ON A CERTAIN MECHANISM OF ABSORPTION OF ULTRASOUND IN PARAMAGNETIC METALS IN A MAGNETIC FIELD

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One of the mechanisms of ultrasonic absorption in paramagnetic metals is discussed, namely, the appearance of currents as the result of variation of the temperature and the magnetic susceptibility. The magnitude of the effect is estimated.

IF the susceptibility of a medium depends on temperature, and an external magnetic field is applied, then the magnetization varies along with the temperature as a longitudinal sound wave passes through each point in the medium. In a conducting medium, currents are induced in such a case, leading to an additional sound absorption. An estimate of the absorption of a plane wave in an isotropic medium, brought about by this effect, is carried out below.

It is evident that there will be no effect for $\mathbf{H} \parallel \mathbf{k}$ ($\mathbf{k}$ is the wave vector of the sound wave), since a longitudinal magnetization wave arises and no currents are induced. For $\mathbf{H} \perp \mathbf{k}$, the effect is at a maximum. In this case, as is easy to see from Maxwell's equations, a transverse current wave arises, propagating with the velocity of sound and polarized perpendicular to the vectors $\mathbf{H}$ and $\mathbf{k}$, with amplitude

$$j = -\sigma H\theta\left(\frac{\partial\mu}{\partial T}\right)\frac{v}{c}\left[1 + \frac{i}{2\pi^2}\left(\frac{\lambda}{\delta}\right)^2\right]^{-1}. \qquad (1)$$

Here σ is the conductivity, μ the magnetic permeability, v the speed of sound, λ the wavelength, δ the thickness of the skin layer, and θ the amplitude of the acoustic fluctuations of the temperature. The quantity θ is connected with the amplitude of the displacement in the sound wave, u. For adiabatic vibrations,[1]

$$|\theta| = akuT, \quad a = \alpha\rho\left(v_l^2 - \tfrac{4}{3}v_t^2\right)\Big/ C_p = \alpha E/3C_p(1 - 2\varkappa),$$

where α is the coefficient of thermal expansion, E is Young's modulus, and κ is the Poisson ratio.

The dissipation and the absorption coefficient are computed in the usual way with the aid of (1). The linear absorption coefficient is equal to

$$\gamma = \gamma_m\left[1 + \frac{1}{4\pi^4}\left(\frac{\lambda}{\delta}\right)^4\right]^{-1}, \qquad \gamma_m = \frac{\sigma}{2v\rho}\left(\frac{aHT}{c}\frac{\partial\mu}{\partial T}\right)^2. \qquad (2)$$

For low frequencies ($\lambda/\delta \gg 1$), we can neglect unity in the denominator, so that $\gamma = 4\pi^4(\delta/\lambda)^4\gamma_m$, i.e., the absorption coefficient increases in proportion to the square of the frequency. At high frequencies, when $\lambda/\delta \ll 1$ (which is true in practice even at $\omega \sim 10^8\ \text{sec}^{-1}$), a limiting value, equal to γ_m, is obtained.

The dependence of the absorption on the field and on the frequency is the same as takes place in the motion of a conducting medium in a sound wave in a magnetic field (as the result of eddy currents).[2] The absorption coefficient in the latter case is given by Eq. (2), except that of $aT\partial\mu/\delta T$ is replaced by μ. The ratio of the absorption coefficient found from (2) to the absorption coefficient due to the eddy currents is thus equal to $(aT/\mu)^2(\partial\mu/\partial T)^2$. This ratio is almost always small. Exceptions are the strongly paramagnetic rare-earth metals close to the ferro- and antiferromagnetic transition points, where the derivative $\partial\mu/\partial T$ is relatively large. Thanks to this situation, the effect considered can be shown to be even stronger than the effect brought about by the eddy currents. In dysprosium, for example, for T = 180°K (close to the Néel temperature of 175°K) we have $\partial\mu/\partial T \approx 0.01\ \text{deg}^{-1}$.[3] We did not succeed in obtaining experimental data which permitted the calculation of the parameter a for rare-earth metals. For "tabular" metals, a is of the order of unity: aluminum — 2.3; copper — 1.8; silver — 2.5; and platinum — 2.3. Therefore, setting $a \sim 1$, we find $(aT/\mu)^2(\partial\mu/\partial T)^2 \approx 3$. For $\sigma \sim 10^{16}\ \text{sec}^{-1}$ (reference 4), $v \approx 3 \times 10^5$ cm/sec, $\rho = 8.6$ g/cm^3 and $H \sim 10^4$ oe, the absorption coefficient (2) is of the order $\gamma_m \sim 10^{-3}\ \text{cm}^{-1}$.

We note that relaxation of the magnetization has not been taken into account in the estimate given above. This is obviously permissible under the

condition $\omega\tau \ll 1$, where τ is the time of spin-lattice relaxation. As S. A. Al'tshuler kindly informed the author, there is a basis for expecting the time of spin-lattice relaxation in rare earth metals to be very small, and therefore the condition $\omega\tau \ll 1$ can be assumed to be satisfied up to very high frequencies.

[1] L. D. Landau and E. M. Lifshitz, Механика сплошных сред (Mechanics of Continuous Media) Gostekhizdat, (1953).

[2] R. A. Alpher and R. J. Rubin, J. Acoust. Soc. Am. **26**, 452 (1954).

[3] Elliott, Legvold, and Spedding, Phys. Rev. **94**, 1143 (1954).

[4] Legvold, Spedding, Barson, and Elliott, Revs. Modern Phys. **25**, 129 (1953).

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