final states and to the positron and electron; ω_1, ω_2, ϵ_+, and ϵ_- are the corresponding energies.

For high energies of all the particles involved in the process the differential cross section $d\sigma_2$ has a sharp maximum near the direction of the momentum of the incident neutrino. All of the emerging particles are concentrated in a narrow cone around this direction, with angular aperture $\vartheta \approx m/\omega_1$. This follows from the fact that the denominator of the expression (2) contains the factor

$$[\omega_1\omega_2(1-\cos\vartheta_{12})+\omega_1\varepsilon_+(1-v_+\cos\vartheta_{1+}) - \omega_2\varepsilon_+(1-v_+\cos\vartheta_{2+})]$$

(ϑ_{ik} is the angle between the momenta of the i-th and k-th particles, and v_+ is the velocity of the positron), together with the fact that the effective recoil momentum of the nucleus is $q \sim m$.

The reduction of the "effective" solid angle sharply lowers the degree of the energy dependence of the total cross section. Apart from terms of second order in m/ω_1 the total cross section is

$$\sigma_2 = \frac{8g^2(Ze^2)^2\omega_1^2}{3(2\pi)^3}\alpha\left(\ln\frac{\omega_1}{m}-\beta\right), \qquad \omega_1 \gg m, \tag{3}$$

where $\alpha, \beta \sim 1$; $1 < \beta < 2$. Comparison of Eqs. (1) and (3) shows that for $Z/137 \approx 1/2$ the cross section σ_2 becomes comparable with σ_1 only for incident neutrino energy $\omega_1 \approx 10$ Mev. It is only at energies higher than this that the process of production of an electron-positron pair may become observable.

The writers express their gratitude to Ya. A. Smorodinskiĭ for his interest in this work and for a discussion of the results.

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[1] C. L. Cowan, Jr. and F. Reines, Phys. Rev. **107**, 528 (1957).

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INSTABILITY IN A SEMICONDUCTOR AMPLIFIER WITH NEGATIVE EFFECTIVE CARRIER MASS

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KRÖMER has shown[1] that a crystal of germanium or silicon, of the p type, in which there exists a strong field in the [100] direction ("longitudinal" direction), will have in any direction perpendicular to the [100] ("transverse directions") a negative conductivity. The use of this negative conductivity for amplification and generation is precisely the idea of the new semiconductor instrument proposed by Krömer, the NEMAG (negative effective mass amplifier and generator).

This device differs from diodes with negative conductivity (for example, tunnel or parametric) in that its negative conductivity is specific. This circumstance leads to an unstable operating state of the device, as can be seen from the following consideration. Assume that in a certain microvolume, the thermal fluctuations of the hole concentrations result in an accumulation of a small positive charge. Then the field produced by this charge causes in the surrounding medium a current flowing not from the charge (as in the case of positive specific conductivity) but to the charge (more accurately, to the [100] line, passing through the charge). The charge will start increasing exponentially with a time constant called the time of dielectric relaxation ($\tau = |\epsilon\rho|$ where ϵ is the dielectric constant and ρ the negative specific resistivity of the semiconductor) and this process will slow down and cease only when a transverse field E_t is produced strong enough to make the conductivity in it positive (a negative conductivity is observed only at sufficiently small transverse fields).

An analogous process leads to the formation of a negative charge (region where the concentration of the holes is less than the concentration of the charged impurity centers — acceptors), if the initial fluctuation reduces the concentration of the holes compared with the equilibrium value.

In the stationary state the charge is arranged around the [100] axis with a density that decreases with the distance from this axis. The state with negative conductivity (weak transverse field) is retained only in a thin cylinder about this axis, and the finite thickness of the cylinder is determined only by the diffusion loss of holes, and amounts to a fraction of a micron (of the order or less than kT/eE_t). Such cylinders are attracted to each other when their charges are of the same polarity, and are repelled when they are different, and consequently, as can be shown, the distances between the cylinders in the state of stable equilibrium are of the same order as or greater than the thickness of the crystal in the transverse direction. But this thickness is always much greater than the thickness of the cylinder and furthermore the lineary density of the charge in the cylinder is negligible (on the order of $kT/2$); therefore the contribution of the cylinders to the total conductivity of the crystal is negligibly small. This conductivity will be determined essentially by the conductivity of the regions with strong transverse field (the region of the crystal outside the cylinders), i.e., it will be positive.

It may turn out that the qualitative considerations given by us clearly refute the idea of using the negative effective mass for amplification and generation. This is not so, however. Let us consider the NEMAG to be a carrier-poor layer, produced in a reverse-biased junction,* in which we introduce holes one by one at time intervals greater than the travel time of the holes. Clearly in such an instrument there will be no transverse field produced and its action will obey in its entirety the Krömer theory. Naturally, in order for the device to have resistance, the hole need not be alone; one merely needs a sufficiently small number of holes. In terms of the phenomenological theory, this condition will be formulated as follows: the negative specific conductivity should be so small, and the length of the device in the longitudinal direction should be so short, that the time of the dielectric relaxation be greater than, or at least of the same order as the travel time of the carrier through the entire device. The point is that since the positive electrode producing the longitudinal field is an equipotential surface (the field is perpendicular to the surface), it causes the material to have a negative conductivity. The process of charge formation and the formation of the transverse field requires a finite time, equal to several times the dielectric relaxation time. But simultaneously with accumulation of charge, the charges are carried away by drift motion towards the negative electrode and leave the device. The meaning of the requirement formulated above is that the device can have a negative conductivity only when the process of formation of the transverse field has not yet a chance to be completed and the charges formed have already drifted out from the instrument. It is possible to obtain negative conductivity without limitations on the lengths of the structure by operating in the pulsed mode.

Thus, although the possibility of using the negative effective mass is not completely eliminated by the appearance of instability, it is considerably restricted, and the idea of the device loses a considerable portion of its attractiveness. Probably the NEMAG as an amplifier will be a highly noisy device (in contrast to what Krömer predicts), since the initial stage of the process of charge formation should be subject to very strong fluctuations. On the other hand, small negative conductivities and short structures, which are required for continuous operation, necessitate a large value of RC (on the order of the time of flight) and a small thickness of the device. One should indicate that the device could be used as a noise generator.

Although all the foregoing is in the nature of rough qualitative ideas, they indicate undoubtedly that the distribution of the charges and fields in this device, and also its properties, will be much more complicated than proposed by Krömer's theory.

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*I.e., in the double charge layer of the donor and acceptor impurities, which are formed around the junction (separation boundary) between the regions of the semiconductor with n and p conductivities, when a reverse voltage is applied to the semi-conductor: plus to the electron region and minus to the hole region.

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[1] H. Krömer, Proc. IRE **47**, 231 (1959).

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