The Energy Relations of Certain Detectors used in Wireless Telegraphy

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XXXI. *The Energy Relations of Certain Detectors used in Wireless Telegraphy.* By W. H. ECCLES, D.Sc., A.R.C.S.*

[Plate VIII.]

THE results of an experimental examination into the physical properties of four very different types of detector used in radio-telegraphy are set forth briefly in the following pages. The conditions of the experiments have been made generally identical with those arising in the ordinary employment of the detectors, and, in particular, the quantities of energy given to the instruments, in the form of electrical oscillations, have been of the same order in these experiments as in actual practice. The detectors investigated are the electrolytic, the carborundum rectifier, the zincite detector, and a thermoelectric detector. All these have before this been subjected to close scrutiny by various observers, who, however, used methods different from that of this paper; a summary of their work will be given alongside the results of the present experiments. These results, it will be seen, are expressed in the form of curves rather than as tables of figures; each curve may be regarded as typical of the detector concerned, and has been selected from a number of curves drawn from measurements accumulated during last year.

The method and apparatus used are the same as were described in a paper "On Coherers," read before the Physical Society in March last (Proc. Phys. Soc. vol. xxii. pt. iii.). The present experiments were for the most part carried out at an earlier date than those described in that paper. The properties of the detectors are examined in three distinct ways. The first way consists in applying to the detector an electromotive force which is gradually increased, and measuring the consequent current at each step. The second way is to fix the electromotive force at some particular value, to send trains of oscillations of various energy values through the instrument, and to measure the intensity of sound produced in the telephone on each occasion. The third way is to send

* Read July 8, 1910.

ELECTROLYTIC DETECTOR.

Fig. 1.—Steady Current Curves.

Fig. 2.—Power Curves.

Fig. 3.—Sensitivity Curve.
 $W = 6.2 \times 10^{-8}$ Watt.

CARBORUNDUM DETECTOR.

Fig. 4.—Steady Current Curves.

Fig. 5.—Power Curves.

Fig. 6.—Sensitivity Curves.
 $W = 6.2 \times 10^{-8}$ Watt.

ZINCITE-CHALCOPYRITE DETECTOR.

Fig. 7.—Steady Current Curves.

Fig. 8.—Power Curves.

Fig. 9.—Sensitivity Curve.
 $W = 6.2 \times 10^{-8}$ Watt.

GRAPHITE-GALENA DETECTOR.

Fig. 10.—Steady Current Curves.

Fig. 11.—Power Curves.

Fig. 12.—Sensitivity Curve.
 $W = 7.85 \times 10^{-8}$ Watt.

trains of constant energy value through the instrument while the steady electromotive force applied to it is varied in steps, and to measure at each step the intensity of the sound produced in the telephone. These modes of experimenting give curves that may be called respectively the steady-current curve, the power curve, and the sensitiveness curve. It will be seen from the curves that the power supplied to the detector in the form of electrical oscillations and the power handed to the telephone in the form of intermittent current are both recorded in fractions of a watt. For this purpose, the circuit-calibrations described in the former paper were used. It must be mentioned here that the calibration of the telephone circuit is probably much less accurate than that of the detector circuit.

RESULTS OF THE MEASUREMENTS.

The Electrolytic Detector.

This detector consisted of two platinum electrodes in dilute sulphuric acid (one of acid to four of water). One electrode was a platinum wire of 0.0006 cm. diameter drawn by the Wollaston process, dipping a fraction of a millimetre into the electrolyte; the other was a piece of thick wire well immersed. When a potential difference less than one volt is established between the electrodes the current that passes is very small; but as the potential difference is increased the counter electromotive force of polarization is overcome, till finally a large current flows with evolution of gas. The stage of the process which is useful for detecting feeble electrical oscillations is that where the bubbles of gas do not yet form on and break away from the point freely. The steady current curves of fig. 1 (Pl. VIII.) indicate the difference between the two cases, point as anode and point as cathode. The power curves for various cases are collected in fig. 2, all from the same detector. Curve *a* shows the relation between the power w delivered by the detector to the telephone and the power W given in the form of electrical oscillations to the detector, when the potential difference between the platinum point and the large electrode has the value 2.9 volts—the voltage of highest sensitiveness. Curve *b* shows the large

fall in sensitiveness caused by altering the applied electromotive force, the point still being anode.

In the same way, curves *c* show the efficiency of the energy transformation when the point is negative. Curve *c* is an attempt to reach the best possible sensitiveness with the point as cathode; but it is to be remarked that when the point is covered with hydrogen, the electrical conditions are somewhat unstable, and the best potential difference is an uncertain quantity. This is in strong contrast with the very definite conditions that rule when the platinum point is polarized with oxygen. This is clearly indicated by the curves of fig. 3, where the ordinates represent the proportion of energy delivered to the telephone when the applied voltage has various values.

This detector has received a very great deal of attention in the past, but the precise mode of operation of the instrument is still unknown. Reich*, after making experiments with superposed direct current and alternating current of low frequency, considered that the phenomena could only be accounted for by a dissolution of the small electrode used as anode and a simultaneous disappearance of oxygen—processes purely chemical. Rothmund and Lessing†, using a Blondlot oscillator and Lecher wires, and measuring the potential difference across the detector and the current through it when the oscillator was working and not working, concluded that the whole action of the instrument depended upon some unexplained “depolarization action” of the oscillations; and by using a variety of electrolytes, proved the incorrectness of the hypothesis, which was a mere surmise unsupported by scientific measurements, that the instrument operated by resistance alterations due to the heat generated in the liquid mass near the minute anode. Later Dieckmann‡ measured the current changes that followed upon the passage of strong oscillations of (unmeasured) intensity through a detector. Later still, Austin§, using alternating current of low frequency, showed that the detector was affected by

* *Phys. Zeitschr.* v. p. 338 (1904).

† *Ann. d. Phys.* xv. 1, p. 193 (1904).

‡ *Phys. Zeitschr.* v. p. 529 (1904).

§ Bulletin, Bureau of Standards, i. 3, p. 435 (1905).

electromotive amplitudes of $1/10000$ volt, and that oscillations produced by spark-discharges in the laboratory affected the detector equally whether the small electrode was anode or cathode. He concluded that in the action of the instrument heat had a share, and that chemical action, electrostatic attraction across the gas film, and also a property styled rectification, all took part.

Carborundum.—The detector was set up by clamping a crystal of carborundum between brass plates, so that a smooth crystalline edge or corner was in contact with one plate, and a blunt and more amorphous part of the crystal in contact with the other plate. The steady current curves of two crystals widely different in their electrical behaviour appear in fig. 4 (Pl. VIII.). Curves ab belong to one crystal, the dotted curves AB belong to another. The upper curve of each pair was obtained when the jagged blunt end of the crystal was positive.

The power curves are given in fig. 5. Lines abc exhibit the energy relations for the crystal that gave ab in fig. 4. Line a was obtained while the blunt end was at a potential 2.62 volt higher than the smooth end; b was got when the potential difference was -0.44 ; curve c was got without electromotive force. Lines A, B, C refer to the other crystal. Line A was obtained while the blunt end was 2.9 volt above the smooth end; line B while the blunt end was 2.1 volt below; line C while no external electromotive force was applied. The curve of fig. 6 shows how sensitiveness altered with the electromotive force applied to the terminals of the detector.

The Carborundum detector has been examined very exhaustively by Pierce*. He has shown that crystals of this substance may be as much as 1000 times more conductive for current in one direction than in the opposite, and has concluded that the substance acts as a detector of high frequency oscillations solely because of this unilateral conductivity. Heat, he considered, played no part in the process. The curves given above show, however, that a crystal may be a good detector even though its unilateral conductivity be not very pronounced.

* Phys. Review, xxv. p. 31 (1907).

Zincite-chalcopyrite.—The detector made by arranging a corner of a fragment of brown zincite (native oxide of zinc) to press against a piece of chalcopyrite (iron copper sulphide) is one of the most sensitive known. It is used extensively in various navies. Fig. 7 gives the results of measurements of current under steady electromotive force. For this particular detector the most sensitive condition was attained when the zincite was maintained at a potential about 0.45 volt below that of the pyrite. The power curves are given in fig. 8; here *a* is the curve when no electromotive force was applied: *b* is the curve for an applied electromotive force of 0.45 volt, zincite negative, and *c* is the curve for an applied electromotive force of 0.45 volt, zincite positive. It will be seen from these that the combination forms a very sensitive detector, even when no external electromotive force is applied. The curves showing the change in sensitiveness with variation of the applied electromotive force are plotted in fig. 9.

Graphite-Galena.—A detector that is very widely used for every-day telegraphy is that consisting of a pointed piece of graphite touching the face of a crystal of galena. The curves connecting applied electromotive force and current flowing through the contact appear in fig. 10. The power curves are shown in fig. 11: curve *a* is obtained when the external electromotive force is not applied, and curves *b* and *c* when electromotive forces of 0.45 volt and -0.45 volt were applied. The connexion between the power given to the telephone and the electromotive force applied to the detector is given in fig. 12.

These two last detectors and others similar to them are sometimes called “rectifiers,” sometimes “thermoelectric detectors.” They are styled thermoelectric because it was originally supposed that they owed their power of detecting high frequency vibrations to the thermoelectromotive forces set up at the contact by the rise of temperature produced at that point—the point of highest resistance in the whole oscillation circuit—in obedience to Joule’s law; but most observers have concluded from experiments with both direct and alternating currents, that these detectors derive their function from an unexplained and hitherto unknown power

of rectifying rather than from a combination of the Joule and Peltier effects. Pierce* has examined the behaviour of contacts made with anastase, brookite, and molybdenite under alternating currents of ordinary frequency, and obtained oscillograms of the current through them. No evidence of thermoelectric or other integrative action was perceived in the photographs. Austin† has examined quantitatively, also by aid of slow alternating currents, the properties of detectors consisting of contacts of silicon and steel, carbon and steel, tellurium and aluminium. Brandes‡ and Raetenkrantz§ have also contributed greatly to our knowledge of the connexion between the steady current curve of a detector and its behaviour under electrical oscillations.

Conclusion.

The chief fact brought to light by the above experiments is that the energy passed to the telephone by a detector is connected linearly with the energy given to the detector in the form of electrical oscillations. This is true for all the detectors examined, even including the coherers discussed in the earlier paper. The curves connecting the input and output of energy though they are straight lines usually pass some distance away from the origin. This implies that for a particular detector under invariable conditions there is a fixed wastage of oscillation energy, amounting commonly to about 1/10 of an erg per second, however large or small the oscillation energy given to the detector may be. Another interpretation is, however, that a small quantity of energy, which is invariable while the detector is undisturbed, is delivered by the detector to the telephone circuit in a form that never makes any proportion of itself manifest as sound. The curves suggest, though they do not prove, that all detectors are fundamentally thermal in their action. That this deduction is opposed to the conclusions reached by previous experimenters is clear from the summary of their

* Phys. Review, p. 153 (1909).

† Bulletin, Bureau of Standards, v. p. 133 (1908).

‡ *Elektro. Zeitschr.* xxvii. p. 1015 (1906).

§ *Phys. Zeitschr.* ix. p. 911 (1908).

work given above. The principal cause of this difference between our conclusions appears to be that nearly all previous observers have used comparatively large quantities of oscillation energy, and have therefore probably brought into play phenomena that never arise in detectors as used in wireless telegraphy.

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ABSTRACT.

The paper is a record of the results of an experimental examination into the physical properties of the electrolytic detector, the zincite rectifier, the carborundum rectifier, and a thermoelectric detector consisting of a light contact between graphite and galena. The conditions of the experiments have been generally identical with those arising in the ordinary employment of the detectors, and, in particular, the quantities of energy given to the instruments, in the form of electrical oscillations, have been of the same order in these experiments as in actual practice. Three ways of investigation are followed. The first way consists in applying to the detector an electromotive force which is gradually increased, and measuring the current at each step. The second way is to fix the electromotive force at some particular value, to send trains of oscillations of various energy values through the instrument, and to measure the intensity of the sound produced in the telephone on each occasion. The third way is to send trains of constant energy value through the instrument while the steady electromotive applied to it is varied, and to measure at each step the intensity of the sound produced in the telephone. These modes of investigation give curves that may be called respectively the steady current curve, the power curve, and the sensitiveness curve. The chief fact brought to light is that the power curves of all the detectors are straight lines, which suggests that all the detectors are fundamentally thermal in their action.