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L. P. Sieg
University of Iowa

AN ATTEMPT TO DETECT A CHANGE IN THE HEAT CONDUCTIVITY OF A SELENIUM CRYSTAL WITH A CHANGE IN THE ILLUMINATION.

L. P. SIEG.

Introduction.—Modern electron theories indicate that the electrical and thermal conductivities of good conductors should stand in very close agreement with each other. One of the first theoretical developments was that of Drude.[1] While, perhaps, it will not be necessary to rewrite his formula here, we can at least state that he determined on purely theoretical grounds that the ratio of the thermal to the electrical conductivities for good conductors should be a function only of the absolute temperature. This theoretical formula has had excellent verification in the work of Jaeger and Disselhorst,[2] who worked with most of the common metals. It occurred to the writer that an interesting experiment could be performed with an isolated crystal of selenium in order to determine whether or not the action of light lowers its resistance to heat conduction in the same or any other measure, that it does in the case of the electrical resistance. Little hope was entertained of obtaining as great a change in the thermal as in the electrical conductivity on account of the high resistance of the selenium, but it was hoped that there might be some small effect in this direction. In looking up the literature of the subject it was found that there was but one published paper, that by Bellati and Lussana,[3] who worked, not with a crystal, but with thin sheets of crystallized selenium. Their method was somewhat crude, but they reported that there was an increase in the thermal conductivity when the thin plate was exposed to sunlight of the same order of magnitude as the increase in the electrical conductivity. (See reference to the Beiblaetter).

Apparatus and Method of Observation.—The apparatus used is illustrated in diagram in figure 27. Heat is generated in the

[1] Ann. d. Phys. 1, 566, 1900; 3, 369, 1900.

[2] Preuss. Akad. Wiss. Ber. Sitzungsber. 38, 719, 1899, also Phys. Tech. Reich., Wiss. Abh. 3, 269, 1900.

[3] Atti del R. Inst. Ven. (6) 5, 19, 1877. Also Abs. Beib. d. Ann. 11, 818, 1887.

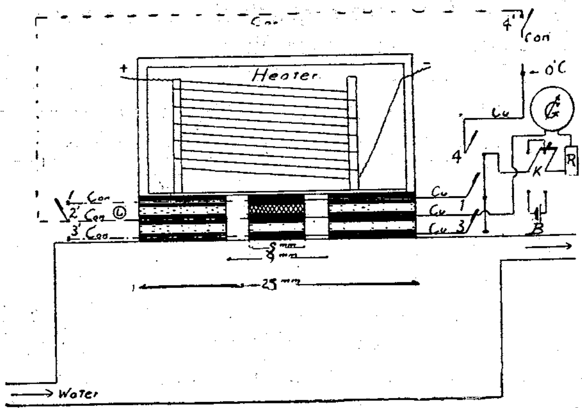

FIG. 27.—Apparatus for detecting change in heat conductivity of selenium crystals.

upper part, marked "heater". This heat flows through five layers of material to be described immediately, and thence to the lower vessel through which tap water flows. There is thus maintained a temperature gradient from the top to the bottom. The five layers are in two parts; the outer, in the form of thin washers, and serving as guard rings; and the inner, consisting of thin discs. The apparatus is drawn to scale, and there are sufficient dimensions shown to make the relative sizes clear. The order of the washers, from top to bottom is: copper, glass, copper, glass, and copper. The order of the discs from the top down is; copper, selenium crystal (fern-like growth, made up of hexagonal crystals), copper disc, glass disc, and copper disc. Thermo couples of copper and constantan which pass through, and are insulated from the outer copper washers, are fastened into the three copper discs in the center. As mentioned, the purpose of the outer washers was to serve as guard rings, so that with a given temperature gradient throughout from top to the bottom there would be very little or no lateral heat transfer. If there is no lateral heat transfer, then we can develop a simple equation for the relation of the thermal conductivity of the selenium to that of the glass. Assuming that the heat transferred passes on from the top to the bottom, we have the formula for the relation of the heat conductivity of the selenium to that of the glass[4]

$$\frac{K_1}{K_2} = C\frac{T_2 - T_3}{T_1 - T_2}$$

[4]See Christiansen, W. Ann. 14, 23, 1881, for derivation of formula.

where T_1, T_2 and T_3, are respectively the temperatures of the top, middle, and bottom copper discs. C is a constant. So this apparatus will not give the absolute thermal conductivity of the selenium, but will give the ratio of that conductivity to that of glass. If we assume, as we are surely justified, that light does not affect the thermal conductivity of glass, then we are in a position with this apparatus to discover if there is any change in the thermal conductivity of the selenium with illumination. The illumination was obtained by means of a 25 watt tungsten lamp, having a full frosted globe, placed at *L* in figure 27.

The connections at the right hand side of the diagram are perhaps clearly enough indicated. By the proper manipulation of the keys it is possible to get the temperature differences (when galvanometer readings are reduced to temperatures) between the various copper discs. Also it is possible, by throwing the key *K* downward, to place a cell in circuit, and thus get the measure of the electrical conductivity by means of the resulting galvanometer deflection.

Without going more into details in regard to the experiment, the table below is referred to for a brief indication of the results. In this table the first six columns represent respectively the temperature difference between the top and middle discs, between the bottom and middle discs, between the room temperature and that of the middle disc, the temperature of the top, of the middle, and of the bottom discs. The seventh column represents the average temperature of the selenium crystal; eighth column the relative electrical conductivity of the crystal; the ninth column represents the ratio of the thermal conductivity of the selenium to that of the glass; the tenth column represents the ratio of the electrical conductivity in the light to that in the dark; and the last column represents the state of the selenium. It will be noticed that the effect sought for is missing, or at least is so small that it becomes inappreciable. There seems a general tendency for the thermal conductivity to increase with increased temperature of the selenium, but there does not seem to be any tendency for any change with the illumination. This is to be noted in connection with the fact that the same illumination increases the electrical conductivity nearly three times.

T_1-T_2	T_3-T_2	T_4-T_2	T_1	T_2	T_3	$T_1+T_2/2$	C	k/k_2 × Const	R	State of Selenium
1	2	3	4	5	6	7	8	9	10	11
10.9	—3.3	6.7	27.2	16.3	13.0	21.8	27	.34	2.48	dark
10.9	—3.4	6.3	27.6	16.7	13.3	22.1	67	.35		light
12.5	—4.1	3.7	31.8	19.3	15.2	25.6	33	.37	2.12	dark
12.8	—4.2	3.7	32.1	19.3	15.1	25.7	70	.37		light
19.4	—7.1	—2.3	44.7	25.3	18.2	35.0	41	.39	1.75	dark
19.5	—7.2	—2.6	45.1	25.6	18.4	35.4	72	.39		light
27.9	—9.8	—7.7	58.6	30.7	20.9	44.7	45	.36	1.67	dark
28.2	—10.4	—7.7	58.9	30.7	20.3	44.8	75	.38		light
46.1	—17.5	—19.8	88.9	42.8	25.3	65.9	53	.39	1.55	dark
46.4	—17.5	—19.2	88.6	42.2	24.7	65.4	82	.38		light
61.7	—23.8	—28.8	113.5	51.8	28.0	82.7	92	.39	1.28	light
61.7	—24.4	—29.4	114.1	52.4	28.0	82.3	72	.40		dark
73.8	—29.1	—37.4	134.2	60.4	31.3	97.3	72	.40	----	dark

Conclusion.—Contrary to the experiments described above, by Bellati and Lussana, I have failed to detect any increase in the thermal conductivity of selenium as a result of exposure to light. At any rate while the electrical conductivity increased nearly *300* per cent., the thermal conductivity increased, if at all, less than *4* per cent. This does not seriously disturb the accepted electron theories, but makes us modify them in connection with the element selenium. It may be that the number of free electrons in the selenium is much smaller than the number in ordinary good conductors, and so that even if a large number of them are made free, there are still too few of them to have much effect on the thermal conductivity. In other words the thermal conduction is by means of the atoms and molecules. On the other hand it may be quite possible that there are no free electrons in the selenium in the sense of being completely free, but that they are unstable in the atom, and that the action of light makes them more unstable. The electrical conduction takes place then because the electric field can draw the electrons out of the atom. There being no field in the case of the thermal conduction, the electrons would stay in the atom, and hence there would be no change in the thermal conductivity with the increased illumination.

PHYSICS LABORATORY,
UNIVERSITY OF IOWA.