It is important to ascertain the causes of the noticeable increase of the spin relaxation time in systems with large exchange interactions (which include the ferrites investigated by us).

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FORMATION OF AN EXCITON DIELECTRIC PHASE IN A MAGNETIC FIELD IN A METAL-SEMICONDUCTOR TRANSITION

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1. In the investigation of pressure-induced transitions from the metallic to the superconducting state in the alloys $Bi_{1-x}Sb_x$ ($x < 0.065$) in a magnetic field, it was observed that the exciton dielectric (ED) phase, predicted in 1968 by Fenton [1] on the basis of the work of Yafet, Keyes, and Adams [2], is produced. Insofar as we know, no stationary ED phase has been observed to date.

The measurements were carried out at a hydrostatic pressure p up to 20 kbar, in magnetic fields H up to 65 kOe, at temperatures 1.9 - 4.2°K.

2. As is well known, Mott excitons [3] can be produced in transitions from the metallic to the superconducting state only at temperatures lower than the exciton binding energy E_B, under the condition $a_B^* < r_D$, where a_B^* is the effective Bohr radius of the exciton and r_D is the Debye screening radius [4 - 6]. In the absence of a magnetic field, this inequality is satisfied for the alloys $Bi_{1-x}Sb_x$ at carrier densities below $\sim 10^{11}$ cm^{-3}. Since there are no samples of such purity at the present time, the transition from a metallic to the superconducting state (as well as the inverse transitions) at $H = 0$ [7] are phase transitions of order 2.5 after I.M. Lifshitz.

In a magnetic field, as shown in [1, 8], the decrease of a_B^* and the increase of E_B, and also the one-dimensionalization of the electron gas, make possible the formation of an ED phase at carrier densities $\sim 10^{15}$ cm^{-3}, corresponding to $Bi_{1-x}Sb_x$ alloys with realistic purity. The formation of this phase is characterized by the occurrence of an energy gap Δ, which increases in the magnetic field, and whose magnitude is determined by the binding energy of the excitons.

Since the magnetic field shifts the band boundaries, we chose for a reliable detection of the ED phase such an orientation of H, at which the gap G in the semiconducting state decreases in the field (the overlap $-G$ in the metallic state increases accordingly).

3. The measurements were performed with samples of $Bi_{0.9725}Sb_{0.0275}$ and $Bi_{0.954}Sb_{0.046}$ with donor densities 2×10^{15} and $\sim 3 \times 10^{14}$ cm^{-3}, respectively. The impurity density and type was determined by measuring the components of the galvanomagnetic tensor in weak fields, in the region where the transition into

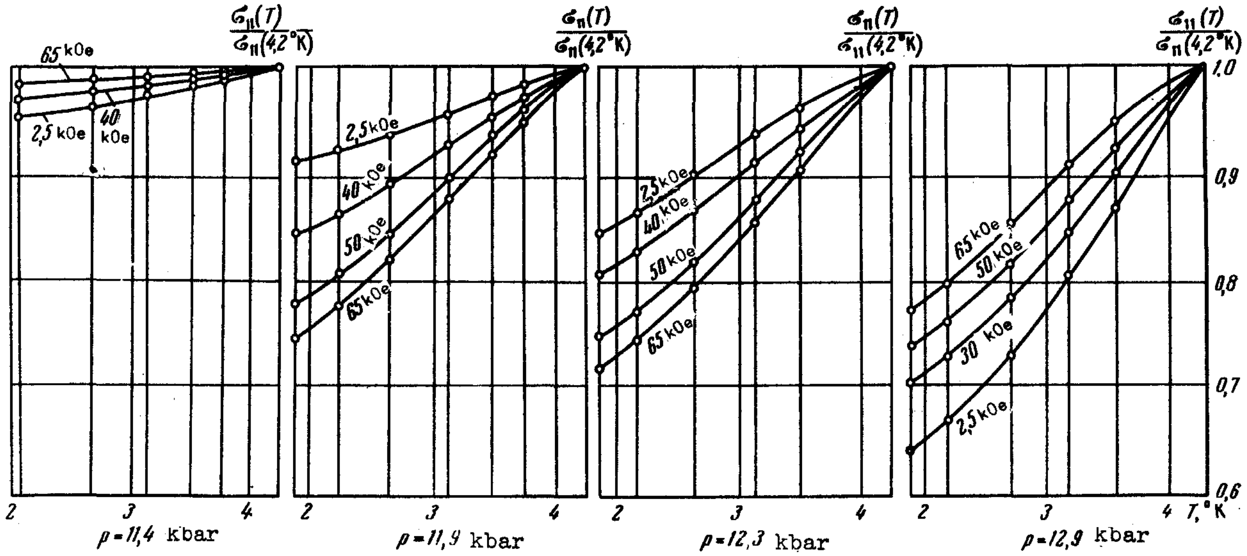

Fig. 1. Dependence of the electric conductivity $\sigma_{11}(T)/\sigma_{1.}(4.2°K)$ on the temperature T in a magnetic field parallel to the current along the binary axis, at four values of the pressure near the point of transition into the semiconducting state $p_{cr} \simeq 12$ kbar (at H = 0) for the alloy $Bi_{0.954}Sb_{0.046}$.

the semiconducting state takes place under pressure. The experimental results that follow pertain to the higher-purity alloy $Bi_{0.954}Sb_{0.046}$ in which the effects connected with the occurrence of the ED phase in fields $H \leq 65$ kOe are more clearly pronounced.

Figure 1 shows the temperature dependence of the electric conductivity $\sigma_{11}(T)/\sigma_{11}(4.2°K)$, measured in a field parallel to the current along the binary axis of the crystal, at four values of p near the point of transition from metallic to the superconducting state and at different values of H from 2.5 to 6.5 kOe (at H = 0 the transition to the semiconducting state occurs in this alloy at $p_{cr} = 12$ kbar).

We see that the character of the temperature dependence of the electric conductivity changes qualitatively in a narrow range of pressures near $p_{cr} = 12$ kbar, in which the overlap -G (at $p < p_{cr}$) or the gap G ($p > p_{cr}$) at H = 0 does not exceed ∿5 and ∿10°K respectively. Whereas outside this region the electric conductivity increases in the magnetic field at fixed temperature, inside this region it changes in the opposite fashion. The increase of the electric conductivity of the alloy in the metallic state at $p \leq 11.4$ kbar, and also in the semiconducting state at $p \geq 12.9$ kbar, is connected with the increase of the overlap -G in the former case and the decrease of the gap G in the latter. The value $\partial G/\partial H = -0.05$ deg/kOe was calculated from the plots of $\ln[\sigma_{11}(T) - \sigma_{11}(0°K)]$ against 1/T at $p \geq 12.9$ kbar in magnetic fields from 2.5 to 65 kOe. This is in good agreement with the value $\partial G/\partial H = 0.06$ deg/kOe, obtained on the basis of the data of [9, 10].

The decrease of the electric conductivity in the magnetic field at a fixed temperature in the pressure region 11.4 kbar < p < 12.9 kbar indicates that a gap that increases in a magnetic field is produced in the energy spectrum.

The dependence of $\ln[\sigma_{11}(T) - \sigma_{11}(0°K)]$ on 1/T at p = 12.3 kbar, shown in Fig. 2a, illustrates the character of variation of the initial gap G in the semiconducting state with increasing H and the appearance of the gap Δ of the

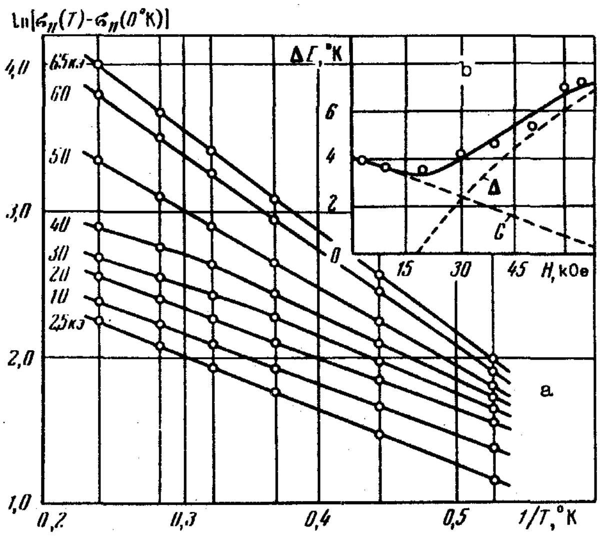

Fig. 2. a) Plot of $\ln[\sigma_{11}(T) - \sigma_{11}(0°K)]$ against 1/T for the alloy $Bi_{0.954}Sb_{0.046}$ under a pressure p = 12.3 kbar at different values of the magnetic field H parallel to the current along the binary axis of the crystal; the curves are arbitrarily shifted in the direction of the ordinate axis. b) Dependence of the measured energy gap ΔE for the alloy $Bi_{0.954}Sb_{0.046}$ on the magnetic field H parallel to the current along the binary axis at p = 12.3 kbar and T = 1.9°K. The dashed curves represent the dependence of G on H and the proposed form of the dependence of Δ on H.

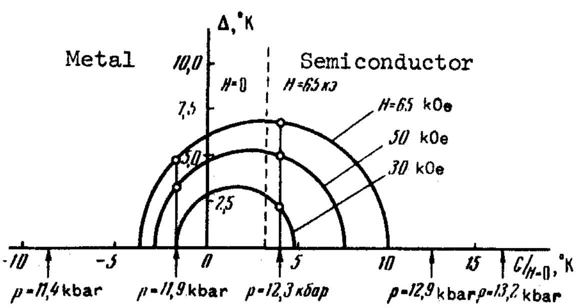

Fig. 3. Schematic dependence of gap Δ of an exciton dielectric at different values of the magnetic field H on the gap G or on the overlap -G in the non-reconstructed energy spectrum of the alloy $Bi_{0.954}Sb_{0.046}$ at H = 0 and T = 1.9°K. The circles denote the calculated values of Δ at p = 11.9 kbar and p = 12.3 kbar. The dashed straight line corresponds to G = 0 at H = 65 kOe.

ED phase in the magnetic field. An analysis of this dependence of $\ln[\sigma_{11}(T) - \sigma_{11}(0°K)]$ on 1/T shows that the measured energy gap ΔE first decreases slightly in the field, and then increases (Fig. 2b). The dashed curves in Fig. 2b are the plot of G(H) and the proposed plot of $\Delta(H)$. The "kinks" on the $\ln[\sigma_{11}(T) - \sigma_{11}(0°K)]$ curves at H = 30 kOe and H = 40 kOe are apparently connected with the fact that the ED phase is destroyed at the corresponding temperatures ∿2.7°K and ∿3.2°K1) and a semiconducting state is produced, with gaps G ∿ 2.5°K and ∿ 2.0°K (the latter estimates are based on the slopes of the straight lines in Fig. 2 and are quite approximate, see Fig. 2b).

The scheme whereby the ED phase is produced in a magnetic field on going from the metallic to the semiconducting state is shown in Fig. 3. The arrows along the abscissa axis indicate the values of the gaps G or of the overlap -G (at H = 0) at different pressures. The values of the gaps G at $p \geq 12.19$ kbar were calculated from the corresponding plots of $\ln[\sigma_{11}(T) - \sigma_{11}(0°K)]$ against 1/T at H = 0, while the smaller values of the gap and of the overlap -G were determined from the formula

$$G = \partial G/\partial p(p - p_{cr}).$$

The value $\partial G/\partial p$ = 14 deg/kbar, obtained for p > 12.9 kbar, agrees well with the results of more exact investigations [7, 10]. To construct the gap function $\Delta(G)$ of the ED [1, 5, 6] at different values of X, we used the values

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1) We note that the temperature T_{cr} at which the ED phase is destroyed is connected with Δ, in accordance with [5, 6], as follows: $T_{cr} = \alpha\Delta$, where $\alpha \lesssim 1$.

of Δ and G at $p = 11.9$ and $p = 12.3$ kbar, calculated from the experimental data. The shift of the gap functions of the ED with increasing H corresponds to motion of the band boundaries in the magnetic field. At $p = 12.3$ kbar and $H = 65$ kOe, the gap G of the unreconstructed spectrum is close to zero, and consequently the energy gap $\Delta E \simeq 7^\circ\mathrm{K}$, determined from the dependence of $\ln[\sigma_{11}(T) - \sigma_{11}(0^\circ\mathrm{K})]$ on $1/T$, coincides practically entirely with the maximum value of Δ of the ED phase at $H = 65$ kOe.

No ED phase is produced at $p \leq 11.4$ kbar and $p \geq 12.9$ kbar in fields $H \leq 65$ kOe, because $|G| > \Delta$ at these pressures.

In conclusion, we take the opportunity to thank A.A. Abrikosov and L.V. Keldysh for a discussion of the results and V.G. Karavaev for help with the measurements.

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ELECTROMAGNETIC WAVES NEAR HOLE CYCLOTRON RESONANCE IN BISMUTH

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The spectrum of the cyclotron waves predicted by Kaner and Skobov [1] consist of three branches. In the case of a strong spatial dispersion ($KR \gg 1$, where K is the wave number and R is the cyclotron radius), two branches of the spectrum have a normal dispersion and lie near the cyclotron-resonance line on the side of the strong magnetic fields ($\omega < n\Omega$, where ω is the frequency of the electromagnetic wave, n the number of the harmonic of the cyclotron resonance, and Ω the cyclotron frequency), while the third branch has a normal dispersion and approaches closely the resonance on the side of the weak magnetic field. In the case of weak spatial dispersion ($KR \ll 1$) in metals with a quadratic carrier dispersion law, all the branches of the spectrum have anomalous dispersion and are located near the resonance on the side of the strong magnetic field [2, 3]. In metals with nonquadratic dispersion, there can exist at small KR cyclotron-wave branches that are far from the cyclotron-resonance line. In compensated metals having several types of carriers (electrons and holes) with equal concentration, there can exist in some cases cyclotron-wave spectrum branches at small KR, approaching closely to the cyclotron-resonance line not only from the strong-field side, as in the case of longitudinal polarization [4, 5], but also from the weak-field side[1].

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[1] Similar questions were considered in a paper by E.A. Kaner and V.G. Skobov, delivered at the Soviet-Japanese Conference in Novosibirsk, 1969.