$$\frac{\sigma_e^{(2)}}{\sigma_e^{(1)}} \approx \mathrm{tg}\,\alpha\,\frac{M_2}{M_1}\,, \qquad (2)$$

where M_1 and M_2 are the masses of the heavy and light atoms.

Ratios of positron elastic scattering cross sections in inert gases.

Inert-gas mixture	$\mathrm{tg}\,\alpha$	$\sigma_e^{(1)}/\sigma_e^{(2)}$
Xenon - helium	0.13 (± 10%)	260 ± 25.0
Xenon - neon	0.15 (± 10%)	44 ± 5.0
Xenon - argon	0.52 (± 6%)	6.4 ± 0.4
Argon - helium	0.22 (± 13%)	46 ± 6.0

The results are listed in the table. The obtained positron elastic scattering cross sections agree with the available data for helium, neon, and argon [4 - 6]. Using the absolute values of the positron elastic cross sections for helium, $\sigma_e = 0.023\pi a_0^2 \pm 25\%$ and for neon, $\sigma_e = 0.14\pi a_0^2 \pm 25\%$, obtained in [4 - 5] and recently confirmed by an independent method in [6], and comparing the cross-section ratios from the table, we obtain as an experimental estimate of the average positron elastic cross section in xenon the value $\sigma_e = 6\pi a_0^2$ at energies 1 - 5 eV.

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INFLUENCE OF MAGNETIC FIELD AND OF DEFORMATION ON THE OPTICAL ORIENTATION OF EXCITONS IN CRYSTALS WITH WURTZITE STRUCTURE

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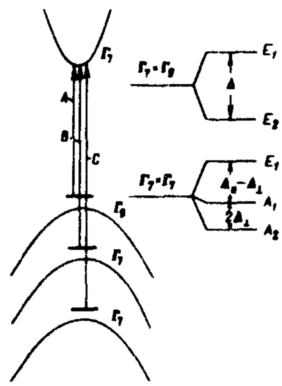
We show in this paper that optical orientation of the exciton should give rise to a number of new effects that distinguish this orientation from that of free carriers [1]. These effects are connected with the fact that excitons, unlike free carriers, have integer spin, and an important role is played here by exchange splitting. The excitons can therefore be polarized not only with light of circular polarization, but also with linearly polarized light. Accordingly, the excitons become either oriented or aligned, in analogy with the situation in optical excitation of atoms in gases [2].

In turn, upon recombination of polarized excitons, depending on their state, the emitted light can be not only circularly but also linearly polarized, something impossible in the recombination of oriented free or bound carriers. This makes possible the conversion of the circular polarization of the exciton luminescence into linear polarization, and vice versa, under the influence of external fields, viz., magnetic, electric, or deformation. The details of these effects are determined by the symmetry of the crystal and by the type of the band structure, on which the character of the splitting of the optically-active exciton states under the influence of the external fields depends. We shall analyze these effects using as an example hexagonal crystals with wurtzite structure, whose exciton spectrum has been well investigated and for which optical orientation of the excitons has been observed [3].



The band structure of these crystals is shown in the figure, together with the exchange splitting of the ground state of the excitons $A(\Gamma_7 \times \Gamma_9)$ and B and $C(\Gamma_7 \times \Gamma_7)$.

We consider the case when both the exciting light and the luminescence radiation propagate along the hexagonal axis C. The only optically active term is in this case the doubly degenerate term E_2, which corresponds to states with an exciton angular momentum projection ±1 on the C axis. When the exciton is excited by light of circular polarization, one of these states becomes excited, while linearly polarized light excites a superposition of these states.

Influence of magnetic field. The dependence of the exciton orientation on the transverse magnetic field H is determined by the character of the Zeeman effect. For the $\Gamma_7 \times \Gamma_7$ exciton, the Zeeman effect is quadratic: the splitting of the level E_1 in the magnetic field is $\delta E_H = 2|\gamma|H^2$, the constant γ is of the order of $\mu_0^2/(\Delta_\parallel - \Delta_\perp)$, where μ_0 is the Bohr magneton and $\Delta_\parallel$ and $\Delta_\perp$ are the values of the exchange splitting (see the figure). There is no Zeeman effect in a transverse magnetic field for the $\Gamma_7 \times \Gamma_9$ exciton [4].

Excitation by circularly-polarized light in a magnetic field should cause extinction of the circular polarization of the luminescence and the appearance of linear polarization. If the exciton lifetime in the optically active state τ_1 is much shorter than the spin relaxation time, $\hbar/\tau_1 \ll \Delta_\parallel - \Delta_\perp$, and $\delta E_H \lesssim \Delta_\parallel - \Delta_\perp$, then these effects are determined for the $\Gamma_7 \times \Gamma_7$ exciton by the ratio $K = \delta E_H \tau_1/\hbar$ and are described by the formulas

$$P_{circ} = P^0_{circ}/(1 + K^2), \quad P_{lin} = P^0_{circ} K/(1 + K^2), \tag{1}$$

where P^0_{circ} is the degree of circular polarization in the absence of a magnetic field. The linear-polarization plane makes in this case an angle $\pi/4$ with the direction of the magnetic field. We note that in the case of indirect excitation of the excitons at $g_{e,h}\mu_0 H\tau/\hbar \gtrsim 1$ it is necessary to take into account the decrease of the degree of polarization of the electrons and holes during the time τ required for binding into an exciton. For the $\Gamma_7 \times \Gamma_9$ exciton, the decrease of the circular polarization is determined by the ratio $R(g_e\mu_0 H/\Delta)^2 (1 + \tau_2/\tau_1)$, where τ_2 is the exciton lifetime in the optically inactive state E_2. In strong magnetic fields, when $R \gg 1$ the value of $P_{circ}(H)$ does not decrease to zero, but tends to a value of P_{circ} that depends on the excitation condition. In the case of excitation by circularly-polarized light, no linear luminescence polarization occurs for the $\Gamma_7 \times \Gamma_9$ exciton.

Excitation with linearly polarized light in a magnetic field should cause extinction of the linear luminescence polarization and appearance of circular polarization. For the $\Gamma_7 \times \Gamma_7$ exciton these effects depend on the angle χ between the plane of polarization of the light and the direction of the magnetic field, and are determined by the formulas

$$P_{lin}(H) = P^{\circ}_{lin} \{ \cos^2 2\chi + \sin^2 2\chi / (1 + K^2) \}, \tag{2}$$

$$P_{circ}(H) = P^{\circ}_{lin} \{ \sin 2\chi \, K / (1 + K^2) \} .$$

The plane of polarization of the luminescence in a magnetic field is rotated in this case relative to the plane of polarization of the exciting light through an angle ϕ_0:

$$tg^2 \phi_o = \frac{\gamma}{|\gamma|} \frac{K^2}{2} \sin 4\chi / (1 + K^2 \cos^2 2\chi). \tag{3}$$

For the $\Gamma_7 \times \Gamma_9$ exciton, no circular polarization of the luminescence occurs upon excitation with linearly polarized light, and the linear polarization in a magnetic field remains unchanged.

Influence of deformation. Anisotropic transverse deformation causes a splitting of the optically active state E_1 for both the $\Gamma_7 \times \Gamma_7$ and $\Gamma_7 \times \Gamma_9$ excitons. This leads to deformation effects which do not exist for free carriers. The constant C, which determines the deformation splitting $\delta E = 2c\varepsilon$, where $\varepsilon^2 = (\varepsilon_{xx} - \varepsilon_{yy})^2 + 4\varepsilon^2_{xy}$, is proportional to the ratio of the exchange splitting to the splitting of the nearest valence bands Γ_9 and Γ_7 and can be of the order of 1 eV in II - VI crystals, where this ratio reaches 0.1. When $\delta E_\varepsilon/\Delta$ and $\delta E/(\Delta_{\shortparallel} - \Delta_{\_}) \ll 1$, the deformation effects are the same for the excitons A, B, and C.

Transverse deformation and excitation of the excitons with circularly polarized light cause extinction of the circularly polarized luminescence and excitation of linearly polarized luminescence in a plane making an angle $\pi/4$ with the principal axis of the deformation tensor. When the excitons are excited with linearly polarized light, deformation causes extinction of the linearly polarized luminescence and appearance of circularly polarized luminescence. These effects are determined by formulas (1) - (3), with $K = \delta E_\varepsilon \tau_1/\hbar$ and χ the angle between the plane of polarization and the principal axis of the deformation tensor. Similar effects can be produced also by a transverse electric field, in analogy with luminescence in gases [2]. The indicated effects can be observed in cubic crystals deformed along [100] or [111], and by varying the sign of the deformation it is possible to vary the locations of the bands Γ_9 and Γ_7.

We note that the foregoing formulas are directly applicable to excitons bound on charged donors or acceptors or neutral traps. The effects indicated above should also be observed for free excitons, but the quantitative theory of such excitons should take into account also the annihilation interaction, which leads to additional splitting of the terms if the exciton wave vector $\vec{q}$ is not parallel to C.

The circular polarization of the luminescence of the free excitons $\Gamma_9 \times \Gamma_7$ was observed in n-CdSe [3], where the Henle effect was not observed in fields up to 10 kOe. This may be due to the fact that the excitons were produced by binding of pairs, and only the holes were oriented in the n-type material.

Calculation shows that in this case $P_{circ}(H)$ does not depend on the magnetic field and is equal to the degree of orientation of the holes, if no change in the degree of hole orientation occurs upon binding of the exciton.

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THE "QUASI-EIKONAL" APPROXIMATION

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We propose below for the scattering amplitude a simple approximation, which is quite exact at high energies $s \simeq 2m_N E >> m_N^2$ (and small $|t| = |q^2| \lesssim m_N^2/\ln(E/m_N)$), with account taken for the contributions of the Regge poles and all the rescatterings [1, 2] from them (Fig. 1).

We write down, in the representation of the impact parameter b, the amplitude[1)]

$$M(s, q^2) = \int e^{i\vec{\kappa}b} f(s, b) \frac{d^2b}{2\pi} = \int_0^\infty I_0(\kappa b) f(s, b) b\, db \qquad (1)$$

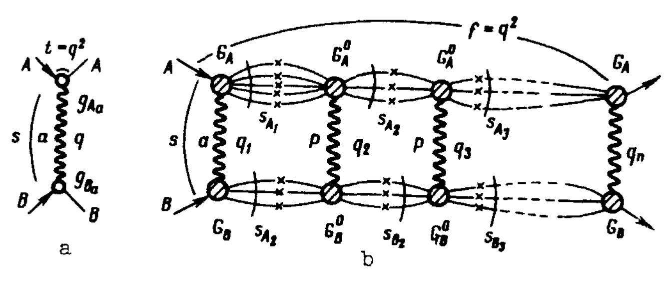
in terms of the partial wave f(s, b), in analogy with the eikonal model [3]

$$f(s, b) = [e^{\chi'} - 1 - \chi' + C\Sigma_a \chi_a]/2iC. \qquad (2)$$

Here χ' is the quasi-eikonal

$$\chi = C\chi_P(s, b) + \sum_{a \neq P} C_a \chi_a(s, b),$$

$$\chi_a = 2i\int M^{(1)}(s, \kappa^2)\, e^{-i\vec{\kappa}b} \frac{d^2\kappa}{2\pi}, \qquad (3)$$



a b

Fig. 1

[1)] We are considering spinless particles; the normalization is such that $d\sigma/dt = 4\pi|M(s, t)|^2$, $\sigma^{tot} = 8\pi \mathrm{Im}M(s, 0)$.