SPONTANEOUS EXCITATION OF ELECTROMAGNETIC OSCILLATIONS AT A FREQUENCY ON THE ORDER OF SEVERAL Hz

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It is known that a state with a temperature gradient ∇T in highly-conducting crystals can become unstable at sufficiently low temperatures (below that of liquid hydrogen) [1-3]. This is accompanied by the appearance of growing almost-purely-magnetic (and therefore almost-transverse) waves, called thermomagnetic. In crystals of high symmetry (cubic, hexagonal, tetragonal) the state with a temperature gradient is unstable only in the presence of an external magnetic field in the interval

$$\left|\frac{\nabla T_{cr}}{\nabla T}\right|\frac{c}{\mu} < H < \frac{c}{\mu}\left|\frac{\nabla T}{\nabla T_{cr}}\right|, \tag{1}$$

with

$$|\ T_{cr}| = \frac{c}{4\pi\sigma\,|\alpha_1|\,L}.$$

Here σ - conductivity, α_1 - Nernst coefficient, μ - carrier mobility, c - speed of light, L - linear dimensions of the crystal. The necessary temperature drop is minimal and approximately equals $\Delta T_{cr} = |\nabla T_{cr}|L$ at $H \approx c/\mu$. In anisotropic crystals with trigonal, rhombic, or lower symmetry, the state with ∇T is unstable also in the absence of an external magnetic field, if ∇T is not perpendicular to any of the twofold axes. The feasibility of extracting the generated oscillations to an external circuit was demonstrated in [2].

The purpose of the present communication is to show that thermomagnetic excitation of the oscillations is possible in a large number of metals and that oscillations with a frequency on the order of several Hz can be generated in this case.

At a relative temperature drop $\Delta T/T > \Delta T_{cr}/T$, waves of frequency $\omega \approx c\alpha_1|\nabla T|1/L$ are generated.

The Nernst coefficient of Sb with residual conductivity $\sigma = 10^{20}$ abs [4] is unknown. Estimating it by means of the formula $\alpha_1 \approx (\mu/e)(T/\epsilon_F)\gamma$ (ϵ_F - Fermi energy, γ - coefficient taking into account the increase of α_1 as a result of dragging of the electrons by the phonons) and assuming that [5] the coefficient of phonon dragging at helium temperature is $\gamma \approx 100$, we obtain $\omega \approx 15$ Hz for the oscillation frequency and $\Delta T_{cr} = 0.4°$ for the critical drop.

In Cu with 0.01% Fe, the thermal emf at helium temperature, according to [6], is $\alpha \approx 2\mu V/deg$ (effect of anomalous impurity scattering), and the conductivity is $\sigma \approx 10^{21}$ abs. Then

$$\alpha_1 \approx \alpha\frac{\mu}{c} \approx 4\times 10^{-3}\ \mu V/Oe\cdot deg,$$

$\omega \approx 3$ Hz, and $\Delta T_{cr}/T \approx 0.1$. The magnetic field required as a result of the cubic symmetry of the copper is H ≈ 0e. The anomalous impurity scattering apparently makes possible an instability of states with temperature gradient in other metals of the first group, too (Ag, Au).

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HOT ELECTRONS IN CROSSED ELECTRIC AND QUANTIZING MAGNETIC FIELDS

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Even in a fairly weak field, carrier heating may cause the effective temperature[1)] T* in a semiconductor to exceed greatly the temperature of the thermostat [1], which equals the lattice temperature[2)] T. The energy received by the electrons from the electric field is first transferred to the long-wave phonons (LP) (for only they interact with the electrons), from which it is subsequently transferred to the short-wave thermal phonons (TP). If the frequency of the collisions between the LF and the electrons, τ_{pe}^{-1}, is much smaller than the frequency τ_{pp}^{-1} of collision between the LP and the TP, then the LP have practically the same temperature T* as the electrons, and the energy relaxation process is limited by the frequency τ_{pp}^{-1} (the phonon "bottleneck" effect). When $\tau_{pe}^{-1} \ll \tau_{pp}^{-1}$, the LP have the same temperature as the TP (the thermostat) and the rate of energy relaxation is limited by the value of τ_{pe}^{-1}. We wish to call attention in this paper to an experimental possibility of varying, in a wide range, the ratio of τ_{pe}^{-1} and τ_{pp}^{-1} with the aid of a quantizing magnetic field. We shall consider the heating of electrons in orthogonal fields, and electric field E_x and a quantizing magnetic field $\vec{H}$. The temperature of the "hot electrons" T* is usually calculated from the energy-balance equation by equating the Joule power W to the power P_{ep} obtained by the phonons from the electrons. If the samples are bounded and $\Omega\tau \gg 1$ ($\Omega = |e|H/mc$ - carrier cyclotron frequency and τ - their momentum relaxation time), it becomes necessary to take into account the contribution of the Hall field to W, since it exceeds the external applied field by a factor $(\Omega\tau)$.[3)] We shall assume that the work performed by the electric field (including the Hall field) when the electron is displaced a distance $\sim \ell = \sqrt{ch/|e|H}$ (ℓ - magnetic length, or in our case the quantum Larmor radius) during the course of scattering is small compared with the

[1)]This concept can be used only when the frequency of the inter-electron collisions is the highest among the characteristic frequencies of the problem.

[2)]The sample is assumed to be small enough to neglect the change in the total phonon energy resulting from the heating of the electrons.

[3)]The Hall field was not taken into account in [2, 3], and therefore the results obtained there hold for bounded samples only when the electron and hole densities are equal, and possibly also in special devices such as the Corbino disc.