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LONGITUDINAL AND TRANSVERSE THERMOMAGNETIC WAVES IN ANISOTROPIC CONDUCTING MEDIA

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In this paper, the conditions for the excitation of thermomagnetic waves are theoretically investigated. It is shown that, depending on the value of the electrical conductivity tensor, thermomagnetic waves are excited in the longitudinal and transverse directions. It is proved that the excited wave is mainly of a thermomagnetic nature. In theory, the resulting dispersion equation is algebraically high powers with respect to the oscillation frequency. It is proved that if the value of the electrical conductivity tensor is the same, then the frequency of propagation of thermomagnetic waves is different.

It was proved in (L.E. Gurevich "Plasma theory", Development of physics in the USSR. ZhETF, vol. 44, no. 1, p. 166, 1963, Moscow, Russia, L.E. Gurevich, E.R. Gasanov, Theory of spontaneous oscillations of current in crystals of the type of germanium doped with gold, FTP vol. 3, N8, pp. 1201-1206, 1969, St. Petersburg, Russia)that hydrodynamic motions in a plasma, in which there is a constant temperature gradient, a magnetic field arises. In this case, the plasma has oscillatory properties that are noticeably different from ordinary plasma. In such a plasma, thermomagnetic waves are excited, in which only the magnetic field oscillates. In the presence of an external magnetic field, the wave vector of thermomagnetic waves is perpendicular to the magnetic field or lies in the plane $\vec{H}, \vec{\nabla} T$

The speed of thermomagnetic waves is comparable to the speed of sound and the speed of the Alfven wave. The temperature gradient is independent of time and coordinates. The Larmor frequency of charge carriers is less than the frequency of their collisions, i.e.

$$\psi\tau << 1 \qquad \psi = \frac{eH}{mc}$$

THEORY

$$\vec{E} = \xi\vec{j} + \xi''\left[j\vec{H}\right] + \xi''\left(\vec{j}\vec{H}\right)\vec{H} + \mathrm{K}\frac{\partial T}{\partial x} + \mathrm{K}'\left[\vec{\nabla}T\vec{H}\right] + \mathrm{K}''\left(\vec{\nabla}T\vec{H}\right)\vec{H}$$

$$E_i = \xi_{ik} j'_k + \left[j\vec{H}\right]_k j'_{ik} + \xi''_{ik}\left(\vec{j}\vec{H}\right)\vec{H}_k + \mathrm{K}_{ik}\frac{\partial T}{\partial x_k} + \mathrm{K}'_{ik}\left[\vec{\nabla}T\vec{H}\right]_k + \mathrm{K}''_{ik}\left(\vec{\nabla}T\vec{H}\right)\vec{H}_k$$

$$E'_i = \xi_{ik} j'_k + \mathrm{K}'_{ik}\left[\vec{\nabla}TH\right]_k$$

$$rot\vec{E}' = -\frac{1}{c}\frac{\partial \vec{H}'}{\partial t}$$

$$rot\vec{H}' = \frac{4\pi}{c}\vec{j}' + \frac{1}{c}\frac{\partial \vec{E}'}{\partial t}$$

$$E'_i = \xi_{ik} j'_k + \mathrm{K}'_{ik}\left[\vec{\nabla}TH\right]_k$$

$$j' = \frac{ic^2}{4\pi\varpi}\left[\vec{k}\left[\vec{k}\vec{E}'\right]\right] + \frac{i\varpi}{4\pi}E'_{ik}$$

$$E'_i = \frac{ic^2}{4\pi\varpi}\xi_{ik}\left(\vec{k}\vec{E}'\right)\Lambda_k + \frac{i\left(\varpi^2 - c^2k^2\right)}{4\pi\varpi}\xi_{ik}E'_k + $$
$$+ \frac{c\mathrm{K}'_{ik}}{\varpi}\left(\vec{\nabla}T\vec{E}'\right)\Lambda_k - \frac{c\mathrm{K}'_{ik}}{\varpi}\left(\vec{k}\vec{\nabla}T\right)E'_k$$

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A.N. Novruzov, E.R. Hasanov, “Thermomagnetic waves in impurity semiconductors”, AMEA, Fizika İnstitutu, “Fizika”, No. 1-2, cild XIII, pp.134-136. 2007, Baku, Azerbaijan.

Transverse thermomagnetic waves $\vec{k}\perp\vec{\nabla}T$

$$k_1\neq 0, k_2=k_3=0, k_1\frac{\partial T}{\partial x_1}=\left(\vec{k}\vec{\nabla}T\right)=0,$$

$$\frac{\partial T}{\partial x_2}\neq 0, \frac{\partial T}{\partial x_3}=0$$

$$E'_i=\left(C\xi_{il}k_lk_k+D\varsigma_{ik}+\frac{c\mathrm{K}'_{ik}}{\varpi}k_l\frac{\partial T}{\partial x_k}\right)E'_k$$

$$E'_i=\delta_{ik}E'_k, \delta_{ik}=\begin{cases}1, npu\ \ i=k\\ 0, npu\ \ i\neq k\end{cases}$$

$$C=\frac{ic^2}{4\pi\varpi}, D=\frac{i\left(\varpi^2-c^2k^2\right)}{4\pi\varpi}$$

$$\varphi_{ik}=C\xi_{il}k_lk_k+D\varsigma_{ik}+\frac{c\mathrm{K}'_{il}}{\varpi}k_l\frac{\partial T}{\partial x_k}$$

$$\psi_{11}=\frac{i\varpi}{4\pi}\varsigma_{11}, \psi_{12}=i\eta\varsigma_{12}+\frac{\varpi_{12}}{\varpi},$$

$$\psi_{13}=i\eta\varsigma_{13}, \eta=\frac{\varpi^2-c^2k^2}{4\pi\varpi}$$

$$\psi_{21}=\frac{i\varpi}{4\pi}\eta_{21}, \varphi_{22}=i\eta\xi_{22}+\frac{\varpi_{22}}{\varpi},$$

$$\psi_{23}=i\eta\xi_{23}$$

$$\psi_{31}=\frac{i\varpi}{4\pi}\xi_{31}, \psi_{32}=i\eta\xi_{32}+\frac{\varpi_{32}}{\varpi},$$

$$\psi_{33}=i\eta\xi_{33}$$

$$\psi_{31}\psi_{12}\psi_{23}+\psi_{21}\psi_{32}\psi_{13}+(\psi_{11}-1)(\psi_{22}-1)(\psi_{33}-1)-\psi_{31}\psi_{13}(\psi_{22}-1)-\psi_{32}\psi_{23}(\psi_{11}-1)-\psi_{21}\psi_{12}(\psi_{33}-1)=0$$

$$\sum_{i=1}^{5}u_i\varpi_i+u_0=0$$

$$\xi_{12}=\xi_{13}=\xi_{22}=\xi_{23}=\xi_{32}=\xi_{33}$$

$$\xi_{11}=\xi_{21}=\xi_{31}$$

$$\frac{1}{2\pi}\left(\frac{i\xi_{11}}{2}+\xi_{22}\right)\varpi^2+\left[\frac{i\xi_{11}}{4\pi}(\varpi_{13}+\varpi_{12}-\varpi_{22})-1\right]\varpi+\varpi_{22}+\varpi_{33}-\frac{ic^2k^2}{2\pi}\xi_{22}=0$$

$$\varpi=\varpi_0+i\phi, \qquad \phi<<\varpi_0$$

$$\frac{1}{2\pi}\xi\varpi_0^2-\frac{1}{4\pi}\xi\varpi_0\phi-\frac{\xi}{4\pi}(\varpi_{13}+\varpi_{12}-\varpi_{22})\phi-\varpi_0+\varpi_{22}+\varpi_{33}=0$$

$$\frac{1}{4\pi}\xi\varpi_0^2+\frac{1}{2\pi}\xi\varpi_0\gamma+\frac{\xi}{4\pi}(\varpi_{13}+\varpi_{12}-\varpi_{22})\varpi_0-\phi-\frac{c^2k^2\xi}{2\pi}=0$$

Longitudinal thermomagnetic wave $\vec{k} \parallel \vec{\nabla} T$

$$k_2 = k_3 = 0, \quad k_1 = k$$

$$\frac{\partial T}{\partial x_2} = \frac{\partial T}{\partial x_3} = 0, k_1 \frac{\partial T}{\partial x_1} \neq 0$$

$$\frac{\partial T}{\partial x_2} \neq 0, \quad \frac{\partial T}{\partial x_3} = 0$$

$$\psi_{11} = \frac{i\varpi}{4\pi}\xi_{11}, \psi_{12} = i\eta\xi_{12} + \frac{\varpi_{12}}{\varpi},$$

$$\psi_{13} = i\eta\xi_{13} + \frac{\varpi_{13}}{\varpi}$$

$$\psi_{21} = \frac{i\varpi}{4\pi}\xi_{21}, \psi_{22} = i\eta\xi_{22} + \frac{\varpi_{22}}{\varpi},$$

$$\psi_{23} = i\eta\xi_{23} + \frac{\varpi_{23}}{\varpi}$$

$$\psi_{31} = \frac{i\varpi}{4\pi}\xi_{31}, \phi_{32} = i\eta\xi_{32} + \frac{\varpi_{32}}{\varpi},$$

$$\phi_{33} = i\eta\xi_{33} + \frac{\varpi_{33}}{\varpi}$$

$$x^4 + 16\pi i x^3 + \left(-48\pi^2 + 12\pi i \varpi_{22}\xi\right)x^2 + 64\pi^3 i\left(-1 + i\frac{\varpi_{22}\xi}{2\pi}\right)x - \varpi_{22}\xi = 0, x = \xi\varpi, ck\xi << 1$$

$$x_0^4 - 48\pi x_0^2 x_1 - 48\pi^2 x_0^2 - 24\pi\varpi_{22}\xi x_0 x_1 + 64\pi^3\frac{\varpi_{22}\xi}{2\pi}x_0 + 64\pi^3 x_1 - \varpi_{22}\xi = 0$$

$$4x_0^3 x_1 + 16\pi x_0^3 - 96\pi^2 x_0 x_1 + 12\pi\varpi_{22}\xi x_0^2 - 64\pi^3 x_0 - 32\pi^2\varpi_{22}\xi x_1 = 0$$

$$-24\pi\varpi_{22}\xi x_0 x_1 + 32\pi^2\varpi_{22}\xi x_0 + 64\pi^3 x_1 - \varpi_{22}\xi = 0 \qquad -96\pi^2 x_0 x_1 - 64\pi^3 x_0 - 32\pi^2\varpi_{22}\xi x_1 = 0$$

$$-\frac{i}{64\pi^3}\left(\xi_{31}\xi_{21}\xi_{23} + \xi_{31}\xi_{13}\xi_{32}\right)\varpi^4 + \frac{1}{64\pi^2}\left(\xi_{11}\xi_{22} + \xi_{11}\xi_{33}\right)\varpi^3 + \left[\frac{i}{64\pi^3}\left(\xi_{31}\xi_{21}\xi_{23} + 2\xi_{31}\xi_{13}\xi_{32}\right)c^2k^2 + \right.$$
$$\left. + \frac{i}{4\pi}\left(\xi_{11} + \xi_{22} + \xi_{33}\right) + \frac{\varpi_{22}}{16\pi^2}\left(\xi_{11}\xi_{33} + 2\xi_{31}\xi_{13}\right)\right]\varpi^3 + \left[-\frac{1}{64\pi^3}\left(\xi_{11}\xi_{22} + \xi_{11}\xi_{33}\right)c^2k^2 - 1 + \frac{i\varpi_{22}}{4\pi}\left(\xi_{11} - \xi_{21}\right)\right]\varpi -$$
$$-\frac{ic^2k^2}{4\pi}\left(\frac{1}{64\pi^2}\xi_{31}\xi_{13}\xi_{32}c^2k^2 - \xi_{22} - \xi_{33}\right) - \frac{1}{64\pi^2}\varpi_{22}c^2k^2\left(\xi_{11}\xi_{33} + \xi_{13}\xi_{31}\right) - \varpi_{22} = 0$$

$$\chi_1 = \frac{2\pi}{3}$$

$$\varpi_1 = \frac{2\pi}{3}\cdot\frac{1}{\varsigma}$$

$$\varpi_0 = -\frac{\varpi_{22}}{2\pi}\cdot\frac{2\pi}{3} = -\frac{\varpi_{22}}{3}$$

$$\frac{\varpi_0}{\varpi_1} = \frac{\varpi_{22}}{3}\cdot\frac{3\xi}{2\pi} = \frac{\varpi_{22}\xi}{2\pi} << 1$$

$$\varpi_{22}\xi << 2\pi$$

Output figures and outcome results:

Thermomagnetic waves with different frequencies are excited in anisotropic conducting media. These waves can be longitudinal $\vec{k} \parallel \vec{\nabla} T$ and tansverse $\vec{k} \perp \vec{\nabla} T$

Frequencies in anisotropic media change depending on the value of electrical conductivity in these media. These waves are growing in all experimental values of the electrical conductivity of the medium

In contrast to isotropic media, in anisotropic media, thermomagnetic waves are excited with some values without an external magnetic field. Dispersion equations (26) and (27) have solutions in different approximations with respect to the real frequency of thermomagnetic waves. Naturally, thermomagnetic waves can propagate in different approximations. We managed to solve dispersion equations (26) and (27) in approximations under existing experimental conditions.