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Actinoelectric Effects in Tartaric Acid Crystals*

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Tartaric acid crystals illuminated with light from a carbon arc exhibit a flow of current when connected to a galvanometer without the aid of an impressed battery. This actinoelectric effect is greatly dependent upon the orientation of the crystal with respect to the illuminating beam of light. It is shown that a section of the crystal can be chosen which shows a series of equipotential lines when its surface is examined with two probes while the crystal is illuminated. The measured currents are about 10^{-12} ampere, when the crystal is illuminated with the light from a carbon arc. The effect is a linear function of light intensity for the lower light intensities, but increases more rapidly for higher intensities. The effect is practically independent of temperature in the range from 20°C to −40°C. The maximum spectral response is at approximately 10,500A.

A NUMBER of experimenters[1] have shown that certain crystals, when illuminated, produce an electrical current which can be measured with an electrometer or galvanometer connected in series with the crystal without the aid of an impressed battery. According to Coblentz[2] the term actinoelectricity was used by Hankel to designate the above phenomenon about 95 years ago. Present theories[1] are not entirely satisfactory, and it appears desirable to investigate the effect in more detail.

Most of the crystals used in this investigation were chosen from a supply of commercially prepared tartaric acid crystals.[3] The results were checked, however, with crystals grown in our laboratory. The "dark resistance" of a crystal three mm thick with a cross-sectional area of approximately 50 sq. mm is 2×10^9 ohms.

The experimental arrangement for carrying out the investigation is shown in Fig. 1. No results are reported when an external source of e.m.f. is used. A carbon arc and a 150-watt gas-filled tungsten filament lamp are used as light sources.

An FP-54 tube is used in a Brown and DuBridge[4] circuit for amplifying the actinoelectric currents. The current sensitivity of the amplifier is 10^{-14} ampere per mm deflection of the galvanometer.

The crystal is held between two brass disks with spring tension on one of the disks. The crystal holder is designed so that the light can be sent either perpendicular or parallel to the direction of the current through the crystal.

Contradictory evidence has been reported by other experimenters as to the origin of the effect. Coblentz,[2] working with molybdenite shows that the seat of the effect is at certain points along the crystal surfaces. Geiger[5] finds, in the case of argentite, no observable effect when the contacts are shielded from light and that the currents are measurable only when at least one of the electrodes is illuminated. Schneider[6] finds, in the case of argentite, that the seat of conversion of light into electronic energy occurs both at the contacts as well as at certain spots on the crystal.

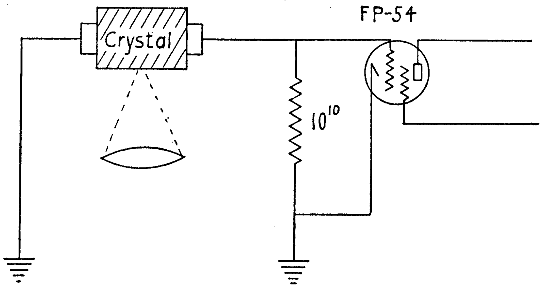

FIG. 1. Experimental set-up.

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[1] For bibliography and a review of theories see B. Lange, *Photoelements* (Reinhold Publishing Corporation, 1938).

[2] W. W. Coblentz, Scientific Papers of Nat. Bur. of Standards, No. 486, April (1924).

[3] Maximum limits of impurities: SO_3—0.01 percent; Ca—0.001 percent; Fe—0.001 percent; other H. M.—0.000 percent.

[4] H. Brown and L. A. DuBridge, Rev. Sci. Inst. **4**, 532 (1933).

[5] P. H. Geiger, Phys. Rev. **22**, 461 (1923).

[6] W. A. Schneider, Phys. Rev. **31**, 82 (1928).

The experiments with tartaric acid crystals show none of the irregular variations in current as the light beam is moved over the surface of the crystal as reported for instance by Coblentz.[2] There were no "sensitive spots" found in the case of a good clear single crystal although the response in many cases varied in a *regular manner* as the surface was explored with a light beam of approximately one mm diameter.

Figure 2 represents the way in which the current varies with the time of illumination when the light beam is at right angles to the flow of the current. The maximum deflection is reached within the period of the galvanometer and then drops down to a final value. This final current remains constant even though the crystal is illuminated for one-half hour or more. As soon as the light is cut off, the current immediately reverses and then drops to zero in the manner indicated by the curve. The decrease in current which takes place a few seconds after the light is turned on is obviously caused by the building up of a space charge or polarization within the crystal which limits the flow of electrons. When the light is turned off, the space charge is neutralized by the rush of electrons in the opposite direction. The residual current, which remains constant after the light has been shining on the crystal for some time, indicates that electrons enter and leave the crystal through the electrodes.

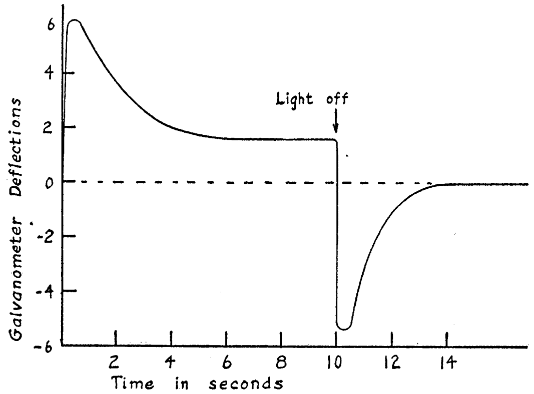

FIG. 2. Variation of actinoelectric current with time of illumination.

Crystals which appear to have flaws and are not very transparent give results which are notably different from those from good clear crystals. The current, in these crystals, starts out in one direction just after the light is turned on, quickly reverses, and then slowly reaches a maximum (approximately after one minute) in the opposite direction.

Figure 3 represents a single crystal of tartaric acid. When the light beam is parallel to the direction of the current (longitudinal effect), the following results are recorded. With the c axis vertical, the electrodes against the orthopinacoid faces, and the clinodome face to the right looking at the illuminated orthopinacoid face, the electrons in the crystal flow in the same direction as the light energy. In this case, a residual current remains after long periods of illumination. When the crystal is turned through 180° about the c axis so that the opposite orthopinacoid face is turned toward the light, the electron flow is still in the direction of light propagation. When the crystal is turned from this position through 180° about the b axis, the electron flow is still in the direction of light propagation, but no residual current remains after 30 sec. or more of illumination. If the crystal is now turned through 180° about the c axis, the electrons flow in a direction *opposite* to the direction of light propagation. In this case, no residual current remains. These

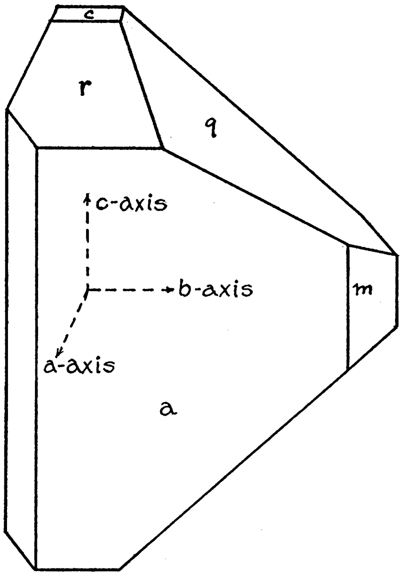

FIG. 3. A monoclinic crystal of tartaric acid with the crystal faces labeled according to crystallographic notation. a—orthopinacoid; q—clinodome; c—basalpinacoid; r—orthodome.

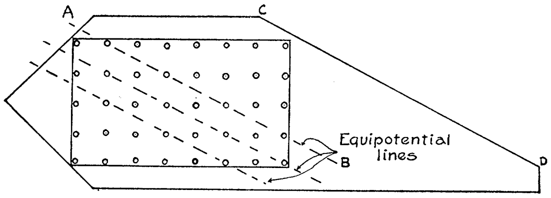

FIG. 4. A section of the crystal cut parallel to the clinodome face.

results are surprising because the crystal, to all outward appearances, is perfectly symmetrical about the *b* axis.

With the two parallel electrodes against the orthopinacoid faces, a light beam falling on the upper clinodome face (transverse effect) produces a deflection of the galvanometer which is just equal to but of opposite sign from the response of the lower clinodome face. The electrons in the crystal travel in opposite directions as the light is shifted from one clinodome face to the other.

A very interesting study is made by cutting a section of the crystal parallel to the clinodome face and exploring its surface with two probes while it is illuminated from above the surface with a carbon arc lamp. A sheet of Cellophane is marked off in two-mm squares and holes made at the corners of the squares to receive the probes. The Cellophane is then cemented to the crystal, and the probes are used to measure the current between two points on the crystal surface as the probes are inserted into the holes in the Cellophane. No current is observed when the two probes are placed anywhere on the line *AB* (Fig. 4). The same is true for all lines parallel to *AB*. These lines are very nearly parallel to the side *CD*. Appreciable galvanometer deflections were noted when one probe was placed at a point on the line *AB* and the other probe was placed at a point on one of the other equipotential lines.

LIGHT INTENSITY INVESTIGATION

The way in which the current varies as a function of light intensity is shown in Fig. 5. The initial value of the current (Fig. 2) is used. The experimental arrangement shown in Fig. 6 is used to obtain this curve. The light intensity is varied by changing the number of glass plates interposed between the carbon arc and the crystal. The light reflected from the glass plate *A* falls on a light shielded photronic cell which is connected to a galvanometer. The light intensity falling on the photronic cell is in a region where the response of the cell is linear. The light intensity falling on the crystal is then directly proportional to the deflections of the photronic cell galvanometer. The curve is similar to that obtained by Schneider[6] for the actinoelectric effects in argentite.

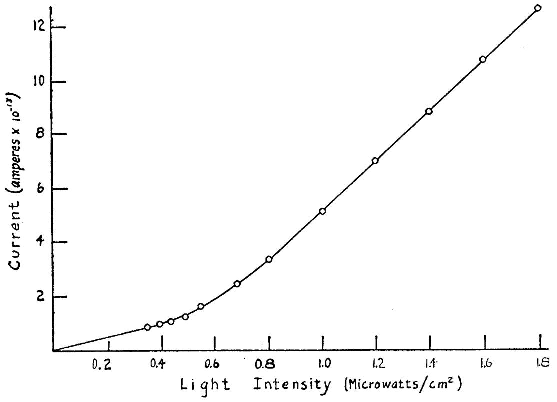

FIG. 5. The variation of the actinoelectric current with light intensity.

From the data given by Barnes and Forsythe[7] for the spectral distribution in energy from a 100-watt gas-filled tungsten lamp, the total intensity falling on a sq. cm at one m distance is determined. In this way the thermocouple is calibrated in microwatts/cm^2 of radiant energy falling on the junction. After the thermocouple is calibrated in microwatts/cm^2, it is used to determine the intensity of light falling on the crystal. This value is compared with the response from the photronic cell. The output from the photronic cell is then used to measure the light intensities in microwatts/cm^2.

EFFECT OF TEMPERATURE

In order to study the effect of temperature on the current response, a crystal is mounted in an evacuated Pyrex tube to prevent moisture from collecting on the crystal as its temperature is lowered. The glass tube is covered with tinfoil except for the portion near the electrodes and is

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[7] B. T. Barnes and W. E. Forsythe, J. Opt. Soc. Am. **26**, 313 (1936).

then surrounded with solid carbon dioxide. The results show no effects of temperature greater than experimental error in the range from −40 to +30°C.

This is in agreement with the findings of Coblentz[2] for molybdenite.

SPECTRAL RESPONSE

Figure 7 shows the way in which the actinoelectric current varies with the wave-length of the light. A carbon arc is used as a light source and is dispersed by means of a double-prism monochromator. The arc has a maximum intensity at approximately 8500A. The energy distribution of the light from the monochromator is determined by means of a thermocouple designed for this purpose. The actinoelectric currents are then corrected for the energy distribution, and the currents are plotted on an equal energy scale. Because of the small galvanometer deflections the monochromator slits must be widened so the wave-length band has a width of 300A at 5500A.

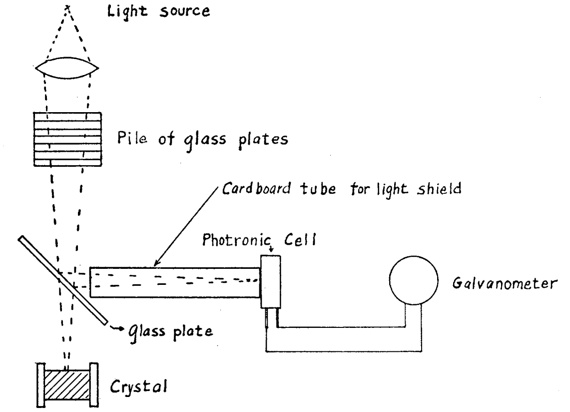

FIG. 6. The experimental set-up for measuring the variation of current with light intensity.

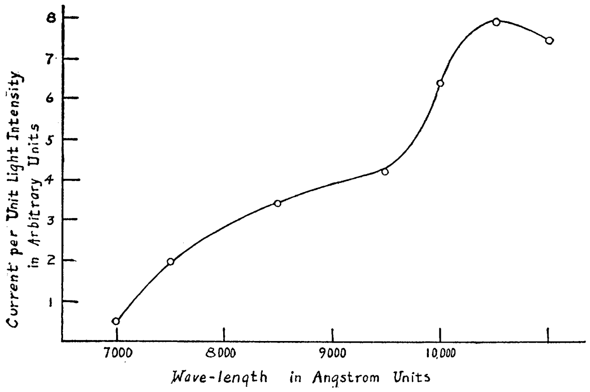

FIG. 7. Spectral response curve.

The maximum response can be seen to be at approximately 10,500A. The light is in a direction perpendicular to the electron flow through the crystal in this case. The actinoelectric response is linear with light intensity for the intensities emerging from the monochromator.

In conclusion, the authors wish to express their thanks to Dr. W. D. Wilkinson of the Geology Department of Oregon State College for orienting the crystals. The senior author wishes to express his appreciation to the Physics Department of the University of California for the loan of the monochromator and to the National Academy of Sciences for the grant-in-aid which made possible the purchase of some of the apparatus used in this research.