations about a mean value. At the end of an hour and a half the oscillations of the weight and also of the deflection had ceased, the latter remaining steady at 5, indicating a current $\cdot 007$ U.S. The weight was now made to perform vibrations of small amplitude, upon which the oscillations of the deflection were greatly increased both in number and amplitude, and the mean deflection was at the same time somewhat increased. If the vibration of the weight be suddenly stopped, it is some little time before a decrease is perceived in the oscillations of the deflection.

After setting the weight in gentle vibration, the effect in causing oscillations in the deflection was observable in less

than a minute. If the vibrations of the weight are kept up for some time, the mean deflection is increased up to a certain limit, as before described. If the vibrations of the weight are increased in amplitude, the oscillations of the deflection become much more irregular, and the limits of variation become greater.

Experiment 7.—A similar wire. $\Theta = 12$. Initial current $\cdot 0014$ U.S. A weight of 3 lbs. was now attached ; and at the end of two minutes there was a current $\cdot 0052$ S.U., falling at the end of an hour and a half to $\cdot 0034$ U.S. The weight was then increased by 3 lbs. at a time and the deflections taken immediately, with the results given in the accompanying Table:—

W.	C.	Direction.
6	$\cdot 0038$	U.S.
9	$\cdot 0019$	U.S.
12	$\cdot 0014$	U.S.
15	$\cdot 0012$	U.S.
18	$\cdot 0012$	U.S.
21	$\cdot 0012$	U.S.
24	$\cdot 0012$	U.S.
27	$\cdot 0010$	U.S.
30	$\cdot 0002$	U.S.
33	*	S.U.

In the experiments after this the weights are given in terms of measures of shot, each of which weighed about 7480 grains.

Experiment 8.—A similar wire. 33 measures left on for about 40 hours. $\Theta = 12^\circ$. Deflections read immediately after removal of weight. Direction of current S.U. There was no initial deflection.

M.	C.
33	$\cdot 0095$
30	$\cdot 0046$
27	$\cdot 0035$
28	$\cdot 0039$
21	$\cdot 0049$
18	$\cdot 0060$
15	$\cdot 0067$
12	$\cdot 0074$
9	$\cdot 0084$
6	$\cdot 0091$
3	$\cdot 0098$
0	$\cdot 0105$

Experiment 9.—A similar wire. $\Theta = 12^\circ$. No initial deflection. Deflections read immediately after application of weight.

M.	C.	Direction.
3	·0025	U.S.
6	·0025	U.S.
9	·0021	U.S.
12	·0014	U.S.
15	·0014	U.S.
18	·0014	U.S.
21	·0014	U.S.
24	·0014	U.S.
27	·0011	U.S.
30	·0007	U.S.
33	·0004	S.U.
36	·0014	S.U.

Experiment 10.—A steel wire ·47 millim. diameter. $\Theta = 12^\circ$. Initial deflection 4 U.S. On attaching the empty can for containing the shot to the end of the lever the deflection increased to 20 U.S., falling to 14·5. The strain was gradually increased by pouring shot into the can until the wire broke. The deflection changed very little until the wire began to stretch, when the deflection fell very rapidly, passed through zero, and went up to about 40 S.U.

The more rapid the stretching the stronger is the current produced. When the strain was slightly lessened, so as to stop the stretching, the deflection fell very quickly to 20 S.U. On removing the strain the deflection fell rapidly, passed through zero, and went up to 2 or 3 U.S., making irregular vibrations. The weight was replaced and additional shot poured in very slowly. The deflection almost instantaneously changed to about 2 S.U., which increased slightly until the wire broke.

Experiment 11.—A copper wire ·24 millim. diameter. $\Theta = 15^\circ$. Initial deflection 1 S.U.

M.	D.
0	1
3	1
6	3
9	3
12	3
15	4
18	4
21	2·5
24	2·5
27	2
30	1·5
33	1·5
36	1·5
39	1·5
42	1·5

The direction of the current was S.U. Several small weights were added to the can; but the deflection remained steady at 1·5. In copper wire, no fall in the deflection was observed when the weight was left suspended for some time.

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XXVI. *On the Influence of Temperature on the Passage of Air through Capillary Tubes.* By FRANCIS GUTHRIE, LL.B.*

IN using "Marsh's" apparatus for testing for arsenic, it may be noticed that, when heat is applied to the exit-tube to decompose the arsenuretted hydrogen, the liquid rises in the tube which supplies the sulphuric acid, thus leading to the supposition that the passage of the gas through the exit-tube is checked by the increase of temperature, thereby producing increased pressure. This observation suggested the following experiments on the effect of heat on the passage of gases through capillary tubes.

The apparatus used was as follows:—From a vessel, A, water drops into a funnel, *b*, causing a continued overflow.

* Communicated to the Physical Society, April 13, 1878. A note of the results was communicated to the British Association, 1876.