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THE INFLUENCE OF ILLUMINATION ON THE ANGULAR DISTRIBUTION OF ANNIHILATION QUANTA IN CRYSTALLINE SELENIUM

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The angular distribution of annihilation quanta have been measured in case of crystalline selenium both illuminated and not illuminated during the measurements. The results obtained are practically the same for angles greater than about 3.5 mrad, for smaller angles, however, the distribution function corresponding to illuminated selenium considerably exceeds that corresponding to unilluminated selenium. This difference has been explained in terms of annihilation of positons with electrons of a "subset" formed as a result of the influence of light.

Introduction

The aim of the study presented in this paper was to investigate whether the changes which occur in the electronic structure of selenium during its illumination are somehow reflected by the behaviour of the angular distribution curves of annihilation quanta. In view of the general character of these studies the source of light used was a quartz lamp which gave white light. The investigated samples were made of grey (crystalline) selenium. The crystals were grown by means of the method proposed by Krebs [1]. Chemically pure selenium was sealed in evacuated glass phials; the vacuum was of the order of 10^{-3} millimeters of mercury.

After melting the selenium was stored for several hours at 230°C. Next the temperature was decreased to 200°C and at this temperature the phials were stored for three weeks .The changes in temperature during this thermal treatment did not exceed ±5°C. Crystalline selenium obtained in this way was used for preparing the samples.

Experimental

The angular distributions of the gamma quanta from the annihilation of positons in crystalline selenium have been measured both for selenium samples stored in the dark during the measurements and for samples illuminated with light from a quartz lamp. In the first

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case the samples were stored in the dark for several days before the measurements, since, as it is well known, selenium is characterized by long relaxation time needed to get to equilibrium state violated by illumination, strong fields, and other factors [2, 3].

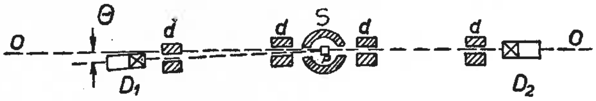

Fig. 1. Schematic drawing of the geometry of the experimental set up. P – sample and positon sources, S – radiation shielding, d – lead diaphragms, D_1, D_2 - scintillation counters

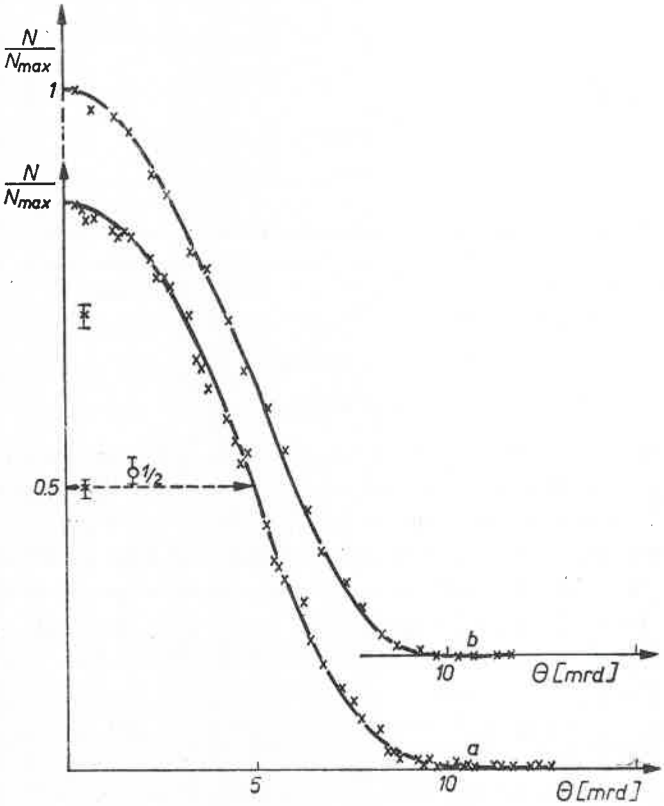

Fig. 2. Angular distributions of annihilation quanta for selenium samples. a) unilluminated selenium, b) illuminated selenium

Fig. 1 shows the geometry of the experimental set-up for angular distribution measurement. The sample together with the positon source is denoted in the figure by P. The positon source was ^{22}NaCl deposited in stainless steel cups and shielded by a thin mica layer of 1 mg/cm^2. Two such positon sources of the total activity of 4 mCi were located on both sides of the selenium sample. In order to shield the environment from radiation and to decrease the background registered by the counters, the radiation sources and the sample were surrounded by a lead layer denoted in the figure by S. The two gamma quanta from the annihilation of a positon-electron pair were registered by means of two scintillation counters D_1 and D_2 placed on both sides of the sample. The counter D_2 was fixed while the other counter D_1 was movable in order to make measurements at various selected angles θ. The system of diaphragms d selected the gamma quanta falling on the counters. The electronic coincidence circuit for registration of the gamma quanta from the two-photon annihilation of positons was a standard circuit commonly used for such measurements. Detailed technical data on the construction of the spectrometer with which the angular distributions have been measured can be found in the paper of Rozenfeld *et al.* [4].

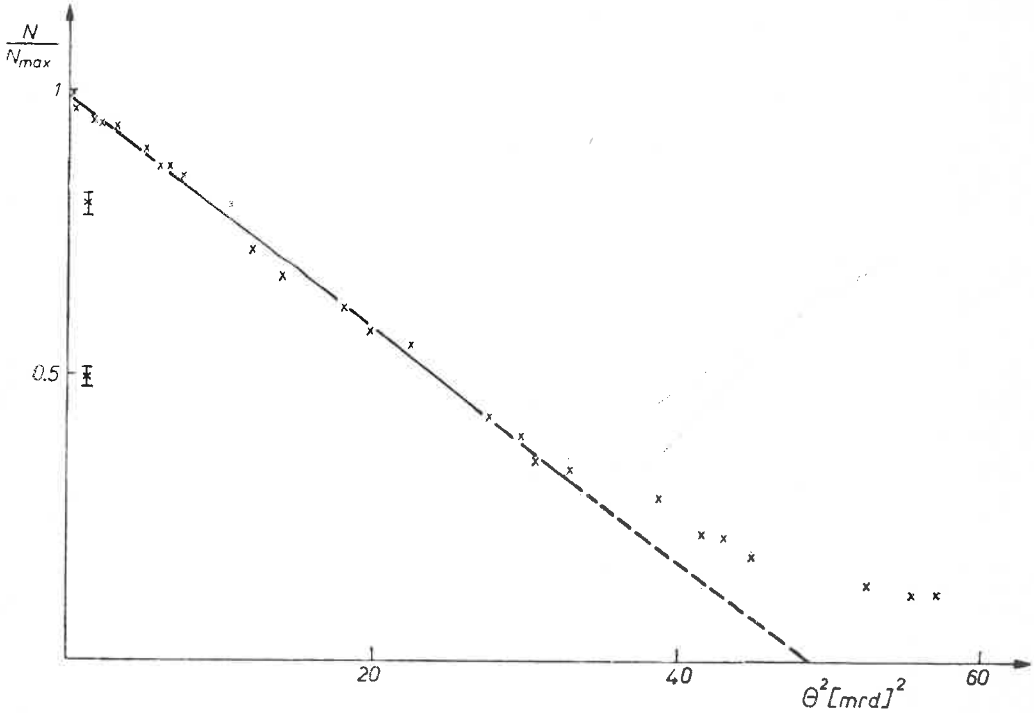

Fig. 3. Results of measurements for unilluminated selenium presented in the coordinates (N, θ^2)

Results and their interpretation

Fig. 2 shows the angular distributions obtained from the measurements of both illuminated and unilluminated selenium. The curves have been normalized to the same height at $\theta = 0$. For such normalization the area under the curve corresponding to illuminated selenium is about 7% smaller than that corresponding to unilluminated selenium and the main difference between the two distributions is observed in the small angle region.

Figs. 3 and 4 show the results of measurements presented in the coordinates (N, θ^2). The following characteristic features can be observed in these figures. The experimental points obtained in case of unilluminated selenium (Fig. 3) up to $\theta^2 = 35$ mrad^2 lie on one straight line whereas the points obtained in case of illuminated selenium in the same θ^2-range lie on two straight lines (Fig. 4). This means that the essential part of the angular distribution of annihilation quanta obtained from unilluminated selenium can be described by a parabola (Fig. 5*b*) while that corresponding to illuminated selenium has to be described by two parabolas (Fig. 5*a*). One can conclude from this analysis that the factor which is responsible or the parabolic part of the angular distribution curve in case of unilluminated selenium is annihilation of positons with electrons from only one set. An analogous consideration in case of illuminated selenium yields that on the background of the angular distribution coming from the annihilation of positons occurring with this set of electrons (component *II* in Fig. 5*a*) one can distinguish a "subset" of electrons where annihilation of positons gives the component *I* of the angular distribution. The term "subset" of electrons has been used owing to the smaller contribution to the overall angular distribution rather than to their subordinate role.

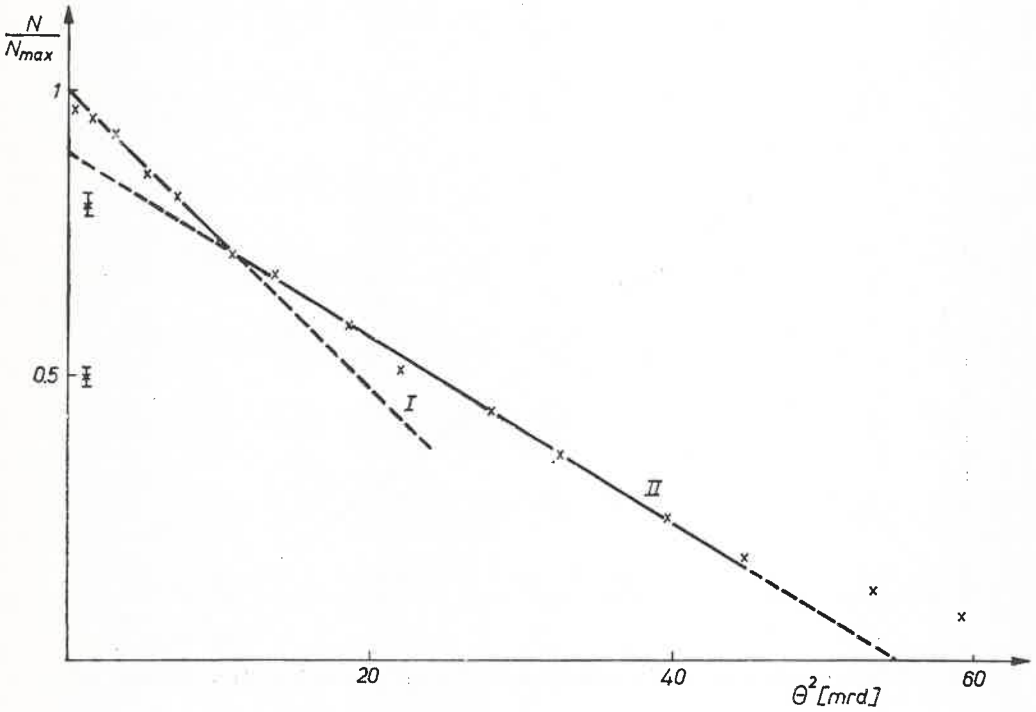

Fig. 4. Results of measurements for illuminated selenium presented in the coordinates (N, θ^2)

It should be pointed out that both the straight line in Fig. 3 and the straight line *II* in Fig. 4 intersect the θ^2-axis at similar θ^2-values. It is thus possible to compare the angular distribution curve obtained in case of unilluminated selenium with the part *II* of the curve obtained for illuminated selenium. This is shown in Fig. 6*a*. In order to make this comparison the ordinates of all experimental points obtained in case of unilluminated selenium have been multiplied by a common factor so that the maximum of the curve given by these points would coinside with the maximum of the parabola *II* which formed a part of the angular distribution obtained for illuminated selenium. It can be seen in Fig. 6*a* that the experimental points obtained in case of unilluminated selenium lie within the limits of statistical error on this parabola. This fact justifies the previous assumption that both in the case of unilluminated selenium (parabolic part of the curve in Fig. 5*b*) and illuminated selenium (parabola *II* in Fig. 5*a*) the annihilation of positons occurs with electrons belonging to the same set. On the basis of this analysis the part of the area in Fig. 6*a* contained between the parabolas *I* and *II* should be attributed to the annihilation of positons with the "subset" of electrons separated as a result of illumination of the selenium sample. Fig. 6*b* shows this part of the area obtained by subtracting the parabola *II* from parabola *I*.

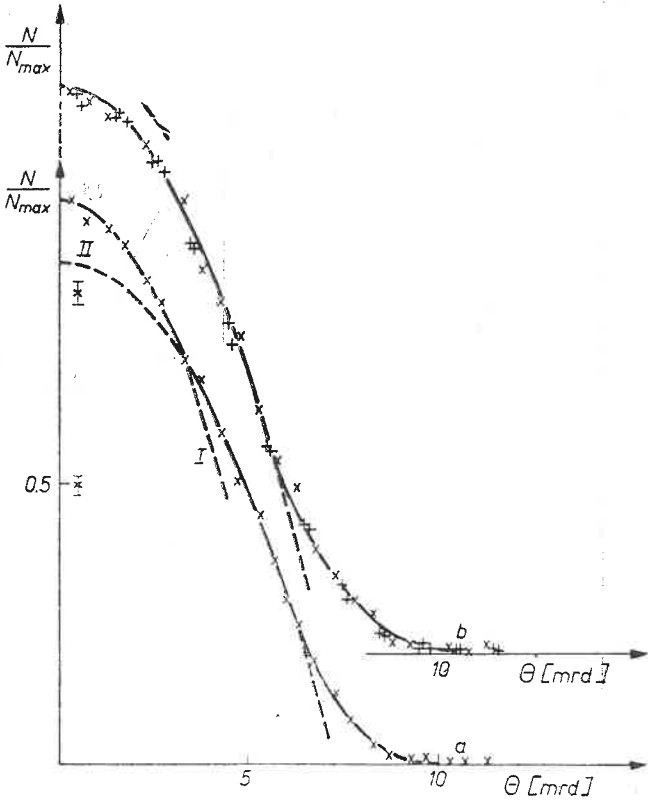

Fig. 5. Decomposition of the angular distribution curves into parabolas. *a*) in case of illuminated selenium samples, *b*) in case of unilluminated selenium samples

The studies on the properties of selenium [5, 6] have shown that all selenium samples investigated so far were p-type semiconductors. This is connected with the presence of oxygen which gives deep acceptor levels. In spite of the vacuum method of obtaining crystalline selenium it is very difficult to prevent the presence of oxygen. Other impurities also lead to p-type semiconduction. There is a common opinion that single selenium atoms can also play the role of acceptors. It follows that even if the concentration of possible impurities is unknown, it is highly probable that the investigated selenium samples were p-type semiconductors.

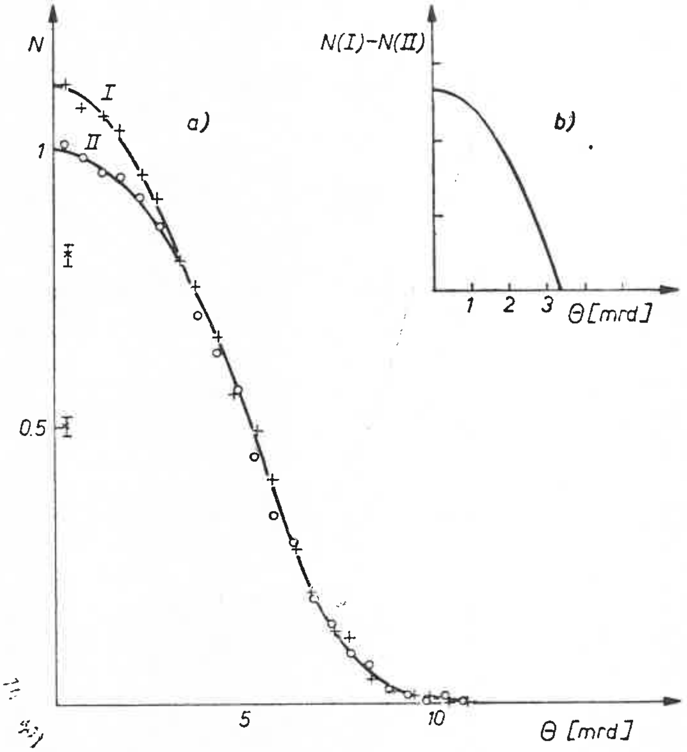

Fig. 6*a*. Comparison of the results obtained in case of unilluminated selenium (open circles) with the second component (parabola *II*) in case of illuminated selenium. *b*. Curve presenting the difference between parabola *I* and *II* (for detailed explanation see text)

On the basis of the angular distribution measurements made by the authors in this work with illuminated selenium samples it is difficult to state (owing to the use of light of continuous wavelength spectrum) what kind of phenomenon is responsible for the appearance of the "subset" of electrons which gives rise to the appearance of the component *I* in the angular distribution curve in Fig. 6. This may be electrons which went over to the conduction band, under the influence of light or electrons excited by light to acceptor levels.

Whatever their nature, one fact remains essential (provided that our conclusions are correct), namely that this number of excited electrons, although negligibly small compared to the total number of electrons in selenium sample, can be "detected" in measurements of the angular distributions of annihilation quanta.

Future studies will certainly give a more precise and unambiguous explanation of this phenomenon.

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