ure a nuclear spin relaxation time in a paramagnetic crystal. The measurement was made on the protons in the water of crystallization of $Ce_2Mg_3(NO_3)_{12} \cdot 24H_2O$ at 0.086°K.[3] It was impossible to achieve saturation, and only an upper bound on the relaxation time was obtained: $T_1 < 32$ sec. A rough estimate using formula (2) yields $T_1 \approx 10^{-1}$ sec. The estimate is rough because $g_{\|} = 0.25$ for the Ce^{3+} ion[4] and the condition $2g_{\|}\beta H \gg kT$ is poorly fulfilled. This result does not contradict the experimental one.

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[1] N. N. Bogolyubov, Лекции по квантовой статистике (Lectures on Quantum Statistics) Kiev, 1949.

[2] J. H. Van Vleck, Phys. Rev. **74**, 1168 (1948).

[3] Estle, Hart, and Wheatley, Phys. Rev. **112**, 1576 (1958).

[4] K. D. Bowers and J. Owen, Reports on Progress in Physics **18**, 304 (1955).

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SEMICONDUCTOR AMPLIFIERS AND GENERATORS WITH CARRIERS HAVING NEGATIVE EFFECTIVE MASS

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KRÖMER[1] proposed the use of the negative effective mass of carriers in a semiconductor for the amplification and generation of electromagnetic waves, for when such carriers move in a field they give up their energy to the field interacting with them, i.e., they possess negative losses. To obtain such states, the use of a constant electric field is proposed.

In the present communication we shall show that it is impossible to obtain a state with negative losses by using a constant electric field in a semiconductor.

In fact, negative losses mean that, at least for some ϵ_1 and ϵ_2 ($\epsilon_2 > \epsilon_1$), the following condition is fulfilled:

$$wf(\varepsilon_2)[1-f(\varepsilon_1)]\,n(\hbar\omega) - wf(\varepsilon_1)[1-f(\varepsilon_2)]\,n(\hbar\omega) = wn(\hbar\omega)\{f(\varepsilon_2)-f(\varepsilon_1)\} > 0, \quad (1)$$

where $f(\epsilon)$ is the distribution function for electrons, $n(\hbar\omega)$ is the number of photons of energy $\hbar\omega = \epsilon_2 - \epsilon_1$, and w is the probability of spontaneous emission. We do not consider spontaneous transitions, since they are not relevant to the process of amplification. From (1) it follows that at least at some points in the interval $\epsilon_2 - \epsilon_1$, $\partial f(\epsilon)/\partial\epsilon > 0$ should hold. At thermodynamic equilibrium, $\partial f/\partial\epsilon < 0$ always holds for any ϵ, independently of the type of distribution of the particles, and consequently amplification is impossible.

The creation of a semiconductor amplifier or generator using the effect of negative losses should be considered from the viewpoint of the possible destruction of thermodynamic equilibrium and the attainment of states with $\partial f/\partial\epsilon > 0$ in some interval of energy. However, in the steady state in a constant electric field E, as assumed by Krömer,[1] it is impossible to obtain such states for a semiconductor, as direct calculation shows.[2-5] The distribution functions found up to the highest values of fields, have $\partial f(\epsilon, E)/\partial\epsilon < 0$ for all values of ϵ [$\partial f(\epsilon, E)/\partial\epsilon \to 0$ as $E \to \infty$]. In very strong fields when the processes of electron scattering at lattice phonons are unimportant, it is also impossible to obtain an amplifying state, even if impact ionization and the Zener effect are ignored. In this case the electron will oscillate periodically between the upper and lower edges of the permitted band, so that electron states with positive and negative masses are equally probable.

Everything that has been said above can be generalized directly to the case of an anisotropic band in which, for some values of the quasi-momentum **p**, some components of the tensor-effective mass are negative; here, too, it is impossible to have $\partial f/\partial\epsilon > 0$ in a constant electric field, since in semiconductors the constants of interaction with acoustical and optical phonons are of the same order of magnitude.

Thus, to create semiconducting systems with negative losses, it is necessary to obtain a state with negative temperature, where $\partial f/\partial\epsilon > 0$. Such states can in principle be attained by excitation of the electrons with sufficiently powerful monochromatic radiation, causing transitions between the levels of one band or different bands using a pulsed system or a steady state system, as in molecular generators and amplifiers, or using pulsed excitation by an electric field.[6]

We note that to obtain a negative temperature using a pulsed electric field, it is expedient to use interband transitions of electrons, and not transitions inside a single band, since the time for which negative temperatures exist is much shorter in the latter case.

[1] H. Krömer, Proc. I.R.E. **47**, 397 (1959); Phys. Rev. **109**, 1856 (1958).

[2] B. I. Davydov, JETP **7**, 1068 (1937).

[3] I. Yamashita and M. Watanabe, Progr. Theor. Phys. 12, 443 (1954).

[4] R. Stratton, Proc. Roy. Soc. **A242**, 355 (1957).

[5] L. V. Keldysh, JETP **37**, 713 (1959).

[6] Basov, Vul, and Popov, JETP **37**, 587 (1959), Soviet Phys. JETP **10**, 416 (1960).

Translated by K. F. Hulme
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ON POSSIBLE PROPERTIES OF D^0 MESONS

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In connection with the communication on the D^+ meson,[1] various "peculiar" decays of unstable particles,[2] which were observed in the past, are being reanalyzed.[2] An opinion becoming prevalent is that the D^+ meson, and in accordance with presently popular systematics of elementary particles (e.g., the Gell-Mann-Nishijima scheme[3]) also the D^- meson, exist, have a mass of 742 ± 20 Mev, decay according to the scheme

$$D^{\pm} \rightarrow K + \pi + Q, \tag{1}$$

and are particles of strangeness ± 2. Thus from among all the bosons of the Gell-Mann-Nishijima scheme only the ρ_0 meson has not been detected experimentally.

In the notation of the Salam-Polkinghorne scheme[4]

$$Q/e = \tau_3 + \mu_3 \tag{2}$$

(Q — magnitude of electric charge, τ_3 corresponds to the isospin and μ_3 to the strangeness) the $D^{\pm}$ mesons are described by $\tau_3 = 0$ and $\mu_3 = \pm 1$. If we also include $\tau_3 = 0$ and $\mu_3 = 0$ here, we obtain a triplet D^+, D^0, D^- which may be viewed as a vector in μ-isospace. Consequently the suggestion occurs that this group of isotopic singlets may have similar properties. If such a view were to be accepted then the D^0 meson would also have a mass of the order of the mass of the charged D mesons, and decay according to the scheme

$$D^0 \rightarrow K^{\pm 0} + \pi^{\mp 0}. \tag{3}$$

We wish to call attention to the communications existing in the literature on the decay of neutral particles according to the scheme

$$V_3^0 \rightarrow K^{\pm} + \pi^{\mp} \tag{4}$$

with $m(V_3^0) \approx 650 - 700$ Mev.[5] Thus there are indications that a neutral unstable particle exists with a mass and a mode of decay analogous to the characteristics of the $D^{\pm}$ mesons. If we identify the V_3^0 particle with the above indicated D^0 meson, we come to the conclusion that an isotopic singlet D^0 meson exists with strangeness $S = 0$ which, although it could formally undergo a fast decay into π mesons satisfying the condition $\Delta S = 0$,[6] decays slowly into decay products with strangeness ± 1. However this conclusion contradicts the premises on which the indicated systematics are based unless fast decays of the type $\Sigma^0 \rightarrow \Lambda^0 + \gamma$ and $D^0 \rightarrow n\pi$ are somehow forbidden.

The most convenient method for production of such D^0 mesons would be from reactions of the type

$$\pi^- + p \rightarrow n + D^0, \tag{5}$$

and also from photoproduction of the type studied by Bernardini et al.[7]

We have analyzed over 50 "anomalous" V^0 events detected at various times in cosmic ray experiments.[8] We obtained the following results: 1) no neutral meson exists with a mass of the order of 750 Mev and a decay mode (3); 2) the published anomalous V^0 events are more likely evidence for the existence of two neutral cascade mesons D_1^0 and D_2^0 with the above indicated decay mode (3) with $Q_1 = 38$ Mev and $Q_2 = 63$ Mev; 3) the flux of these mesons amounts to $1 - 2\%$ of the flux of Λ^0 and θ^0 particles (there were approximately 30 of them among the 50 "anomalous" V^0 events); 4) the decays of both D_1^0 and D_2^0 through the two channels $K^+ + \pi^-$ and $K^- + \pi^+$ are in the ratio of 1 : 1.

In connection with the questions discussed here it would be of interest to check the data obtained with bubble chambers irradiated with π-meson beams with momenta in excess of 1 Bev/c. The purpose of this check would be a systematic search