POLARIZABILITY OF EXCITON AND EFFECT OF REVERSAL OF THE MAGNETIC FIELD IN THE SPECTRUM OF THE YELLOW EXCITON SERIES OF A CRYSTAL

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The effect of reversal of the magnetic field in the exciton spectrum was first noted [1] in the CdS crystal. This phenomenon consists of a shift of the Zeeman components and a change of their intensity when the magnetic field acting on the crystal is reversed. This effect is not observed in the spectrum of the free atom, and can occur for an exciton moving in a solid crystal (i) when account is taken of the finite nature of the wave vector of the electromagnetic wave (spatial dispersion) and (ii) when the crystal has no inversion center.

Excitons excited by a light wave have a directional velocity $\vec{v} = \hbar\vec{k}/M$, where $\vec{k}$ - wave vector of the exciton, equal to the wave vector of the exciting light wave, and M - effective mass of the exciton.

In a magnetic field H, in a coordinate system moving together with the exciton, there is produced an electric field [1)]

$$\mathcal{E} = \hbar/cM\vec{k} \times \vec{H}. \quad . \quad . \qquad (1)$$

In crystals in which there is no inversion center, the states of the exciton should have a dipole moment $\vec{d}$ directed along the C axis of the uniaxial crystal such as CdS, as a result of which the energy of the exciton transition $\hbar\omega_e$ in the magnetic field acquires an increment

$$-(d, \mathcal{E}) = -\frac{\hbar}{cM}(d, [k \times H]) \ldots\ldots \qquad (2)$$

Expression (2) reverses sign when the direction of the magnetic field H is reversed, so that a change takes place in the energy of the exciton level.

The energy shift ΔW of the exciton absorption line produced upon reversal of the magnetic field, which is a consequence of the motion of the exciton in the crystal, is determined by the expression:

$$\Delta W = 2\frac{\hbar}{cM}(d\ [k \times H])\ldots \qquad (3)$$

In crystals having an inversion center, where d = 0, say in Cu_2O, the reversal effect should not be observed and is not observed [4]. Reversal of the magnetic field in the exciton spectrum can occur in such crystals, however, if an induced dipole moment is excited in the

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1) The action of such a field on an exciton was considered in 1955 by A. G. Samoilovich and L. L. Korenblit [2], and was taken into account in formulas (4) and (5) of their paper. The question of the electric field connected with the motion of the center of gravity of the exciton in a magnetic field was also considered by B. P. Zakharchenya, P. P. Pavinskii, and the author [3]. This magnetic effect was assumed to be weak in [3] and was not taken into account ([3], p. 2179).

excitons of these crystals by an additional external electric field applied to the crystal placed in the magnetic field H.

The diameters of the excitons in Cu_2O range from 100 to 2500 Å, depending on their degree of excitation (on the values of the quantum numbers, from n = 2 to n = 10), i.e., they exceed by hundreds of times the diameters of the isolated atoms. The polarizability α of the exciton should be several orders of magnitude larger than that of the free atoms [1]. Therefore the induced dipole moment of the exciton in an electric field $\vec{E}$, namely $\vec{p} = \alpha\vec{E}$, can be appreciable.

The dispersion shift ΔW of the absorption line in the exciton spectrum will then be determined, just as in (3), by the expression

$$\Delta W = 2\frac{\hbar}{cM}(\mathbf{p}[\mathbf{k}\times\mathbf{H}]) = 2\frac{\hbar}{cM}\alpha(\mathbf{E}[\mathbf{k}\times\mathbf{H}])\dots. \qquad (3')$$

To observe this effect in our experiments, the Cu_2O single crystal was placed at 4.2°K in mutually perpendicular electric and magnetic fields E and H, lying in a plane perpendicular to the direction of the light beam passing through the crystal. We investigated the effect of reversing the magnetic field on the terms of the yellow series of the exciton with quantum numbers n = 3, n = 4, and n = 5, in magnetic fields H up to 30 kOe and in electric fields E up to 3 kV/cm.

In an electric field E = 0, we observed no effect of reversal of the magnetic field on the spectrum of the yellow series of the Cu_2O exciton, since d = 0 in Cu_2O. When an additional constant electric field $\vec{E} \perp \vec{H}$ was superimposed on the magnetic field H and the direction of the magnetic field H was reversed, we observed a change in the energy position of the line in the exciton spectrum of Cu_2O - the effect of reversal of the magnetic field.

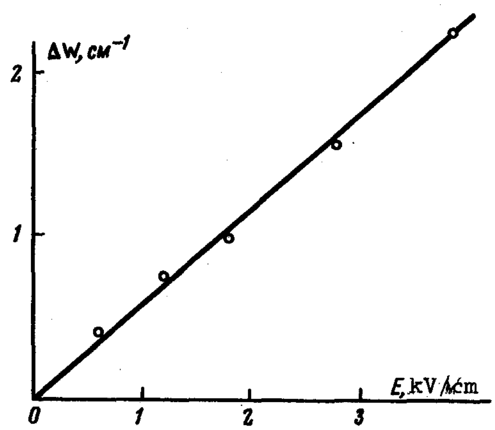

Fig. 1. Reversal shift of the n = 3 line of the yellow series of the exciton vs. the electric field E at H = 30 kOe ($\vec{H} \parallel C_2$; $\vec{E} \parallel C_4$; $\vec{K} \parallel C_2'$).

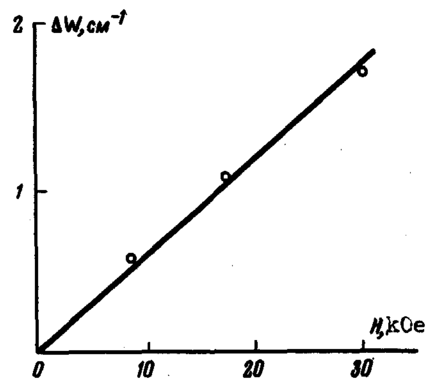

Fig. 2. Reversal shift of the n = 3 line of the yellow series of the exciton vs. the magnetic field H at E = 3 kV/cm ($\vec{H} \parallel C_2$; $\vec{E} \parallel C_4$; $\vec{K} \parallel C_2'$).

[1] This conclusion that the exciton polarizability α is very large is confirmed by the tremendous diamagnetism of the exciton [5].

With H = const and the sign of the electric field $\vec{E}$ reversed ($|E|$ = const), the reversal effect also takes place, as expected. When $\vec{E} \parallel \vec{H}$, as expected, no effect of reversal of the magnetic field is observed in the Cu_2O exciton spectrum.

The reversal effects were observed by us at $\vec{E} \parallel C_2$, $\vec{H} \parallel C_4$ and at $\vec{E} \parallel C_4$, $\vec{H} \parallel C_2$ in both polarizations $\vec{\xi} \parallel \vec{E}$ and $\vec{\xi} \perp \vec{E}$ (at an observation direction perpendicular to the plane containing $\vec{E}$ and $\vec{H}$ ($\vec{E} \perp \vec{H}$)).

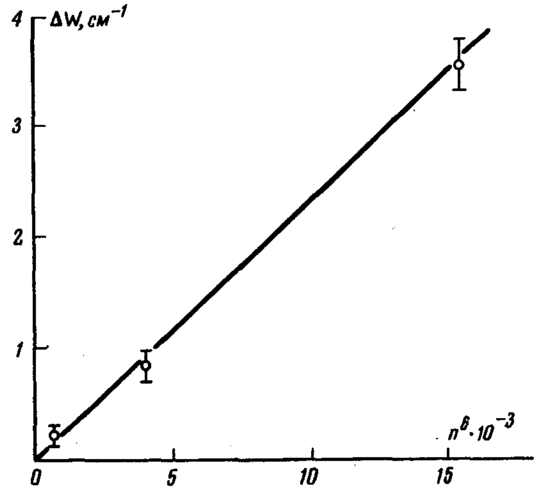

Fig. 3. Reversal shift vs. quantum number of the state of the exciton (n = 3, 4, 5) at E = 0.5 kV/cm and H = 10 kOe ($\vec{H} \parallel C_2$; $\vec{E} \parallel C_4$; $\vec{K} \parallel C_2'$).

Figures 1 and 2 show plots of the inversion shift ΔW for the n = 3 line of the yellow series of the Cu_2O exciton at different values of the electric field E at a constant value of the magnetic field H (Fig. 1) and at different values of the magnetic field H at a constant value of the electric field E (Fig. 2). Figure 1 shows that the reversal effect is proportional to the electric field E and thus to the exciton dipole moment $\vec{p}$ induced by the field E.

Figure 2 shows that the reversal shift, as follows from the theory, depends on the magnetic field H, increasing in proportion to H [1)].

We observed further that the reversal shift ΔW depends on the state of the excitation of the exciton (on the quantum number n of the exciton line). The reversal shift ΔW increases with the quantum number n on going from the line n = 3 to the line n = 4 and further to the line n = 5, as expected, in proportion to the cube of the exciton radius, i.e., to n^6 (Fig. 3).

The reversal shift observed by us in Cu_2O makes it possible to determine experimentally the polarizability α of the exciton for different states of excitation of the exciton, n = 3, 4, and 5, by means of formula (3'):

$$\alpha_{n=3} = 6\cdot 10^{-17}\ cm^3;\quad \alpha_{n=4} = 2\cdot 10^{-16}\ cm^3;$$
$$\alpha_{n=5} = 7\cdot 10^{-16}\ cm^3.$$

The most reliable are the polarizability data for the exciton state with n = 3. The obtained value is in good agreement with the exciton-polarizability values calculated from

1) In our experiments (Figs. 1 - 3) we took account of the fact that the exciton lines can experience a Stark shift due to the Hall photoeffect, the magnitude of which can change with changing H. Special measures, which will be described in a more detailed communication, were taken to exclude the possible influence of the Hall photoeffect on the magnitude of the reversal shift.

the Stark effect [6] for the state n = 3, namely $\alpha = 2.5 \times 10^{-17}$ cm^3, and with the value calculated from the known polarizability of the hydrogen atom [7] starting from the well known radius of the exciton for the state with n = 3, namely $\alpha \approx 10^{-17}$ cm^3.

In this communication we do not describe a number of extraneous phenomena observed by us, such as the long-wave shift of the exciton line under simultaneous action of the magnetic and electric fields, the excitation and variable behavior of the weak extraneous lines in the region of the yellow series of the exciton, the dependence of the ionization of the exciton on the direction of the magnetic field, and other phenomena. These influences will be the subject of a more detailed communication.

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EXPERIMENTAL OBSERVATION OF THE SUPPRESSION OF THE INELASTIC CHANNEL OF A NUCLEAR REACTION IN THE INTERACTION OF RESONANT γ RADIATION WITH NUCLEI AND ELECTRONS IN A SINGLE CRYSTAL

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In resonant interaction of γ quanta with nuclei possessing low-lying levels, the excited nucleus can decay via different channels. If the ratio of the widths of the inelastic and elastic channels $\Gamma_1/\Gamma_2 \ll 1$ then, inasmuch as the magnitude of the resonant cross sec-

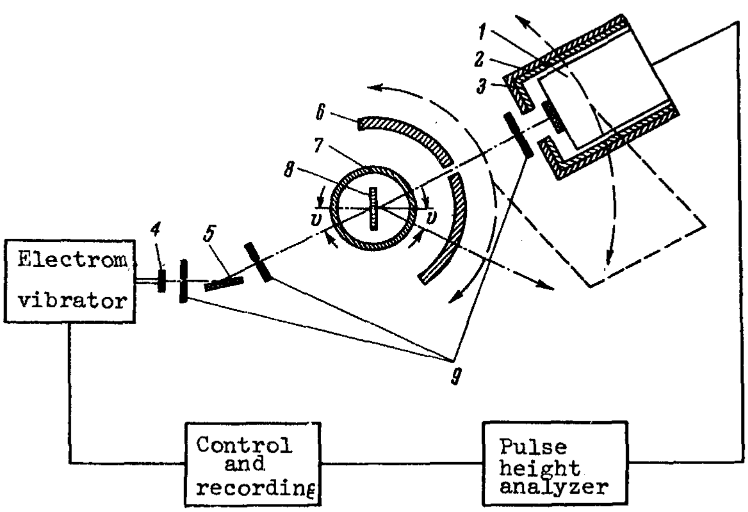

Fig. 1. Experimental setup: 1 - scintillation counter; 2 - lead screen; 3 - steel screen; 4 - $Sn^{119m}O_2$ source; 5 - monochromator; 6 - iron shield; 7 - vacuum chamber of cryostat; 8 - Sn crystal; 9 - diaphragms.