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THE USE OF MINERALS AS RADIO-DETECTORS

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Minerals play an important rôle in wireless telegraphy and telephony. The most common and least expensive type of receiving outfit makes use of the so-called crystal-detector, which takes advantage of the electrical properties of certain crystalline substances. The object of this note is briefly to summarize the present state of our knowledge concerning crystal-detectors, and to call attention to the possibilities of improvement and the desirability of further research in this field.

The action of a detector may be explained as follows: The alternating currents induced by radio waves are of such high frequency that even if a telephone were produced whose diaphragm could vibrate in time with them, the sound resulting from this vibration would be so shrill as to be beyond the range of the human ear. In order that they may be made audible, the waves must either (1) be broken up into like groups or trains which follow one another at an audible frequency (wireless telegraphy), or (2) so "modulated" that their amplitude varies in time with an audible vibration such as speech or music (wireless telephony). In either case they remain high frequency electromagnetic waves. In the receiving apparatus, the high frequency—or "radio-frequency"—electromotive force is impress on a circuit whose function is to distort the alternating current wave in such a way that more current flows in one direction than in the other. This distorted wave may now be thought of as the sum of a radio frequency alternating current and a direct current, of which only the direct current is capable of actuating the telephone receiver. The ideal detector would allow current to pass freely, but in only one direction. A detector is, then, merely an electrical rectifier, and altho in actual practice the rectifying action is far from complete, yet a certain amount of direct current is produced; moreover, it is a *pulsating* direct current, and the final effect in the telephone circuit is an alternating current of comparatively low ("audio-") frequency. Therefore, as the amplitude of the original radio wave changes, the diaphragm vibrates and reproduces—more or less faithfully—the changes imprest on the radio wave at its source.

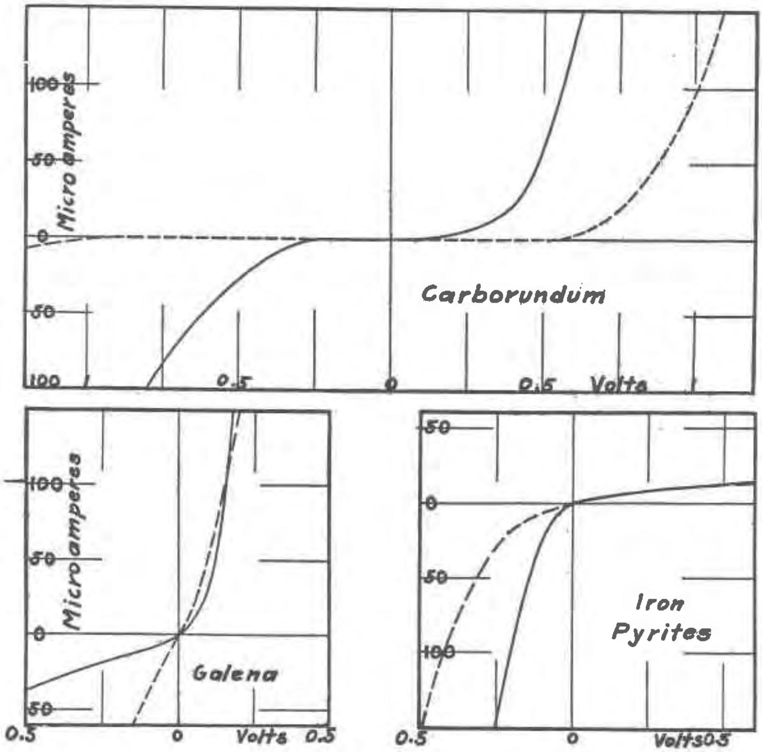

FIGURE I

CHARACTERISTIC CURVES FOR TYPICAL CRYSTAL-DETECTORS

Each of these crystals was mounted in a block of fusible metal. In the case of the carborundum crystal, a flat steel spring, pressing against one of the corners of the crystal, formed the second contact. In the case of the other two, contact was made with a pointed wire of a copper-nickel alloy. The current, in millionths of an ampere, is plotted against the potential difference in volts between the fusible metal base and the spring or wire contact. The solid curve in each case is the characteristic of the more sensitive detector.

The crystal-detector consists essentially of a small area of contact between two suitable conductors, at least one of which is a crystal. It operates by virtue of the fact that the current flowing thru such a contact is not proportional to the electromotive force driving it. This property is illustrated by the curves in figure 1. The efficiency of the detector depends to a great extent on the circuit with which it is used, but in general the efficiency increases with the sharpness of curvature of the characteristic curve and with steepness of the vertical branch.[1]

The more important substances which have been used as detectors are listed in Table 1. Of these substances, all are minerals except silicon and carborundum. The materials marked with an asterisk are known to have been used only in contact with another mineral—usually zincite; the others are commonly operated in contact with a metal.

TABLE 1. THE MORE COMMON MATERIALS USED FOR CRYSTAL DETECTORS

Name	Composition	Symmetry	Cleavage
Galena........	PbS	Isometric	(100), perfect; (111), less often
Pyrite.........	FeS_2	Isometric pyritohedral	(100) and (111), indistinct
Carborundum.	SiC	Rhombohedral	None
Zincite........	ZnO	Hexagonal-hemimorphic	(0001), perfect; $(10\bar{1}0)$, sometimes distinct
Octahedrite...	TiO_2	Tetragonal	(001) (111), perfect
Brookite......	TiO_2	Orthorhombic	(110), indistinct; (001), still more so
Bornite.......	Cu_5FeS_4	Isometric	(111), traces
Chalcopyrite..	$CuFeS_2$	Tetragonal-sphenoidal	(201), sometimes distinct; (001), indistinct
Molybdenite...	MoS_2	Hexagonal	(0001), eminent
Argentite.....	Ag_2S	Isometric	(110), (110), traces
Covellite*.....	CuS	Hexagonal	(0001)
Niccolite*.....	$NiAs$	Hexagonal	—
Enargite*.....	Cu_3AsS_4	Orthorhombic	(110), perfect; (100), (010) distinct; (001), indistinct
Silicon........	Si	Isometric	—

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[1] The combination of crystal detector and telephone is essentially a device for the conversion of energy from one form to another, and as such the efficiency of conversion should be high. Of the total electrical energy in the circuit, a small portion is given to the telephone in the form of a pulsating direct current to be converted into sound. A large part of the energy associated with this direct current, as well as all of the energy not directly associated with it, is wasted in the form of heat. It is therefore desirable, first, that the crystal contact oppose a very high resistance to the flow of current in one direction, in order to increase the ratio of direct to total current; and second, that it oppose a reasonably low resistance to the

From a study of this table it may be seen that all of the substances are of comparatively simple composition; only 3 of the 14 materials contain as many as 3 elements. Consequently, crystal systems of high symmetry predominate: 10 of the substances belong either to the isometric or to the hexagonal system, while the monoclinic and triclinic systems are not represented at all. As regards cleavage, no regularities are apparent. Some good detectors, such as galena and zincite, show well-developed cleavage, while others, pyrite for example, cleave only indistinctly.

The mechanism of conduction in a crystal rectifier and the reasons for its unilateral conductivity are not well understood. Numerous theories have been advanced to explain the operation of crystal-detectors; for example, the direct current yielded by a crystal has been ascribed to thermo-electromotive forces at the contact or junction. Without attempting to review the subject completely, or to discuss the merits of the various theories, we shall merely note what seems to us the simplest type of explanation.

It is common knowledge that a fragment of material such as galena possesses the rectifying property only at certain spots on the surface; moreover, these "sensitive spots" are usually not on smooth parts of the cleavage-surfaces, but seem to show a preference for places where the surface is irregular. It is not unlikely that at these sensitive spots there is indistinct octahedral cleavage and that the sensitive spots are merely small surfaces parallel to the octahedral faces (111). Now, the (111) planes of galena contain either all lead or all sulfur atoms, and a boundary layer containing only one kind of atom might be expected to exhibit a strong unbalanced electrostatic field due to the electrons of the oriented atoms. The (111) planes, then, in contact with a conductor, e.g. a metallic point, would, according to this view, yield an unsymmetrical conductivity curve as result of the unbalanced electrostatic field at the contact, the adjacent electrons playing a rôle analogous (altho perhaps not similar) to that of the electrons in a vacuum-tube detector.[2]

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flow of current in the other direction, in order to increase the total current. The characteristic of such a crystal, if plotted in the figure, would consist of two lines nearly parallel to the two axes and connected by a very sharp curve. The first of the two desiderata is found in carborundum and the second in most of the other common detectors; but a substance combining the two is yet to be discovered.

[2] There is also a striking similarity between the current-voltage characteristic of the vacuum tube and that of the crystal detector.

Granting the correctness of this view, we might expect that any crystalline material which is a conductor of electricity would show a rectifying action at any surface (cleavage or crystal face) at which there exists a layer of only one kind of atom. This last condition is readily attained only in crystals of simple composition. Pyrite, another favorite detector, shows cubic and also octahedral cleavage, both indistinct. The (100) planes as well as the (111) planes contain either all iron or all sulfur atoms, and with pyrite, therefore, presumably any true cleavage surface would, if of a size comparable with that of the contact point, be a sensitive spot.

For other crystals, such as carborundum, the relation is not so simple. This substance seems to function best when a "point" of the hexagonal plate is pressed against a hard metal surface, the other electrical connection being made as usual by embedding a considerable part of the crystal in metal. The "point" is really a small edge formed by the intersection of two prism or of two rhombohedral faces. The crystal structure of carborundum is not well known, but if it should turn out that the sensitive edges are formed from one kind of atom, the action of this type of detector would also be explainable by the hypothesis here proposed. It must be admitted that little really conclusive evidence can be adduced in favor of this view, but at least there are no facts which controvert it, and it is offered as a simple and reasonable working hypothesis. Further research on the rectifying properties of properly identified crystal surfaces is obviously needed.

In comparison with the vacuum-tube detector, the crystal-detector is simpler, more compact and cheaper. In its present form it is considerably less sensitive than the vacuum-tube and can not be used as an "amplifier." It has, however, a considerable field of usefulness which might be greatly broadened if its sensitivity could be increased.

A list of the more important papers dealing with crystal detectors is appended.

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The action of the silicon carbide detector. F. Luchsinger. *Physik. Z.,* **22,** 487, 1921.

Carborundum and its rectification effect. H. M. Dowsett. *Radio Review,* **2,** 580, 1921.

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