VOLUME RECTIFICATION OF CRYSTALS

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ABSTRACT. Experiments have been performed to show that the volume rectification effect is not confined to crystals like carborundum, zincite and silicon alone, which have no centres of symmetry, but that it is also exhibited by crystals like galena, iron-pyrites and pyrolusite possessing centres of symmetry. From the results of these experiments it is suggested that the so called volume rectification may not take place within the body of the crystal, but may be due to the differential effect of the surface rectification occurring at the two large contacts of the crystal with the electrodes.

INTRODUCTION

The rectifying action of crystals has usually been divided into two classes—(*a*) one is associated with a point contact at one end of the crystal and a large electrode at the other, (*b*) the other is obtained when the crystal has large contacts at both the ends, *e.g.*, when the crystal is placed between two mercury electrodes. The former kind of rectification has been called point or surface rectification and the latter kind, volume rectification. It has been thought that this volume rectification takes place within the body of the crystal, and following Krönig,[1] this effect has been attributed to the asymmetry in the crystal structure. The experiments of Khastgir and Dasgupta[2] have shown that crystals like carborundum (SiC), zincite (ZnO) and silicon, which have no centres of symmetry, give volume rectification when placed between mercury electrodes, whereas with symmetrical crystals, *e.g.*, galena (PbS), iron-pyrites (FeS_2), pyrolusite (MnO_2), etc., no trace of such rectifying effect was obtained by passing low-frequency alternating current through the crystals similarly placed between two mercury electrodes of large contact areas.

Natural Cu_2O crystals, which show the Dember effect, exhibit rectifying properties when illuminated. In this case, however, it has been shown[3] that the action does not occur at the electrodes but takes place in the body of the crystal. It is to be noted here that artificial Cu_2O crystal, in which the Dember effect is absent, does not show any rectifying effect.

In course of the investigation on the effects of heat and ultra-violet light on crystal rectification[4] the present author noticed that besides carborundum, zincite and silicon, crystals of iron-pyrites, galena and pyrolusite exhibited pronounced rectifying properties when placed between mercury electrodes. It was, therefore, felt desirable to further study this phenomenon of volume rectification and the preliminary results obtained were reported in a short note.[5] The details of some experiments are, however, given in the present paper.

EXPERIMENTAL

The method of mounting the crystals was practically the same as that adopted by Khastgir and Dasgupta in their study of volume rectification,[6] with an additional arrangement for slowly moving the glass tube, carrying the crystal vertically up and down. For this purpose the stand of a travelling microscope was utilised. The glass tube with the crystal was kept vertical by passing it through a hole in a cork which was fitted to the microscope stand in the position of the microscope, so that the crystal holder could be moved up and down as required with the associated slow-motion attachments. With this arrangement the contact-area between the crystal and the mercury at the lower end could be conveniently altered, that at the upper electrode remaining constant, and the effect of the change of contact area at one of the electrodes could be studied. The source of low-frequency alternating voltage was a 1000-cycle audio-oscillator. For the measurement of the rectified current a milli-ammeter was generally used which was, however, sometimes replaced by a shunted galvanometer.

The following symmetrical crystals were tested, both with low-frequency and high-frequency alternating currents, for volume rectification and in each case prominent rectified current was obtained, the nature of which is given below in detail. Characteristic curves have also been obtained in all cases by applying direct voltage in the usual way.

Low-frequency Test.

(1) Galena : When the alternating current is passed through a good crystal of galena put between mercury electrodes, there is a pronounced rectified current as indicated by the shunted galvanometer placed in the circuit. Next, keeping the upper contact-area constant, as the lower contact-area is gradually altered the following changes, as regards direction and magnitude, are noticed in the rectified current : When the lower end of the crystal just touches the mercury surface, the rectified current flows upwards, the magnitude being nearly 1 milli-ampere. But this current is rather unsteady and occasionally goes downwards. When the lower contact area is made sufficiently large, the rectified current remains steady. The current now flows upwards and its strength is 1.25 milli-amps. On further

increasing the contact-area gradually the rectified current first increases a little, then diminishes, becomes zero and finally changes direction and flows downwards. This result has been reproduced several times during the experiments.

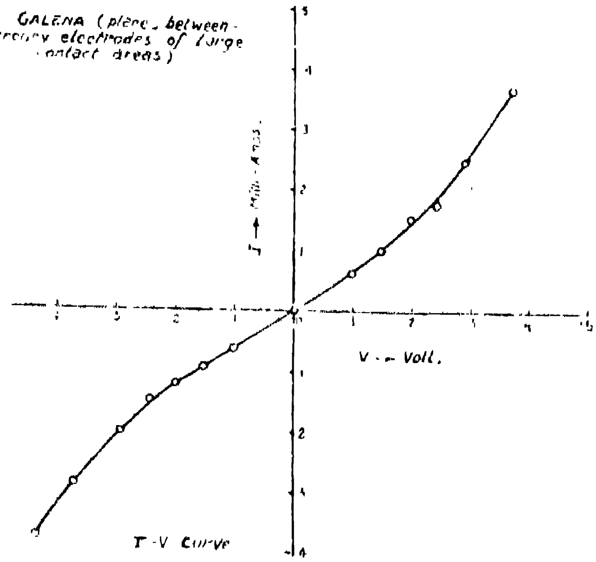

FIGURE 1

Characteristic curve is next drawn with both ends of the crystal well within mercury. The data given in Table I and the curve in Fig. 1 clearly show that under the given arrangement the crystal produces good rectificition.

(2) Iron-pyrites : Alternating voltage is applied to the crystal placed between mercury electrodes. A steady rectified current flows up when there are large contact-areas at the electrodes at both ends of the crystal. The upper contact-area is kept constant and the lower one is changed when the following results are obtained : (*a*) For a small area of contact the rectified current flows upwards, (*b*) for increasingly large contact-area the rectified current diminishes gradually, reaches a minimum value and then changes direction, *i.e.*, flows downwards through the crystal. The experimental results obtained with direct voltage applied to the crystal are given in Table I and in Fig. 2. In this case characteristic curves have been obtained under two different adjustments. For the first, the rectified current flows upwards through the crystal and for the second it flows downwards. The curves reveal marked asymmetry and it is evident that the crystal should give good rectification effect under both the adjustments.

(3) Pyrolusite : In the case of the pyrolusite crystal the rectified current is highly prominent and as in the previous two cases it also changes direction under

suitable adjustments of the contact-areas at the electrodes. The results of D. C. test for this crystal are given in Table I and Fig. 3. The characteristic

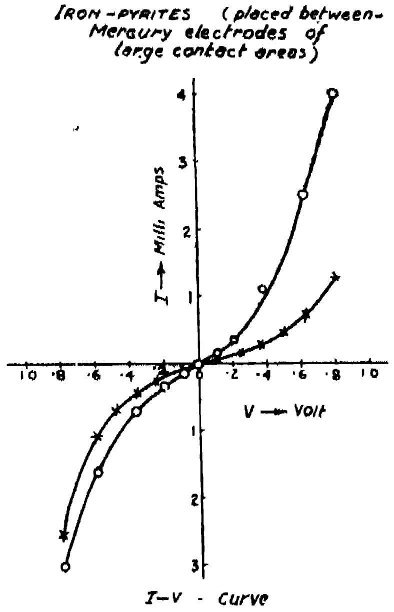

FIGURE 2

o – o—o—o for rectified current flowing upwards

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istic curve here also indicates the existence of a strong rectification effect with the crystal placed between mercury electrodes.

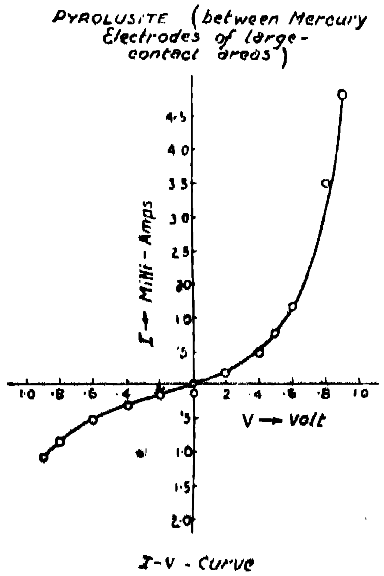

FIGURE 3

TABLE I

Voltage (volt)	Current (milli-amps)		Voltage (volt)	Current (milli-amps)	
	Up	Down		Up	Down
			Iron-pyrites		
Galena			(*a*)		
.10	.64	.62	.10	.15	.13
.15	1.00	.92	.20	.40	.30
.20	1.50	1.20	.38	1.10	.70
24	1.80	1.49	.62	2.50	1 60
29	2.50	2 00	.82	4.00	3.00
.37	3.75	2.85			
.43	4.80	3.70	(*b*)		
			.10	.05	.05
Pyrolusite			.24	.16	20
.2	.18	.15	.38	.30	38
.4	.50	.30	.50	.45	.60
.6	1.15	.50	.62	.70	1 00
.8	3.00	.90	.82	1.30	2.50
.9	4 30	1.10			

(*a*) For rectified current flowing upwards.
(*b*) For rectified current flowing downwards.

High-frequency A. C. test.

All the crystals are next tested with high-frequency alternating voltage obtained from a valve oscillator. In every case there is a pronounced rectified current so that it is definite that volume rectification is exhibited by these crystals, also with high-frequency current, when placed between mercury electrodes.

Crystals tested for the Dember effect.

To be sure that the volume rectification, so far obtained with the crystals in the above experiments, is not due to any Dember-effect produced by the diffused sun-light, experiments are repeated after cutting off the light from the crystal surfaces. Good rectification effect was, under this condition, obtained in all the cases by passing alternating current through the crystals.

DISCUSSION

In point-rectification it is an admitted fact that different parts of the surface of a crystal possess rectifying properties to quite different degrees. It may also be noted here that parts which have good rectifying properties exhibit very poor conductivity, whereas parts having good conductivity show very little rectifying action. Moreover, the rectification effects at different parts are also of different sense, *i.e.*, at some points the rectified current flows from crystal to whisker while at others it flows from whisker to crystal. The results of the experiments reported in the present paper, combined with the facts stated above, point to the conclusion that the volume rectification in crystals is due to the differential or the average effect of point or surface rectification occurring at the two electrodes. For, the surface of a crystal may be divided into a large number of rectifying regions of varying efficiency and giving rectification in opposite directions. At any particular electrode these regions, having varying degrees of rectification and revealing the effect in opposite directions, will produce a net rectified current whose magnitude and direction at that electrode will be determined by the predominance of the total effect in one direction (*i.e.*, of one sign) over that in the other. When we take into account the effects at both the electrodes, the final resultant direction of the rectified current through the crystal, for any particular adjustment of the contact areas of the electrodes, will be determined by the combined effects at the two surfaces of the crystal in contact with the electrodes. For instance, if the net rectification effect at one electrode A produces current from, say, crystal to electrode and that at the other contact B gives current from electrode to crystal, then the combined effect will be a very strong rectified current flowing through the crystal in the direction B-A. If, on the other hand, rectification effect at the end A produces current from crystal to electrode and that at the other end B also sends the current from the crystal to the electrode, then the resultant direction and magnitude of the rectified current will be determined solely by the strength or rather the difference of the strengths of the rectified currents produced at the two electrodes. Thus there is no distinction between point-rectification and the so-called volume-rectification of crystals, as regards the mechanism by which the effects take place. Both must be due to the same cause. The only difference between the two lies in the contact area at one of the electrodes. As a matter of fact the end of the whisker, in point-rectification, has never such an extremely small area as to lie on a single rectifying region but it would possibly rest on a number of rectifying regions generally of varying efficiency and different signs. It is thus quite possible for all crystals, exhibiting point-rectification, to give the effect—

the so-called volume-rectification—when placed between large electrodes on both sides.

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REFERENCES

1. Krönig, *Nature*, **123**, March 2 (1929).
2. Khastgir and Das Gupta, *Ind. J. Phys.* **9**, 259-60 (1935).
3. Groetzinger and Lichtschim, *Phys. Zeit*, **38**, 202 (1937).
4. Sen, *Ind. J. Phys.* **10** 91-102 (1936).
5. Sen, *Nature*, **140**, 1102 (1937).
6. Khastgir and Das Gupta, *Ind J. Phys.*, **9**, 259 (1935)

ERRATA

In the paper '*On effect of resistance component in wave filter elements and performance of non-ideal filter sections*' by Waquar Ahmed (August, 1942, p. 231), in equation (2c), instead of " =a pure resistance," read "a reactive impedance" and in equation (5), instead of RR in first term under radical sign, read RR$'$.