

The Photoelectric Sensitivity of Various Substances*

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SOME time ago an examination was made of various substances to determine their electrical sensitivity to light; and in view of the fact that some of the results, obtained are at variance with the measurements made by Case,¹ it seems desirable to publish a summary of our observations.

Two of the herein described substances were examined for change in electrical conductivity caused by the action of light upon them, and all of them were examined for photoelectrical activity when they were charged to a negative potential in an evacuated bulb and exposed to light.

When the substances were examined for an increase in electrical conductivity, a potential of 2 to 6 volts was connected through a resistance of zero to 100,000 ohms into a circuit containing a d'Arsonval galvanometer and the substance under investigation. In most cases the substances were slightly conducting when not exposed to light, so that the "dark current" had to be annulled by joining a counter e. m. f. through a resistance of 10,000 ohms to the terminals of the galvanometer. This counter e. m. f. was obtained by shunting across a resistance of 100 ohms which was in series with a cell of 2 volts and a variable resistance of zero to 70,000 ohms.

The source of light, when not otherwise specified, was a 16-c. p. carbon incandescent lamp, placed at a distance of 10 cm. from the substance under investigation. One disappointing feature of this investigation is that no substance was found which is comparable in sensitivity with the potassium photoelectric cell and with the selenium cell.

SUBSTANCES EXAMINED

Gallium.—The material examined was the highly purified metal prepared and supplied by Dr. H. S. Uhler. This metal was solid, thus differing from the impure material, which is a liquid. It was melted and solidified over a platinum wire sealed into a glass bulb, thus forming the negative electrode of a photoelectric cell from which the air was exhausted. The anode was a loop of platinum wire, situated at a distance of about 12 mm. above the gallium electrode.

A potential of 340 volts was applied to the cell which was connected to a sensitive iron-clad Thomson galvanometer ($i = 5 \times 10^{-10}$ amp.).

The results obtained proved disappointing, this metal being quite insensitive to light. When the cell was exposed to daylight the photoelectric current produced a deflection of only 4 to 5 mm., whereas similarly exposing a potassium photoelectric cell the photoelectric current was sufficient to give a deflection beyond the range of the scale.

Silver Sulphide.—The sample examined was a thin flexible strip, 6 by 10 mm. in area, prepared by Mr. G. W. Vinal.² In one test the silver sulphide formed the negative electrode of a photoelectric cell (evacuated glass bulb about 5 cm. diameter with a ring of platinum wire for the anode) similar to the gallium cell just described. It was connected through an iron-clad Thomson galvanometer to a battery of 340 volts. When exposed to daylight a deflection of perhaps 1 to 2 mm. was observed, but no deflection resulted from exposure to the standard carbon lamp.

In the second test, copper wires were melted to the ends of a strip (3 by 5 by 0.3 mm.) of silver sulphide which was connected in series with a high resistance, a storage cell of 2 volts, and a d'Arsonval galvanometer. When exposed to the standard lamp, the galvanometer deflection was 10 mm. In another sample about 2 cm. long, the ends joining the copper wires were covered to prevent thermoelectric currents. The exposed area was 14 by 4 mm. The radiation from the standard lamp produced a deflection of 13 to 17 mm. Both samples were quick acting, and after exposure to light there was no lag such as obtains in selenium in recovering its dark resistance.

Selenium.—A crystal of selenium, prepared by Dr. F. C. Brown³ and having a receiving surface of less than one sq. mm., when exposed to the standard lamp gave a deflection of more than 50 cm., which shows its great sensitivity as compared with other substances.

The mounting of the selenium crystal consisted of metal electrodes between which the crystal was held by compression. When operated as a photophone, by connecting the selenium crystal with an audion amplifier a loud musical note was obtained.

Tellurium.—This metal is said to change in resistance when exposed to light. The present tests were made

upon a mirror of tellurium deposited upon a glass plate by cathode disintegration. Suitable terminals were attached to a sample about 4 by 50 mm. No change in conductivity was observed when it was exposed to light.

Boleite.—The sample of boleite $[3PbCl(OH).CuCl(OH) \times AgCl]$, from Boleo, Mexico, examined was a single rectangular crystal 3 by 3 by 1.5 mm. It was held by compression between copper electrodes. No change in conductivity was observed when the crystal was exposed to daylight or to the standard incandescent lamp.

Stibnite.—Samples of this same specimen of stibnite, Sb_2S_3 , were supplied to Elliot⁴ for investigation. The purpose of the present investigation was to obtain a comparison of its sensitivity with that of other substances containing antimony.

The size of one sample examined was 4 by 7 by 0.5 mm. Terminals were attached to it by heating a copper wire to incandescence in a gas flame and bringing it in contact with the plate of stibnite.

The standard carbon lamp caused a deflection of 5 cm. Stibnite may be considered as sensitive as boulangerite, to be mentioned presently, but the deflection drifted, due to the decrease in resistance with time already noticed by other observers.

Boulangerite.—The specimen of boulangerite ($3PbS.Sb_2S_3$, Irkutsk, Siberia) investigated was obtained from the Smithsonian collection, No. 78395. Several samples were examined. In one sample, 4 by 7 by 0.8 mm., the electrodes consisted of copper wires melted into the material as just described. The radiation from the standard lamp gave a deflection of 10 to 20 cm.

Another sample, 1 by 1.2 by 2 mm., held by compression between two heavy electrodes of copper, when exposed to the standard incandescent lamp produced a deflection of 2 to 3 cm., which is comparable with the preceding when one considers the size of the exposed surfaces.

Although this substance seems fairly sensitive, it did not appear to be sufficiently so to justify an investigation of its spectral sensitivity with a view of using this mineral as a selective radiometer.

Jamesonite.—($2PbS.Sb_2S_3$; Smithsonian collection No. 12,500; from Cornwall, England.) The sample examined (size 2 by 7 by 1 mm.) had the copper wire terminals attached by fusing the incandescent wire into the material. The standard lamp gave a deflection of only 1 to 2 cm., which seems to indicate that this material is not so light-sensitive as in boulangerite.

Mixtures of galena, PbS, and stibnite, Sb_2S_3 , in various proportions were melted in a crucible and poured upon a plate of metal. Several samples, 5 by 10 by 0.5 mm., were examined, but none of them gave any indication of light-sensitiveness (change in resistance) when exposed to daylight or to the standard incandescent lamp.

Bismuthinite.—Bismuthinite, Bi_2S_3 , was obtained from the Smithsonian collection, No. 85071, from Jefferson County, Montana. This is the most interesting substance examined, in view of the diverse results obtained and the explanation offered therefor.

The sample of bismuthinite examined consisted of a non-homogeneous mass of acicular crystals, which was easily crushed into numerous fine needle-like crystals. The first sample examined was a small mass of crystals (size 1 by 1 by 0.7 mm.) held by compression between two heavy electrodes of copper. When the crystal was exposed to the standard carbon lamp no change in conductivity could be detected with certainty.

A second sample, 3 by 6 by 1 mm., had the copper wire terminals attached by fusion, as already described. The e. m. f.s. applied were the same as for the preceding sample. When exposed to the standard lamp no change in conductivity was observed. These results being contradictory to those published by Case⁵ who used a three stage audion amplifier to detect the change in conductivity of the crystals, the foregoing experiments were repeated in the manner described by him. For this purpose the light from an acetylene flame shining through a slit 2 by 10 mm. was focussed upon the crystal by means of a triple achromatic lens, 6 cm. in diameter and 18 cm. focal length. The light was interrupted by means of a sector disk having 15 openings and operated by means of an electric motor, the speed of which could be varied. The usual speed gave 240 interruptions per second. The crystal was connected to a three stage audion amplifier and telephone receiver. A crystal of selenium or a selenium cell produced a loud note, but the samples of boulangerite and jamesonite, which by previous tests were light-sensitive, did not give a musical sound in the telephone.

The sample of bismuthinite with electrodes sealed on produced no audible note when exposed to light.

At least a dozen samples of bismuthinite held by compression between heavy copper electrodes were

examined in connection with the amplifier. Of this number only two samples appeared to be light-sensitive. One sample produced only a faint sound in the telephone receiver. The second sample produced a loud note in the telephone. The sound was the loudest when the crystal was exposed along the line of contact with the copper electrode. Covering the crystal with red glass did not reduce the loudness of the note very much, indicating that the effect is due to heating of the material. Unfortunately, this crystal was crushed while under investigation. Prolonged tests on other samples gave negative results as regards the production of sound.

In view of the fact that the tests made with a sensitive galvanometer failed to show an increase in conductivity when bismuthinite was exposed to light, it appears that the change in conductivity which was observed when a certain specimen was exposed to intermittent flashes of light (photophone or, rather, radiophone) is the result of a thermal change within the crystal, or perhaps a change in the contact resistance at the electrodes.⁶ In this connection the following experiments on thin strips of metals are of interest.

Platinum and Gold.—In conclusion it is of interest to record the results obtained when using thin blackened strips of platinum and of gold-leaf as radiophones, by connecting them through a battery to an amplifier.

These blackened strips were warmed intermittently by exposing them through a rotating sector disk to the acetylene flame, as already described.

When a sensitive platinum bolometer receiver was used as a radiophone, the sound produced in the telephone was not very audible. This no doubt was due to the great heat capacity of the material which prevented the rapid alternations in resistance, and hence in electric current, from being of sufficient magnitude to affect the telephone receiver.

Using a lightly smoked strip (6 by 2.5 mm.) of gold-leaf, the ends of which were clamped between thin (0.02 mm.) strips of tin, the sound produced in the telephone receiver was as loud as was observed in the photophone made of selenium.

This device was mounted in a glass bulb which could be evacuated. As was to be expected, there was no marked difference in the intensity of the sound produced when operated in air and in a vacuum.

In the gold-leaf radiophone as used, the limit of audibility was attained for a light (radiant power) intensity of 4.8×10^{-5} watts. Using a larger receiver and amplifier and a larger current (which was 0.2 amp. in the present tests) through the receiver, the sensitivity could be greatly increased.

SUMMARY

This paper summarizes the results of an investigation of various substances (1) for an increase in electrical conductivity caused by the action of light upon them, and (2) for electrical discharging activity when they were charged to a negative potential in an evacuated chamber and exposed to light.

Pure gallium and silver sulphide were found to have but small photoelectric discharging action when charged to a negative potential and exposed to light.

No change on exposure to light was observed in the electrical conductivity of tellurium, boleite, bismuthinite, and mixtures of the sulphides of lead and antimony.

An increase in electrical conductivity on exposure to light was observed in crystals of selenium, stibnite, boulangerite, jamesonite, and silver sulphide.

Experiments are described in which crystals of bismuthinite were joined through a battery to the grid circuit of an audion amplifier and a telephone. A change in current in this circuit affected the telephone. The light stimulus was interrupted by means of a rotating sector disk, as used in Bell's selenium photophone. When using a cell or crystal of selenium the fluctuations in light intensity produced a sufficient change in conductivity to cause a musical note in the telephone. Similarly, in several samples of a crystal of bismuthinite a change in conductivity was produced, which caused an audible sound in the telephone. However, from various tests it is believed that this is not a true photoelectrical change (increase) in conductivity, but is due to a thermal resistance change within the crystal or to a change of resistance at the point of contact of the crystal with the metal electrodes between which the crystal was held by compression.

Experiments are described in which a thin blackened strip of platinum or of gold-leaf is joined through a battery to an audion amplifier. The variation in temperature and hence in the resistance of and in the current through the strip, caused by the fluctuation in intensity of the intermittent light, was sufficient in magnitude to produce an audible sound in the telephone receiver.

It would be interesting to determine whether the effect is dependent upon the axial direction of exposure. In the present case the needle-crystals were parallel to the electrodes.

*Journal of the Washington Academy of Sciences. To be published in full in the *Bulletin* of the Bureau of Standards.

¹CASE. Phys. Rev., 9: 305. 1917.

²VINAL. Bureau Standards Scientific Paper No. 310.

³BROWN. Phys. Rev., (2) 4: 85. 1914.

⁴ELLIOT. Phys. Rev., (2) 5: 53. 1915.

⁵Loc. cit.