momenta of $X^0(\vec{k})$ and $\pi^+(\vec{q})$ in this system, ϕ is the angle between the planes $(\vec{k}, \vec{p}_{e^+})$ and $(\vec{k}, \vec{q})$, and $\Delta^2 = (\vec{p}_{e^+} + \vec{p}_{e^-})^2$.

If $J^P(X^0) = 2^-$, then the angular distribution $W(\theta, \phi, \gamma)$ depends little on the angles γ and ϕ. Thus, a study of the distribution $W(\theta, \phi, \gamma)$ makes it possible to determine the spin of the X^0 meson if the number of events is sufficiently large.

The dependence on the polarization of the γ quantum in the $X^0 \to \rho^0\gamma$ decay is different for the alternatives 2^- and 0^-. This fact could be used to determine the spin of X^0 were it possible to measure the polarization of the fast γ quantum. The possibility of determining the spin of X^0 is inherent also in the reaction $\gamma + p \to p + X^0$ on a polarized target.

A detailed analysis of the foregoing questions will be presented in an extensive article.

One can hope that accumulation of experimental data will make it possible to answer the important question of the quantum numbers of X^0 (960) meson in the nearest future.

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[1] Particle Data Group. Phys. Lett. 33B, 1 (1970).
[2] A.N. Zaslavskii, V.I. Ogievetskii, and W. Tybor, ZhETF Pis. Red. 6, 604 (1967) [JETP Lett. 6, 106 (1967)]; Yad. Fiz. 9, 852 (1969) [Sov. J. Nucl. Phys. 9, 498 (1969)].
[3] V.I. Ogievetsky, W. Tybor, and A.N. Zaslavsky, Preprint JINR, E2-5627, 1971, Dubna.
[4] Aachen - Berlin - Bonn - Hamburg - Munchen - Heidelberg Collaboration Phys. Rev. 175, 1669 (1968).
[5] V.A. Khoze and. A.N. Zaslavsky, Preprint YPI, 1971, Yerevan.
[6] V.A. Tsarev, Yad. Fiz. 10, 367 (1969) [Sov. J. Nucl. Phys. 10, 211 (1970)].
[7] W. Ash et al., Preprint LNF-69/6 (1969).

POSSIBILITY OF MULTIPLY-VALUED EQUILIBRIUM DISTRIBUTION OF THE CARRIERS IN MANY-VALLEY SEMICONDUCTORS

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We consider in this article, in the deformation-potential model, the effect exerted by a homogeneous deformation of the lattice, due to the free carriers, on the equilibrium distribution of the electrons over the equivalent valleys. If the concentration of the free carriers exceeds a certain critical value, then this deformation, which increases the elastic energy of the lattice, leads to a general lowering of the thermodynamic potential, connected with the decrease of the energy of the carriers in some of the valleys. As a result, the equilibrium distribution becomes multiply-valued[1)], i.e., there

[1)] The possibility of multiply-valued intervalley redistribution in a different situation (the multiply-valued Sasaki effect) was predicted in [1].

exist several stable electron distributions over the valleys ensuring a minimum of the thermodynamic potential; these distributions correspond to different values of the deformation tensor. The state in which all the valleys are equally populated turned out to be unstable, and the stable states are those characterized by predominant population of one or several valleys.

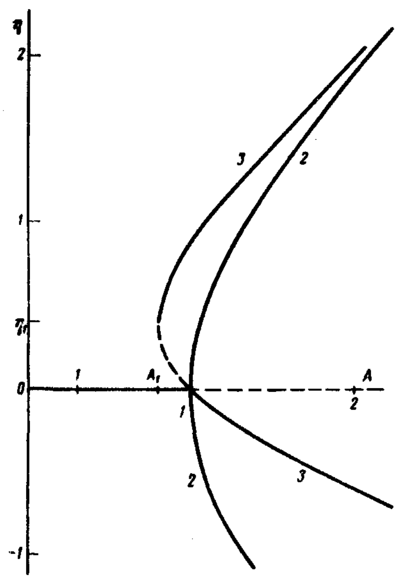
The density of the thermodynamic potential of a non-degenerate homogeneous monopolar semiconductor, in the case of complete ionization of the donors, for an arbitrary fixed deformation, is given by

$$F = \frac{1}{2}\lambda_{ijk\ell} u_{ij} u_{k\ell} + \sum_{r=1}^{\nu} b_{ij}^{(r)} u_{ij} n_r - T\sum_{r=1}^{\nu} \left(n_r - n_r \ln\frac{n_r}{n_{or}}\right), \tag{1}$$

where $\lambda_{ijk\ell}$, u_{ij}, and $b_{ij}^{(r)}$ are the components of the tensors of the elastic moduli, of the strain, and of the constants of the deformation potential; n_r is the concentration of the carriers in the r-th valley, n_{0r} is the concentration in the absence of strain, and ν is the number of valleys. The equilibrium condition, namely the minimum of F with respect to u_{ij} and n_r, in conjunction with the electroneutrality equation, leads to the following system of equations

$$\lambda_{ijk\ell} u_{k\ell} = NT\frac{\partial}{\partial u_{ij}} \ln\sum_{r=1}^{\nu} \exp\left(-\frac{b_{mn}^{(r)} u_{mn}}{T}\right), \tag{2}$$

where N is the total carrier concentration.



The stable solutions are represented by the solid lines and the unstable ones by the dashed lines.

Let us consider a many-valley cubic crystal such as n-Ge or n-Si, for which the tensor of the deformation potential is determined by the expression

$$b_{ij}^{(r)} = b_1\delta_{ij} + b_2 e_i^{(r)} e_j^{(r)}, \tag{3}$$

where $e^{(r)}$ is the unit vector directed in the valley r. We assume for n-Ge the following numbering of the valleys (the coordinate axes xyz are directed along the crystallographic four-fold axes): 1 - [111], 2 - [$\bar{1}$11], 3 - [$\bar{1}\bar{1}$1], 4 - [1$\bar{1}$1]. From the system [2] there are separated equations for the diagonal components u_{ik}, and the latter do not depend on the distribution of the electrons over the valleys:

$$u_o = u_{xx} = u_{yy} = u_{zz} = -\frac{N(b_1 + \frac{1}{3}b_2)}{\lambda_2 + 2\lambda_2}$$

($\lambda_1 = \lambda_{xxxx}$, $\lambda_2 = \lambda_{xxyy}$, $\lambda_3 = \lambda_{xyxy}$). The equations for the nondiagonal components of the deformation tensor have, besides the trivial solution $u_{xy} = u_{zy} = u_{zx} = 0$, corresponding to the state of a semiconductor with equal population of the valleys, two other types of solutions: a) in the triply degenerate solutions of the first type, one non-diagonal component differs from zero, for example, $u_{xy} \lessgtr 0$, $u_{yz} = u_{zx} = 0$; $n_1 = n_3 \gtrless n_2 = n_4$. We put $u_{xy} = (3T/2b_2)\eta$ and $A = Nb_2^2/9\lambda_3 T$. The dependence of η on the parameter A is shown in the figure (curves 1 and 2). When $A < 1$ the only (stable) solution is the trivial solution $\eta = 0$, $n_1 = n_2 = n_3 = n_4$. When $A > 1$ there exist three solutions: the trivial one, which becomes unstable now, and two stable solutions (curve 2); the solution $\eta > 0$ corresponds to the non-uniform distribution $n_1 = n_3 < n_2 = n_4$, and for $\eta < 0$ we have $n_1 = n_3 > n_2 = n_4$. b) In the fourfold-degenerate solutions of the second type, all the non-diagonal components of the deformation tensor are not equal to zero and can differ only in signs. The dependence of η on A for the solution $u_{xy} = u_{zy} = -u_{zx}$ is shown in the figure by curves 1 and 3. There are two critical points here, (0, 1) and (η_1, A_1). Up to the point A_1 there exists only the trivial solution. At $A = A_1 < 1$ there appears jumpwise one more stable solution, corresponding to the distribution $n_4 > n_1 = n_2 = n_3$ (the section $\eta > \eta_1 > 0$ on curve 3). When $A > 1$ the trivial solution is unstable, and the solution corresponding on branch 3 to the section $\eta < 0$, $n_4 < n_1 = n_2 = n_3$ becomes stable. An investigation of the thermodynamic potential shows that when $A > A_1 = 0.8$ the lowest minimum is realized for the distribution corresponding to the position of one of the valleys and to an increase of the remaining three sections $\eta > \eta_1$ on curve 3. When $b_2 = 20$ eV, $\lambda_3 = 0.5 \times 10^{12}$ dyne/cm, and $T = 100$°K the critical value of $A = A_1$ is reached at $N = 4.8 \times 10^{19}$ cm^{-3}.

We denote by n_1, n_2, and n_3, respectively, the concentration of the electrons in the valleys lying on the axes x, y, and z in n-Si. From (2) and (3) it follows that all the components of u_{ij} at $i \neq j$ are equal to zero. For the diagonal components, besides the trivial solution, there exist triply degenerate solutions, corresponding to the identical filling of any two pairs of valleys as a result of the depletion or enrichment of the remaining third pair. Let us consider for concreteness the solution $u_{xx} = u_{zz}$, $u_{xx} - u_{yy} \gtrless 0$, $n_2 \gtrless n_1 = n_3$. If we put $u_{xx} - u_{yy} = (T/b_2)\eta$ and $A = Nb_2^2/3T(\lambda_1 - \lambda_2)$ then, as follows from (2), $u_{xx} = u_{zz} = -u_0 + (T/3b_2)\eta$, and the qualitative form of the dependence of η on A is the same as in the figure (curves 1 and 3). In this case the section of the branch 3, for which $\eta > \eta_1$, corresponds to the distribution $n_2 > n_1 = n_3$, and the stable part of the branch 3 with $\eta < 0$ corresponds to $n_2 < n_1 = n_3$. Stable non-uniform distributions of the electrons over the valleys correspond to uniaxial shear deformation.

The considered effect takes place also if the electron gas is degenerate; in the case of strong degeneracy, it is necessary to replace T in the critical parameter A by $2\varepsilon_F/3$.

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[1] Z.S. Gribnikov, V.A. Kochelap and V.V. Mitin, Zh. Eksp. Teor. Fiz. 59, 1828 (1970) [Sov. Phys.-JETP 32, 991 (1971)].