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The Photoconductivity of Cuprite

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A further investigation has been carried out on the photoconductivity of cuprite under various conditions of illumination. The kinetics of photoconductivity have been studied at various field strengths and light intensities by a "light probe" method. Investigations of the temperature dependence of photoconductivity indicate the presence of a peak of negative as well as positive photoconductivity. The combined action of various types of radiation on the photoconductivity has been studied, and it has been found that the nature of the observed effects depends on the sequence of the illumination processes.

IN A PREVIOUS PUBLICATION[1] the authors studied the effects of field strength and illumination intensity upon the negative photoconductivity of the mineral cuprite. Further work has now been done to study more fully this negative photoconductivity and the conditions under which it arises.

The studies were carried out on single crystals of cuprite whose structure was verified by Debye patterns taken in an X-ray camera using an X-ray tube with a copper anode. Comparison of these measurements with the data in the literature gave very good agreement (measured $a = 4.258$ A; literature value, $a = 4.252$ A).* The measuring circuit is shown in Fig. 1. Light from an incandescent or mercury lamp S is passed through a monochromator with quartz optics, and focussed on the Cu_2O crystal in the form of a narrow ribbon parallel to the electrodes. By reversing the sign of the voltage applied to the crystal, without changing the position of the light beam, it was possible to apply the illumination to either the positive or the negative electrode region.

Since cuprite crystals show both positive and negative photoconductivity in different parts of the spectrum, experiments were carried out to study the spectral distribution of the photoconductivity of cuprite. Typical curves showing the dependence of photoconductivity on the wavelength of the incident light are shown in Fig. 2. The curves have been reduced to constant incident energy. The maximum negative photoconductivity is generally found in the long-wave region of the spectrum ($\lambda = 6400$ A) and the maximum positive photoconductivity in the short-wave region ($\lambda = 4200$ A). From the curves it is evident that the relative magnitudes of the negative and positive photoconductivity depend upon the location of the light probe with respect to the electrodes.

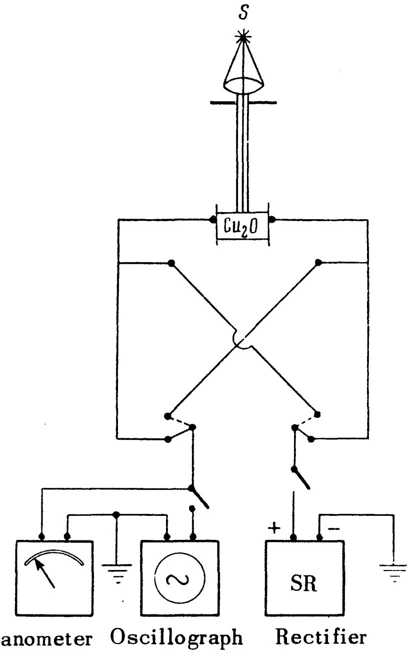

FIG. 1. Diagram of the measuring apparatus.

It has been shown previously that as the light intensity is increased, the negative photoconductivity increases, attains a maximum, and then begins to decrease, changing over to positive photoconductivity at a point which depends on the voltage applied to the crystal. With increasing applied

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*The X-ray structure analysis was carried out at the Giredmet (State Inst. of Rare Metals) in the laboratory of Prof. G. F. Komovskii.

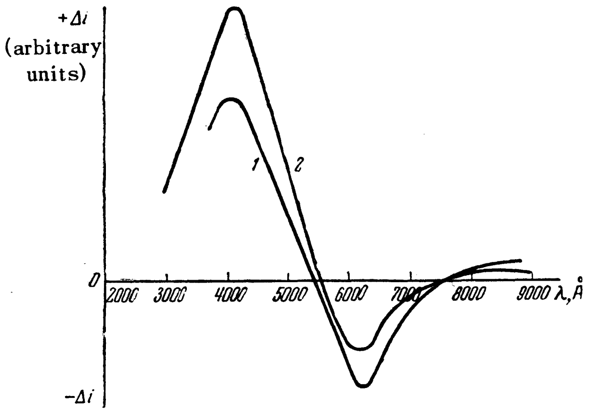

FIG. 2. Spectral distribution of photoconductivity in cuprite for low light intensity. *1*—region of positive electrode (+700 v) illuminated. *2*—region of negative electrode (—700 v) illuminated.

voltage, the transition point shifts to a more intense illumination. The dependence of negative photoconductivity on the intensity of illumination is shown in Fig. 3.

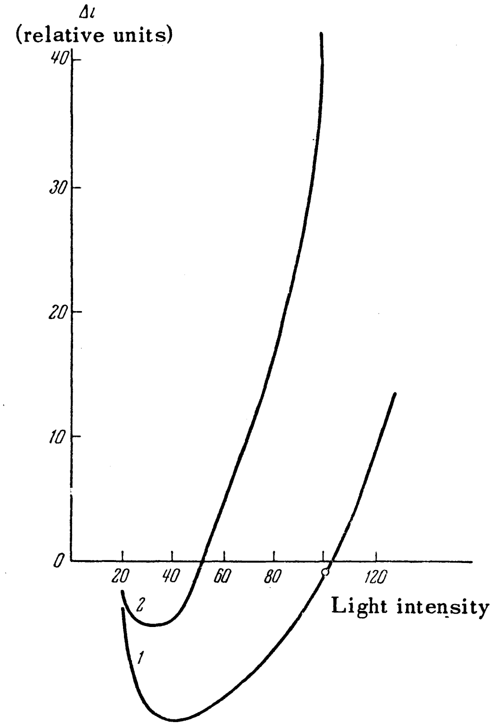

FIG. 3. Dependence of negative photoconductivity on light intensity (λ = 6400 A). *1*—region of positive electrode (+700 v) illuminated. *2*—region of negative electrode (—700 v) illuminated.

When studying the spectral distribution of photoconductivity in cuprite, one must take into account the fact that the relative magnitude of the effects, and even their sign, depend upon the experimental conditions; in particular, they depend to a marked degree upon the conditions of illumination. The spectral distribution curves shown in Fig. 4 were taken at high light intensity. Comparison of these curves with those of Fig. 2 shows that a mere change in light intensity is all it takes to alter the whole character of the spectral distribution. A change in the voltage applied to the crystal can also produce a change in the nature of the spectral curves, since the negative photoconductivity changes more rapidly with field intensity than does the positive (Fig. 5).

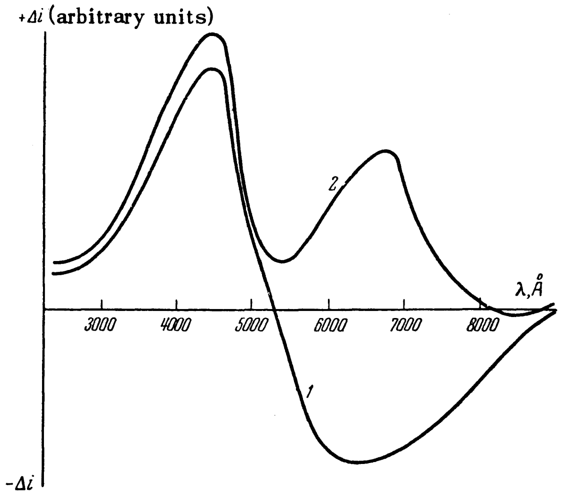

FIG. 4. Spectral distribution of photoconductivity in cuprite at high light intensity. *1*—region of positive electrode (+700 v) illuminated. *2*—region of negative electrode (—700 v) illuminated.

When the strip of light producing the negative photoconductivity was moved from the cathode toward the anode, it was observed that the magnitude of the negative photoconductivity increased. If the crystal was illuminated with light which gave positive photoconductivity, the same direction of movement of the light probe gave a decreased positive photoconductivity. This effect was independent of the orientation of the crystal with respect to the electrodes.

Because of the effect of wavelengths and the polarity of the illuminated region of the crystal upon the magnitude, sign and character of the photoconductivity, all further observations were made under conditions which ensured a peak value of photoconductivity, namely: for negative photoconductivity,

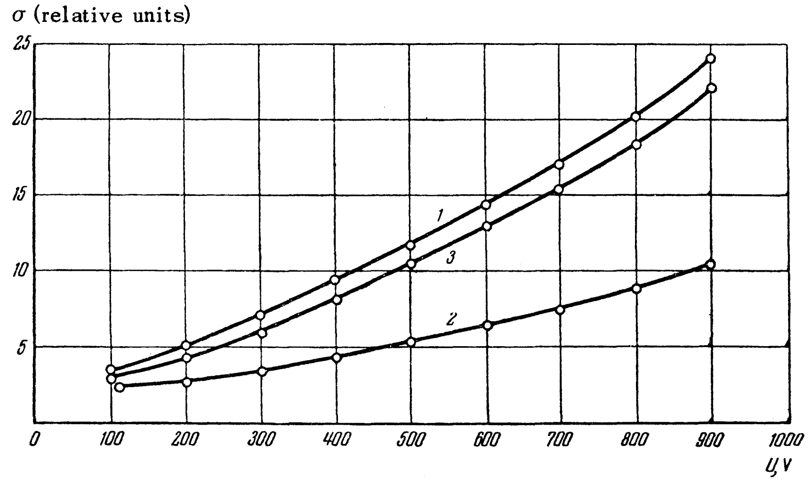

FIG. 5. Dependence of negative and positive photoconductivity of cuprite on the voltage applied to the crystal. *1*–λ = 4200 A; *2*–λ = 6400 A; *3*–dark.

light of wavelength λ = 6400 A applied to a region of the crystal adjacent to the positive electrode; and for positive photoconductivity, λ = 4200 A applied to the negative electrode region.

The time dependence of the negative photoconductivity produced when a region of the crystal in the neighborhood of the positive electrode is illuminated with low-intensity light of 6400 A wavelength is shown in the oscillogram of Fig. 6. When the direction of the electric field is reversed, so that the illuminated region of the crystal is near the negative electrode, it is evident from this figure that the negative photoconductivity is noticeably less than when the positive electrode region is illuminated.

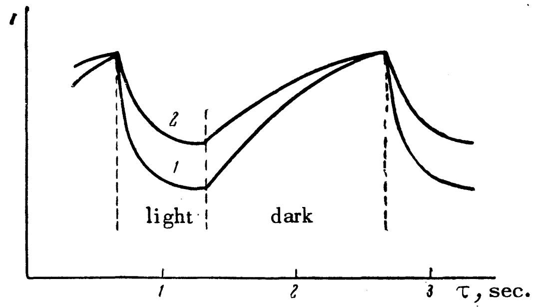

FIG. 6. Oscillogram of current flowing through the crystal. Light of wavelength 6400 A at low intensity applied to positive electrode region (*1*), and negative electrode region (*2*).

The oscilloscope traces obtained with high illumination (Fig. 7) seem to be the result of a superposition of both positive and negative photoconductivity. A further increase of light intensity leads to a growth of the positive photoconductivity and the complete disappearance of the negative effect.

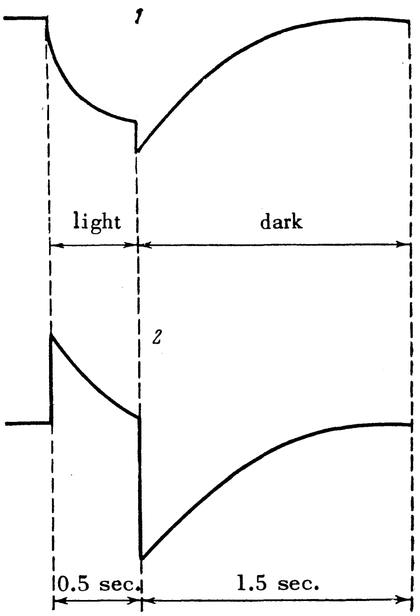

FIG. 7. Oscillogram of current flowing through the crystal for high intensity light of wavelength 6400 A, applied to the positive electrode region (*1*), and to the negative electrode region (*2*).

The observed difference between the magnitudes of the positive and negative photoconductivities produced by illuminating the positive and negative electrode regions indicates that the current carriers are of both signs. Negative photoconductivity is caused by the recombination of the dark-current carriers (holes) with the photo-current carriers, leading to a decrease in the number of positive carriers (holes). The positive photoconductivity is basically due to the increased number of electrons.

Studies of the temperature dependence of photoconductivity have shown that at higher temperatures both the positive (Fig. 8) and negative (Fig. 9) photoconductivities increase, passing through a maximum. Upon raising the temperature higher than this, the photoconductivity drops off, although the dark current continues to increase. When a crystal which has been heated to 100° C is cooled, its original properties are recovered. However, if the cooled crystal is immediately re-heated to 100°, the temperature dependence of photoconductivity has quite a different character (Curve 2 of Fig. 8).

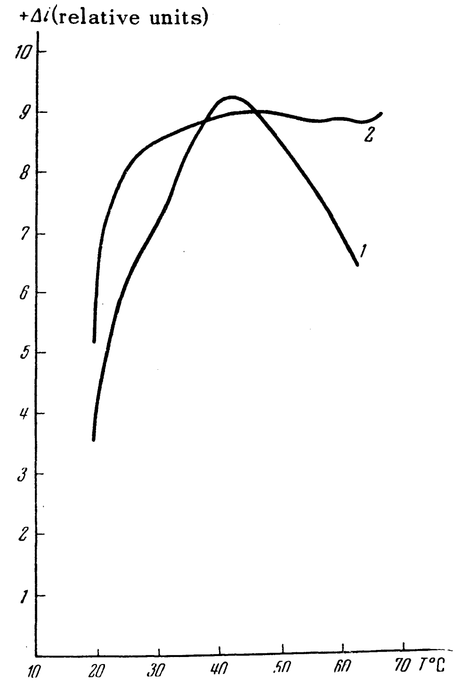

FIG. 8. Dependence of positive photoconductivity on temperature. Curve 2 was measured immediately after a preliminary heating of the crystal.

Heating the crystal to 200°C leads to a complete disappearance of the negative photoconductivity, which is not re-established upon cooling to room temperature. The positive photoconductivity does recover after cooling, but there is a considerable drop in the dark conductivity.

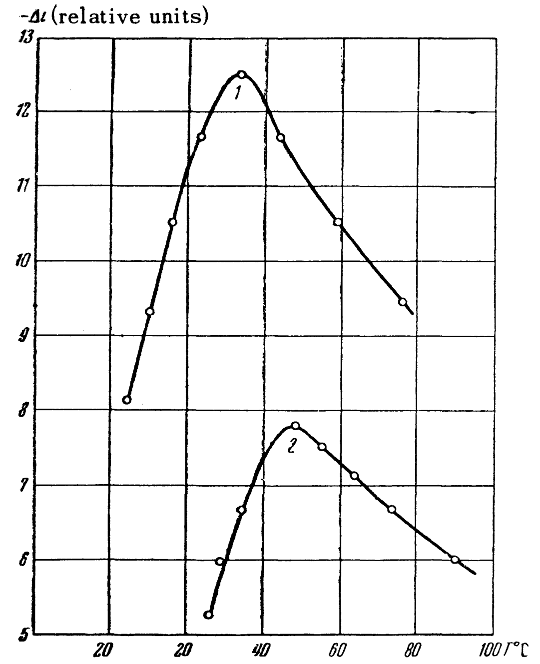

FIG. 9. Dependence of negative photoconductivity on temperature. 1– U = 1000 v. 2– U = 700 v.

We have studied the effect of overall illumination on the photoconductivity of cuprite. If we apply a beam of red light, of intensity required to give the maximum negative photoconductivity n_1 and then a general illumination of blue light which by itself would give a positive photoconductivity n_2, the resulting effect is $n_1 + n_2$. On the other hand, if a general red illumination is applied to a crystal together with a blue beam, its photoconductivity does not change from the value n_1 due to the beam alone.

When the cuprite crystal is irradiated with X-rays[2], the same basic phenomena of negative photoconductivity are observed as in the case of visible light. The irradiation of the crystal with an X-ray beam was carried out using an X-ray tube with a beryllium window, giving a high intensity of soft radiation. For a potential of 50 kv and a plate current of 20 ma, the intensity at the exit window was 30,000 roentgens/min. Upon irradiating the crystal it was observed that as the X-ray tube voltage was raised, the negative photoconductivity also increased. Increasing the anode current above a certain value, while at the same time keeping the voltage constant, had no effect on the negative photoconductivity. These effects are possibly caused by saturation of the negative photoconductivity in the relatively thin layer of cuprite where practically all of the soft X-rays are absorbed. In this case the increased intensity of irradiation due to the increased anode current would not increase the negative photoconductivity, and further increases in intensity might even lead to a decrease. When the voltage applied to the X-ray tube is raised, the rays can penetrate deeper into the crystal and consequently affect a larger volume of the semiconductor, so that we observe a larger value of the negative photoconductivity.

When X-rays and visible light are both applied, the observed effects depend on the order of application. When X-rays are applied to a crystal which is already illuminated with visible light so as to give a maximum of negative photoconductivity, we observe a decrease in the negative photoconductivity, or even the appearance of a positive effect. When visible light is applied to a crystal already irradiated with X-rays, we observe an increase in the negative photoconductivity. A satisfactory simple explanation of these observations is obtained if we assume that visible light is absorbed throughout the whole volume of the crystal, while the soft X-rays are absorbed only in a very thin layer. If the X-ray and visible radiation are both sufficiently intense to produce saturation of their individual negative photoconductivities—the visible light in the whole crystal, and the X-rays in their own thin layer—then the addition of X-rays to light and light to X-rays must lead to different effects, as is actually observed.

[1] A. N. Krongauz and V. K. Liapidevskii, J. Exptl. Theoret. Phys. (U.S.S.R.) **26**, 115 (1954).

[2] A. N. Krongauz, *Studies in X-ray Technique*, Medgiz (1955).

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218

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The Alpha Decay of Pu^{239}

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The α-spectrum of Pu^{239} has been investigated. Three new lines with energies 5064 ± 2, 4999 ± 5 and 4917 ± 5 kev and intensities (0.037 ± 0.005), (0.013 ± 0.005), and (0.005 ± 0.002) percent have been detected. It is shown that the principal α-line of Pu^{239} is related to the decay to an excited level of U^{235} having a spin of $1/2$. Three previously detected lines and two of the newly detected lines belong to the rotational band of this level. The existence of a metastable state of U^{235} with an excitation energy of ~ 3 kev is predicted. A doublet splitting parameter equal to $a = -0.276$ has been found.

THE PRINCIPAL LINES in the α-spectrum of Pu^{239} are well-known[1,2]. These lines have energies 5.147, 5.134 and 5.096 Mev. The intensities of the corresponding transitions are 72, 16.8 and 10.7 percent. From the data presented it is seen that the transition to the lowest of the known levels takes place with great probability. The decay coefficient for this transition is equal to 0.3 (*cf.* Ref. 3), *i.e.*, this transition is allowed. As is known, the spin of the nucleus must not change in an allowed transition. Direct measurements of the spins lead however to $I = 1/2$ for Pu^{239} [4] and to $I = 7/2$ for the daughter nucleus U^{235} [5]. Such difference in spins of the ground states of the parent and daughter nuclei made it necessary to assume[6] that the most intense transition is not to the ground state of U^{235}.

This hypothesis received supporting evidence in experiments on Coulomb excitation[7,8]. The Coulomb excitation of the U^{235} nucleus has led to the observation of a system of levels starting naturally from the ground state of U^{235} and having nothing in common with the levels observed in the α-decay of Pu^{239} (see the level scheme below).

Bohr, Froman and Mottelson[3] have stated the hypothesis that the lowest most intense level known from α-decay has $I = 1/2$ and is the first level starting the rotational spectrum.