current may be modulation of the conductivity by the field's own magnetic field which is superimposed on the external magnetic field. The direct current is then proportional to the square of the alternating-field amplitude.

The closed electric field produces in turn a constant magnetic field, so that the magnetic field in the sample is a sum of the external field and the field produced by the rectified current. At large radio-wave amplitudes it may turn out that when the external magnetic field is turned off the dc does not vanish, since the magnetic field produced by the rectified current itself suffices for the detection. In other words, at alternating field amplitudes above a certain critical value, the metal can exist, even without an external magnetic field, in a "current" state such that a closed direct current flows in the sample. In a zero external magnetic field there are two equivalent "current" states that differ in the direction of the rectified current. Depending on the direction of the "priming" external magnetic field, the sample can be in either of these states.

The foregoing analysis explains many features of the observed phenomena, such as the presence of at least two stable states, the independence of the loop width of the frequency, and the increase of $H_c^{\sim}$ with rising temperature. At the same time, the experimentally observed curves are much more complicated than called for by the model (Fig. 2). The proposed model, however, explains in principle the existence and the large number of states as being due, for example, to anisotropy of the magnetoresistance or to the breakup of the sample into domains. The loop in strong fields (Fig. 2) may be due to a change in the phase relations between the high-frequency currents and the alternating magnetic field. (The amplitude of the rectified current is proportional to the cosine of the phase angle, and the phase shift itself is determined by the total magnetic field, i.e., by the sum of the external field and the magnetic field produced by the rectified current.)

To prove the validity of the proposed model it is necessary to observe directly the magnetic field produced by the closed direct current.

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RESONANT ABSORPTION BY ELECTRONS LOCALIZED ON DONOR PAIRS IN COMPENSATED n-InSb

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A model of the molecular hydrogen ion H_2^+ is proposed for an analysis of the energy levels of the localized electrons in compensated semiconductors. The measured absorption coefficients of n-InSb at 1.6 - 4.2°K are explained within the framework of the proposed model.

Shklovskii and Efros [1] have developed a model of the electric conductivity of weakly doped, $N_d a^{*3} \ll 1$ ($N_d^{1/3} a^* \ll 1$), and strongly compensated ($1 - K \ll 1$) semiconductors (N_d is the donor concentration, a^* is the Bohr radius of

the electron at the donor, and K is the degree of compensation). Owing to the inhomogeneity in the distribution of the impurities, two types of impurity-potential fluctuations, large-scale and small-scale, are significant in such semiconductors. Among the small-scale fluctuations, an important role is played by the potential wells produced when two charged donors come together within a distance $R < R_m \equiv [(3/2\pi)(1 - K)]^{1/3} N_d^{-1/3} < N_d^{-1/3}$ ("impurity pairs"). At low temperatures, $T \to 0$, most electrons are located on these pairs. In [1] they considered only the case of a "pair dimension" $R_m \gg a^*$, i.e., the electron is localized near one donor, and the potential of the second can be regarded as a small perturbation.

At $R_m \sim a^*$, however, the electron is localized to almost equal degrees near two charged donors. Therefore the pairs with $R_m \sim a^*$ can apparently be regarded as an analog of the molecular hydrogen ion H_2^+ with a distance $\sim R_m$ between "nuclei" [2]. It should be noted that the energy spectrum of H_2^+ differs noticeably from the hydrogen-like spectrum of an "isolated" donor. The applicability of the model of H_2^+ to the analysis of donor pairs can be verified, in particular, by measuring the dependence of the absorption coefficient α on the wavelength λ at different R_m (i.e., N_d and K).

To verify the foregoing hypothesis, we measured $\alpha(\lambda)$ in sereral n-InSb samples with $N_d a^{*3} \lesssim 0.05$ and $1 - K \ll 1$. The parameters of two samples that

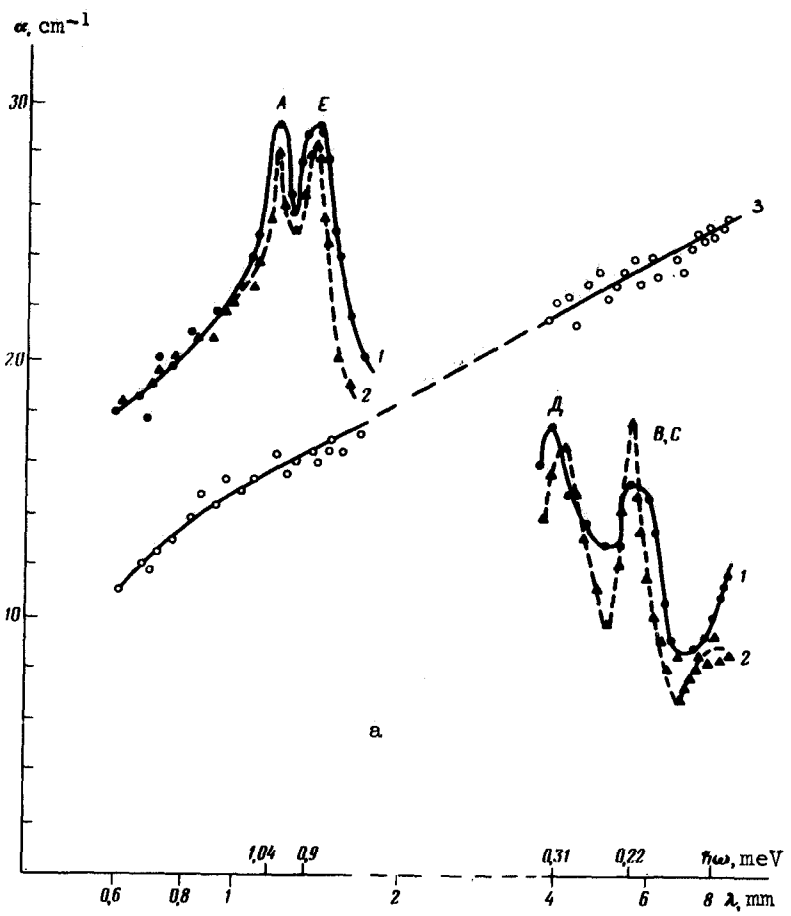

Fig. 1a. Absorption (α) vs. wavelength (λ) for sample 1. 1) T = 4.2°K, E = 0; 2) T = 1.6°K, E = 0; 3) T = 4.2°K, E > E_{imp}.

differ most in their degree of compensations are as follows: 1) $N_d = 1.2 \times 10^{14}$ cm^{-3}, K = 0.88, ε_1 = 1.0 meV; 2) $N_d = 1.4 \times 10^{14}$ cm^{-3}, K = 0.92, ε_1 = 2.0 meV. The values of N_d and K were obtained from the plot of the distribution of the impurities along the n-InSb ingot [3]; the impurity activation energy ε_1 was obtained from the temperature dependence of the resistivity $\rho(T)$. Certain results of the measurements are given below.

The measurement procedure is similar to that described in [4]. It should be noted that under the experimental conditions the sample is acted upon by background radiation of low intensity, produced by the warm part of the cryostat.

Figures 1a and 1b show plots of $\alpha(\lambda)$ of samples 1 and 2 in the ranges λ = 0.5 - 1.7 and 3.8 - 8.4 mm. Curves 1 and 2 on Figs. 1a and 1b correspond to measurements at 4.2 and 1.6°K, respectively, when no constant electric field is applied to the sample, i.e., for localized electrons. Curves 3 were obtained at values of E several times larger than the impurity breakdown field E_{imp} [5], i.e., for free electrons. We see that $\alpha(\lambda)$ decreases monotonically with decreasing λ in the case of the free electrons (curves 3). The plot of $\alpha(\lambda)$ for the localized electrons has four absorption peaks (A, B (C), D, E) for sample 1 and two peaks (A', B') for sample 2; the corresponding photon energies are indicated for the figure. We note that for peaks A and A' with the shortest wavelengths the values of $\hbar\omega$ are several times larger than the ionization energy of the isolated donor (ε_d = 0.67 meV) and are close to the values of ε_1 obtained from $\rho(T)$.

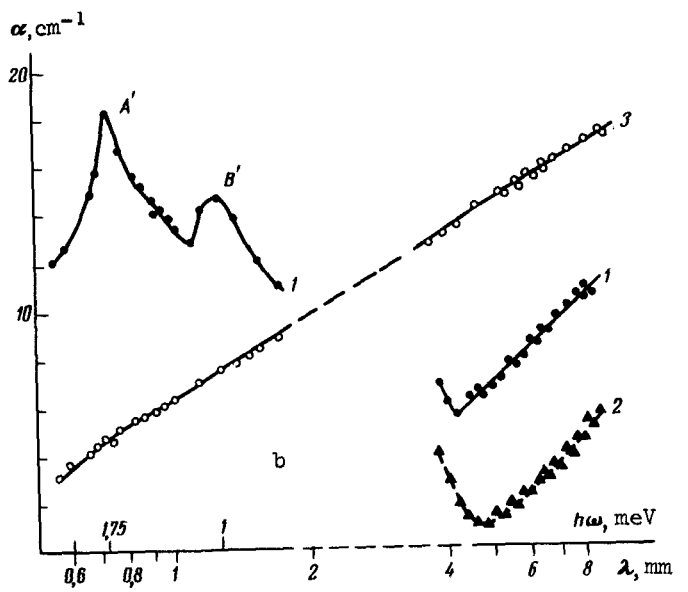

Fig. 1b

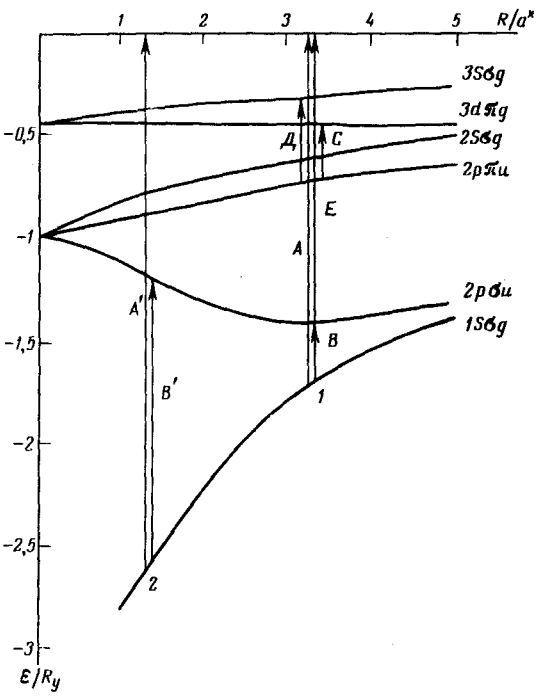

Fig. 2

Fig. 1b. Absorption (α) vs. wavelength (λ) for sample 2. 1) T = 4.2°K, E = 0; 2) T = 1.6°K, E = 0; 3) T = 4.2°K, E > E_{imp}.

Fig. 2. Energy levels of H_2^+ as functions of the distance between the charged donors.

Figure 2 shows several energy levels of H_2^+ plotted according to the data of [2], as functions of the distance between nuclei (charge donors) in units of the Bohr radius. The numbers and letters denote the following: 1, 2, 3... and s, p, d, f... are respectively the principal and orbital quantum numbers of the "combined" nuclei (donors) (helium atom [6]); σ, π, ... are the projections of the orbital angular momentum on the straight line joining the nuclei (donors) and equal 0, ± 1, ± 2...; the indices g and u denote even (g) or odd (u) parity of the coordinate function with respect to inversion of the midpoint between the nuclei.

We have assumed that the short-wave peaks (A and A') are connected with photoionization of the ground state $1s\sigma g$ [7], i.e., their energies are close to the energies $\varepsilon_{1s\sigma g}$. From the experimental energies of these peaks we determined the characteristic dimensions of the donor pairs: $R \equiv R_1 \simeq 3.3a^*$ in sample 1 and $R \equiv R_2 \simeq 3a^*$ in sample 2. We then determined from the data of [2] the states between which dipole transitions with energies close to those observed are possible at the obtained values of R_1 and R_2. The arrows on Fig. 2 show the transitions whose energies correspond to the experimental peaks A, B (C), D, E, and A', B'. For all the transitions, the experimental energies agree with those calculated from the data of [2] within 5 - 7%. We note that according to [8] the short-wave boundary of the photoionization cross section of H_2^+ is sharper than for the hydrogen-like atom. This apparently explains the relative narrowness of the peaks A and A'.

We note also that there are no other resolved peaks for sample 1 in the measured frequency band. For sample 1 we can have rather intense peaks corresponding to the transitions $1s\sigma g \to 3p\pi u$, $1s\sigma g \to 3d\pi g$, and $1s\sigma g \to 3p\pi u$ [2] with energies 1.4 - 1.2 meV, i.e., between the peaks A' and B' (see Fig. 1b). We were unable to resolve these peaks on the $\alpha(\lambda)$ plot.

Thus, a comparison of the energy levels and of the possible transitions for the molecular ion H_2^+ with the spectrum of absorption by localized electrons in compensated InSb shows that complexes of the H_2^+ type are apparently realizable. This is evidence of a surprising fact - the existence of "isolated" donor pairs with a definite characteristic distance between donors ($R \sim a^*$) in a compensated semiconductor with randomly disposed donors. We note that the presence of donor pairs (but with characteristic distance $R \gg a^*$) is one of the main premises of the theory of [1].

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