SOME CHARACTERISTICS OF CRYSTAL DETECTORS.

By Victor A. Hunt and Laurens E. Whittemore.

THIS paper describes an investigation of the behavior of certain crystal detectors, as used in wireless telegraphy, when subjected to varying conditions of temperature, pressure and humidity.

A considerable amount of work has been done in recent years in studying the properties of various crystals and metals which have been found to be rectifiers of high frequency currents.[1] Up to the present time, however, the phenomenon of crystal rectification has been investigated chiefly by the direct application of known potential differences, both direct and alternating, to the terminals of the rectifier.

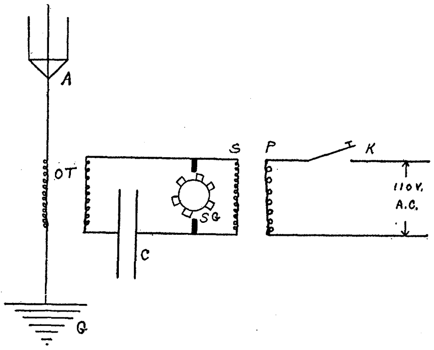

Fig. 1.

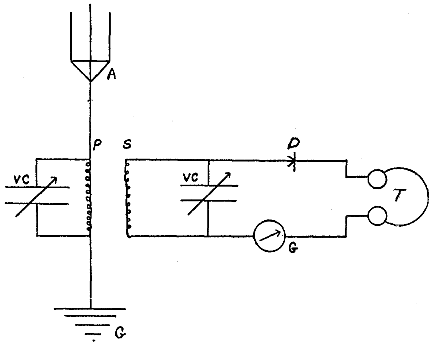

Fig. 2.

Since the most important use of crystal rectifiers at the present time is in wireless telegraphy, it was decided to undertake the investigation of the properties of four of these detectors under conditions similar to those of actual practice. Observations were made of the variations which occurred in the rectified current with changes of temperature, pressure and humidity. For the purpose we erected a sending station and a complete receiving station in different parts of the same building. Fig. 1 and Fig. 2 show simple diagrams of the two circuits. The detectors studied were galena, perikon, silicon and carborundum.

The sending station was arranged to emit a wave of about 500 meters.

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[1] The following papers give a fairly comprehensive list of the recent publications on the subject of crystal rectifiers: Goddard, Phys. Rev., 34, 423, 1912; Flowers, Phys. Rev., 3, 25, 1914; Hartsough, Phys. Rev., 4, 306, 1914.

The normal current in the closed oscillatory circuit was 4.5 amperes, and the power consumed by the transformer was 240 watts. The curve *A* in Fig. 3 shows that when this current was used, such fluctuations as would be present in the power supply would produce only small variations in the galvanometer deflection at the receiving station.

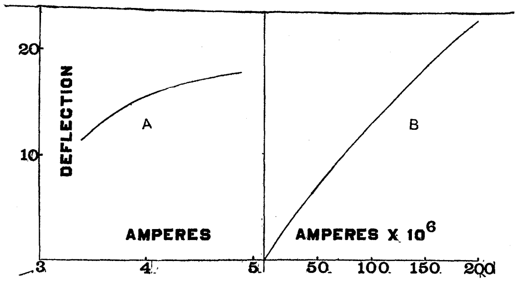

Fig. 3.

The measurements of the current in the detector were made by means of a Leeds and Northrup ballistic galvanometer of 1,069 ohms resistance and having a sensibility of 0.0026 micro-amperes per millimeter. Fig. 4 gives a complete diagram of the connection of the receiving instruments. The signals were sent out from the sending station by closing a key at the receiving station. In order to prevent any inductive effect in the galvanometer circuit from the make and break of the current in the primary of the sending transformer, the key *B* was always left open at the make and break of the sending key. The time during which the current flowed through the galvanometer was determined entirely by the time during

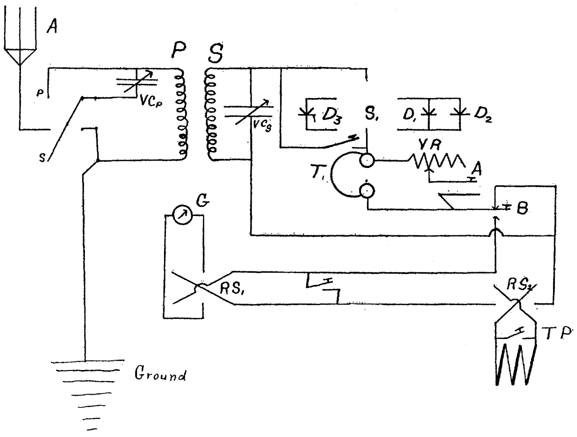

Fig. 4.

which the key *B* was closed. By means of the reversing switch RS_1 the direction of the galvanometer deflections could be changed. The switch S_1 was used to connect in an auxiliary detector with which to receive messages from other stations without disturbing the detector under test.

By far the most troublesome source of error which we encountered was an "extra" E.M.F. of variable magnitude which made its appearance continually throughout the course of the investigation. It originated at the contact of the detector and would cause a seemingly unexplainable deflection of the galvanometer even when no signals were being received. To eliminate this by inserting an opposing E.M.F. from a potentiometer in the circuit proved to be inconvenient and unsatisfactory. The method of elimination which was used consisted in the use of a thermopile which was inserted directly in series with the galvanometer, and was heated by the radiation from a thirty-two candle power carbon filament lamp. To adjust the E.M.F. generated in the thermopile the position of the lamp was varied by moving it back and forth on a sliding track. Since the "extra" E.M.F. often reversed its direction it was necessary to use a reversing switch RS_2 in order that the E.M.F. of the thermopile might always oppose it. This arrangement made it possible to eliminate entirely all extraneous currents from electro-chemical or thermo-electric sources such as have been mentioned by Flowers.[1]

The following is the method of procedure used in taking a series of readings. One observer confined his attention to the galvanometer. He first eliminated whatever "extra" E.M.F. was present by opposing it with the E.M.F. generated in the thermopile. This balance was secured by closing the key *B* and adjusting the distance of the lamp until the galvanometer showed no deflection. The observer in charge of the galvanometer wore the telephone receivers at all times in order to detect any errors in the readings which might occur due to the interference of atmospherics or to the sending of a nearby station, and all data which contained such errors were discarded.

The other observer then closed the key which put the sending station in operation, and, with stop watch in hand, pressed the key *B* for a certain length of time. The first observer then noted the maximum deflection of the galvanometer. Because of its long natural period it did not have time to come to its full deflection in the three seconds during which the current was flowing through it. The curve *B*, in Fig. 3, shows the deflections produced by the corresponding currents flowing for a period of three seconds.

In making a test we did not attempt to secure the most sensitive adjust-

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[1] PHYS. REV., 29, 445, 1909.

ment of the detector, but tried above all to secure one which would remain permanent and which gave a clear, uniform tone. The deflections were adjusted to the range of the galvanometer scale by varying the coupling of the receiving transformer which was then kept the same throughout that particular experiment. In order to subject the detector to the various physical conditions desired, we had constructed a box which consisted of a glass battery cell with a suitable brass cover.

To heat the detector we enclosed it in the box which was then immersed in cylinder oil of a high flash point and heated by a gas burner. In order to cool the detector we suspended it in a U-shaped Dewar flask which contained liquid air. The temperature obtained was measured by means of a pentane thermometer.

The pressure in the box was varied by means of a motor driven air pump and was measured with an open tube manometer.

The humidity of the air in the box was varied by varying the concentration of a sulphuric acid solution which was placed in the bottom of the cell. The air was first dried by putting in a known volume of concentrated sulphuric acid and letting it stand for some time. To increase the humidity the acid was diluted by the addition of known quantities of water. The humidity was allowed to reach a state of equilibrium in each case. This was found to require about ten minutes. The value of the vapor pressure for each concentration was obtained from the Physikalisch-Chemische Tabellen of Landolt, Bornstein and Myerhoff.

Results.

Galena.

The first physical condition which we varied was temperature, since it was natural to suppose that changes in temperature would produce the most noticeable effect. The galena detector was carefully adjusted and placed in the closed box which was then immersed in oil and heated. The heat was supplied continuously and the galvanometer readings taken at successive intervals while the temperature was rising. The galvanometer readings were then plotted against the respective temperatures. Fig. 5 shows one of these curves and is typical of those obtained with galena. In this as well as the other figures the dotted curves indicate the results obtained with other specimens or other adjustments. The rectification falls off very rapidly with the rise in temperature, approaching zero at 170° C. So long as the adjustment remained the same there was no improvement in rectification when the detector was cooled.

The decrease in rectification was not due to increased pressure at the contact, since the needle point was suspended by a very fine coiled spring, so that expansion due to increased temperature would not affect its adjustment. We were much gratified with the uniformity of the readings which we were able to secure with galena, since we had feared that, on account of the light contact needed, a permanent adjustment could not be preserved. The following data show the uniformity of the galvanometer readings under constant conditions at the detector.

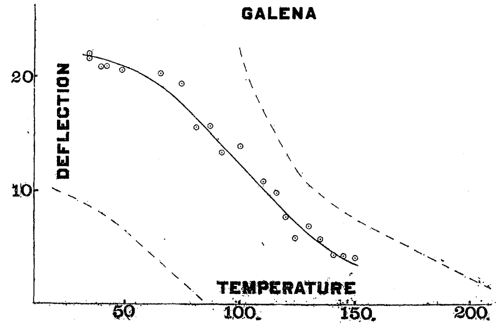

Fig. 5.

Galvanometer Deflection for Signals Three Seconds Long.
Galena Detector under Room Conditions.

15.1
14.6
14.9
15.2
15.0
15.0
14.9
15.3
14.9
15.3
14.9
14.7
15.0

One noteworthy fact in connection with the rectification by galena is that, although in most cases the current flows from crystal to point, it was found that, with some adjustments, the current would flow in the other direction.

It is a well-known fact that when a relatively large current caused either by a heavy atmospheric discharge or by the spark at a sending station nearby, passes through a galena detector, the rectification is impaired. It has occurred to us that a probable explanation of this phenomenon is the local heating of the contact by the passage of the current producing an effect similar to the heating described above.

The temperature at which rectification becomes practically negligible is not always the same but varies with the original adjustment, being higher for better adjustments.

In cooling the galena detector to a low temperature the manipulation was not so easy, for we could not obtain the decrease in temperature as uniformly as we should have liked. By lowering the detector nearer and nearer to the surface of the liquid air in the Dewar flask we were able to obtain sufficient data to determine the behavior of the galena detector in that range of temperature. Fig. 6 shows the results of this experiment. It will be noticed that at about − 50° C. there occurred a decided maximum of rectification, which was corroborated by successive tests.

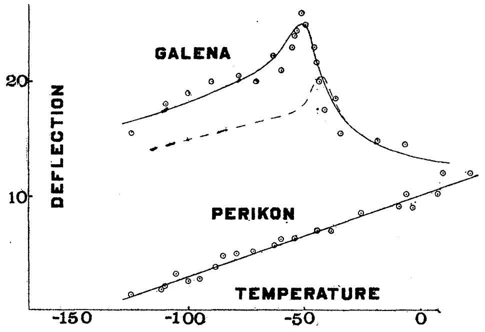

Fig. 6.

One of the greatest difficulties which we encountered in cooling galena as well as the other detectors was the precipitation of frost upon the crystals. If any of this frost melted due to heating at the contact the effect of humidity was superimposed upon that of temperature. In addition, this moisture at the contact had a decided influence on the "extra" E.M.F. causing it to be very strong, although sometimes in one direction and sometimes in the other. The glass-hardness of the surfaces of the crystals at these low temperatures made it very difficult to retain the adjustments. It will be noted that the curve obtained by cooling continues the general trend of the one obtained by heating.

No effect on the rectification by galena could be noted when the detector was completely immersed in liquid air. Good adjustments remained good and poor ones poor.

The results of varying the humidity of the air in the closed box are shown in Fig. 7. The galvanometer deflections are shown which correspond to the vapor pressures of the various concentrations of sulphuric acid solution in the bottom of the box. It will be seen that the presence of a very small quantity of moisture is sufficient to reduce greatly the rectification by the galena detector. Each of the points on Fig. 7 represents the average of at least ten successive readings taken after the vapor pressure had reached a state of equilibrium.

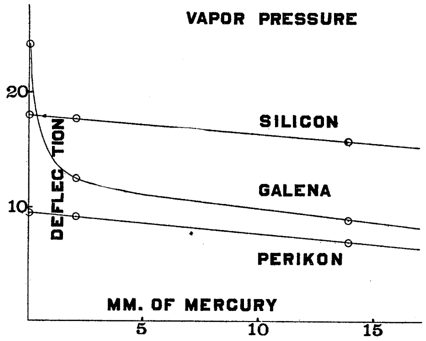

Fig. 7.

Galvanometer deflections corresponding to vapor pressures of sulphuric acid solutions.

Perikon.

The perikon detector used consisted of a contact between crystals of zincite and chalcopyrite. The effect of temperature was more marked in the case of perikon than in the case of any other detector as is shown in Fig. 8. Starting with a deflection of 3 cm. at about 55° C. for a three-second dash, the deflection passed off the scale of the galvanometer at a temperature of about 140° C. When the length of the dash was shortened to one second the deflection became 7 cm. but rose rapidly with the temperature reaching a value of 24 cm. at 210° C.

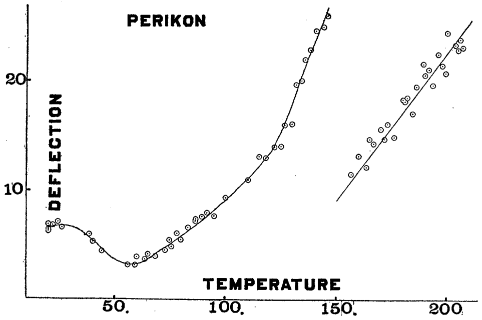

Fig. 8.

The curve obtained upon cooling the perikon detector (Fig. 6) was perfectly continuous with the heating curve, falling rapidly with the temperature. At no time was there any indication of a definite maximum or minimum of rectification within the temperature range which we used, from − 120° C. to 210° C. Immersion of the perikon detector in liquid air caused a complete loss of rectification.

When the vapor pressure of the space surrounding the perikon detector was changed, the results shown in Fig. 7 were obtained. The effect was not so marked as in the case of galena but there appeared a definite decrease in rectification with an increase in humidity.

Silicon.

We found the rectifying action of silicon to be very erratic. This corresponds with the statements made by other observers in regard to the properties of that substance. Miss Frances G. Wick, in a paper on the "Electric Properties of Silicon,"[1] makes the remark that "the position of the element in the periodic system between the metals and the non-metals may explain some of the deviations of its properties from those of the stronger metals."

O. E. Buckley[2] states that, "since different specimens, sometimes even if cut from the same piece, may vary widely in their electrical properties, it is important that measurements of different properties be made with the same specimen." His statement is confirmed by the results of our investigations as shown in Fig. 9. The conditions of heating were identical in obtaining both curves except that different specimens were used. In one case the rectification is seen to increase and in the other to decrease as the temperature rises.

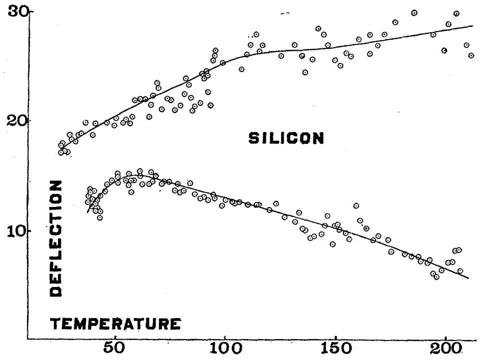

Fig. 9.

In attempting to determine the effect of subjecting silicon detectors

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[1] Phys. Rev., 25, 382, 1907.

[2] Phys. Rev., 4, 482, 1914.

to low temperatures it was found impossible to obtain any consistent results. The rectification would change very rapidly when there was apparently no cause whatsoever, and it was very hard to retain a given adjustment since the surface of the crystal became exceedingly hard and slippery at the low temperatures.

When the silicon detector was completely immersed in liquid air the sound in the telephone receivers increased in the majority of cases. It is possible that in other cases the somewhat violent boiling of the liquid air destroyed the adjustment of the light needle contact.

The behavior of silicon under changes of humidity resembles very much that of the perikon detector, the rectification decreasing somewhat with the increase of vapor pressure. These results are shown in Fig. 7.

Carborundum.

In order to secure a good adjustment with carborundum we found it necessary to use considerable pressure upon the contact point, consequently imbedding the point of the steel needle below the surface of the crystal. The adjustment was very permanent and could not easily be impaired by vibration.

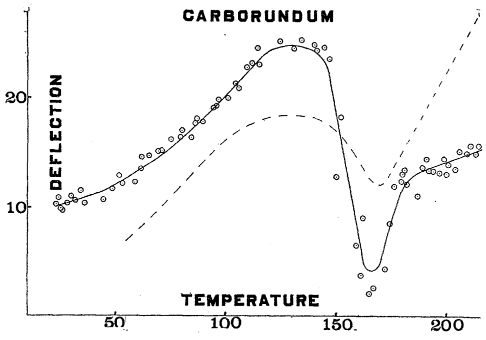

Fig. 10.

Upon heating the carborundum detector very peculiar results were obtained as may be seen in Fig. 10. Successive tests showed that the rectification attained a decided maximum at a temperature of about 130° C. and from there fell off rapidly until a minimum was reached at about 165° C. Above that temperature the rectification again increased as far as the tests were conducted. Even when the glass containing box accidentally broke and the detector was immersed in the hot oil-bath its behavior remained the same. This was probably due to the fact that the oil could not reach the actual contact between the crystal and the needle.

The cooling curve shown in Fig. 11 continued the lower portion of the heating curve. Rectification became zero at about − 85° C. It was noteworthy that upon being warmed the detector largely regained its rectifying properties, the dotted curve showing this rise. In order to prove that the decrease in rectification was not due to an imperfect contact caused by the contraction of the needle and the detector stand, we tried repeatedly to secure a new adjustment at these low temperatures but found it impossible. Likewise immersion in liquid air proved disastrous to all rectification.

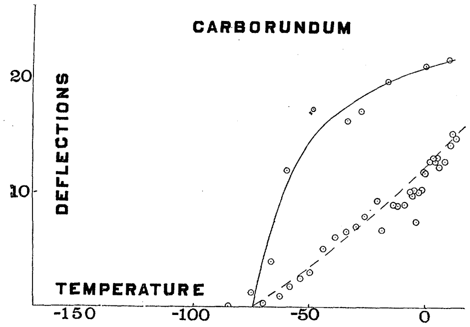

Fig. 11.

It was impossible to obtain any noticeable effects upon the rectification of carborundum by changes of humidity. It is probable that this was due to the imbedding of the contact point in the crystal so that the moisture could not affect it.

Discussion.

It was found that with each of the four detectors, as far as we could observe, change in air pressure had no effect upon the rectification. We were able to vary the air pressure from 25 cm. to 135 cm. of mercury. It is perhaps not surprising that no effect was observed within this range.

One of the peculiarities noticed in our work was that certain crystals did not always rectify the oscillating current in the same direction. With one adjustment the rectified current would flow from crystal to point and with another would flow in the opposite direction. Once, indeed, during a test on the effect of change of temperature upon carborundum the rectification actually reversed although no change had occurred in the adjustment. The most common direction of rectification for silicon and for galena was found to be from the crystal to the brass point which was used. In the case of carborundum the ordinary sense of rectification was from needle to crystal. The perikon detector was the only one of the four which showed no reversal; always rectifying from chalcopyrite to zincite.

The "extra" E.M.F., to which reference has previously been made, is probably of galvanic origin. Although it might have been of thermoelectric origin, due to local heating at the contact, it could not have been the result of a thermo-junction caused by the difference in temperature between the detector and the outside circuit since both leads from the detector were of copper, causing the junctions affected by the heat to oppose each other. In addition the frequent reversal of this "extra" E.M.F. seems to preclude all possibility of its being due to a thermoelectric junction.

Conclusions.

It is possible that there are changes both in the condition of the surface on the crystal and in the body itself of the crystal during changes in the rectification. If both of these changes take place, as has been suggested by some observers, it is probable that the body effect predominates in the variations of rectification with changes in temperature which are most notable in the case of carborundum. In the case of humidity the surface effect probably has the most influence on the variation in rectification.

At certain times when the rectification was especially good, a humming sound was heard in the receivers similar to the inductive hum often heard when the detector circuit was opened. This seems to be evidence of the formation of a high resistance film on the surface of the crystal at the point of contact. Attention has previously been called to the possibility of the presence of this resistance film by Austin[1] and Goddard.[2]

There is apparently no relation between the rectification and the "extra" E.M.F. since the former remains unchanged through rapid fluctuations and often through reversals of the latter. The "extra" E.M.F. often exists even after room conditions of temperature, etc., have prevailed for some time throughout the apparatus. The cause of this "extra" E.M.F. and its relation, if any, to the rectification would be, in itself, a profitable subject for investigation.

We are indebted to Mr. Edison Pettit, of Washburn College, for suggesting this problem and to Professor F. E. Kester and the other members of the Department of Physics of the University of Kansas for their assistance and suggestions during the progress of the investigation.

Blake Physical Laboratory,
University of Kansas,
May 12, 1915.

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[1] Bulletin Bureau of Standards, Vol. 5, p. 146.

[2] Phys. Rev., 34, 423, 1912.