

in the nucleus than in the free state.<sup>6</sup> However, inasmuch as the magnetic moment of the neutron is due essentially to its interaction with the electron,<sup>7</sup> the attraction between the electron and neutron will be stronger in the case of a bound neutron (let us note that this can increase the theoretical value of the shift, which we have calculated for the free neutron).

An experimental observation of the isomer shift can lead to a new method of investigating the nuclear structure and will permit checking assumptions 1 and 2. At the present time, F. Bitter (private communication) is attempting to observe the isomer shift in Hg<sup>197</sup> by means of double magnetic and optical resonance.

The author is grateful to Academicians S. Titeica, H. Jussim and D. Bogdan for many valuable remarks and to Academician E. Bedereu and Professor Ia. A. Smorodinskii for interest in this work.

\*I am grateful to R. L. Lawson who was kind enough to supply me with the corresponding wave functions, calculated on

the Berkeley differential analyzer (some of the functions were calculated specially for our problem).

†In the case of an isotopic shift, this effect is masked by the Coulomb interaction.

<sup>1</sup>R. Weiner, *Nuovo cimento*, Ser. X, **4**, 1587 (1956); *Studii si Cercetari de Fizica* **7**, 596 (1956).

<sup>2</sup>J. Rosental and G. Breit, *Phys. Rev.* **41**, 459 (1932).

<sup>3</sup>Ross, Mark, and Lawson, *Phys. Rev.* **104**, 1613 (1956).

<sup>4</sup>A. Green, *Phys. Rev.* **104**, 1617 (1956).

<sup>5</sup>S. Nilsson, *Kongl. Danske Vidensk. Seleska Mat.-Fys., Medd.*, **29**, No 16, (1955).

<sup>6</sup>Bell, Eden, and Skyrme, *Nucl. Phys.* **2**, 586 (1956-7). J. Bell, *Nucl. Phys.* **4**, 295 (1957).

<sup>7</sup>L. Foldy, *Phys. Rev.* **87**, 693 (1952).

Translated by J. G. Adashko  
43

### SOUND ABSORPTION IN FERROMAGNETIC DIELECTRICS IN A MAGNETIC FIELD AT LOW TEMPERATURES

L. A. SHISHKIN

Kharkov State University

Submitted to JETP editor March 29, 1958

*J. Exptl. Theoret. Phys. (U.S.S.R.)* **35**, 286-287 (July, 1958)

It was shown by Akhiezer and the author<sup>1</sup> that the sound absorption in ferromagnetic dielectrics, which is associated with the internal friction in a system of elementary excitations, phonons and spin waves, is, at low temperatures, principally determined by the spin waves and does not depend on the temperature. An external magnetic field changes the relaxation time in such a system and leads to a change in the temperature dependence of the sound-absorption coefficient.

The relaxation times of spin waves and phonons are determined from the expressions

$$1/\tau_k = 1/\tau_k^{(1)} + 1/\tau_k^{(2)}, \quad 1/\tau_f = 1/\tau_f^{(1)} + 1/\tau_f^{(2)},$$

where  $\tau_k^{(1)}$  is the relaxation time of the spin waves and is connected with the interaction of the spin waves with spin waves;  $\tau_k^{(2)}$  is the relaxation time of the spin waves connected with phonon interaction;

$\tau_f^{(1)}$  is the relaxation time of the phonons relative to phonon interaction, while  $\tau_f^{(2)}$  is the relaxation time of the phonons relative to the spin-wave interaction.

As was shown by Akhiezer,<sup>2</sup> the following elementary processes are of the greatest importance: the conversion of two spin waves into a single spin wave, the conversion of two phonons into a single phonon, and the scattering of spin waves by phonons.

In the presence of an external magnetic field, the energy of the spin wave depends on the field and has the value  $\epsilon_0 + 2\beta H$ , where  $\epsilon_0$  is the energy of the spin wave in the absence of a magnetic field,  $H$  is the intensity of the magnetic field,  $\beta$  is the Bohr magneton. This dependence leads to a dependence of the relaxation times of phonons and spin waves on the magnetic field. Carrying out the calculation gone through in detail in reference 2, we can determine the relaxation time in the presence of the field. In such a case, it is shown that the relaxation time has a different form relative to the spin-spin interaction for the cases of large and small value of  $2\beta H/\kappa T$  ( $\kappa$  is Boltzmann's constant,  $2\beta/\kappa \sim 10^{-4}$ ):

$$\tau_k^{(1)} \approx \frac{\theta_c \hbar}{\omega^2} \left( \frac{\theta_c}{T} \right)^{1/2} \ln^2 \frac{\omega + 2\beta H}{T}, \quad \frac{H}{T} \ll 10^4, \quad T \ll \frac{\theta_c^2}{\theta_c},$$

$$\tau_k^{(2)} \approx \frac{\theta_c \hbar}{\omega^2} \left( \frac{\theta_c}{T} \right)^{1/2} \exp \left\{ \frac{2\beta H}{T} \right\}, \quad \frac{H}{T} \gg 10^4, \quad T \ll \frac{\theta_c^2}{\theta_c}.$$

Here  $w = \beta^2/a^2$  is the energy of the magnetic interaction of two atoms, and  $a$  is the lattice constant.

The relaxation times of the spin waves and phonons relative to interaction among the spin waves and among phonons do not change in the presence of an external magnetic field and have the form

$$\tau_k^{(2)} \approx \frac{\rho}{\hbar} \left( \frac{a\theta_c}{\theta} \right)^5 \left( \frac{\theta^2}{\theta_c T} \right)^{1/2} \exp \left\{ \frac{\theta^2}{4\theta_c T} \right\}; \quad T \ll \frac{\theta^2}{\theta_c},$$

$$\tau_f^{(2)} \approx \frac{\rho}{\hbar} \left( \frac{a\theta_c}{\theta} \right)^5 \frac{\theta^2}{\theta_c T} \exp \left\{ \frac{\theta^2}{4\theta_c T} \right\}; \quad T \ll \frac{\theta^2}{\theta_c},$$

$$\tau_f^{(1)} \approx \frac{\rho}{\hbar} \left( \frac{a\theta_c}{\theta} \right)^5 \left( \frac{\theta^2}{\theta_c T} \right)^5; \quad T \ll \theta;$$

where  $\rho$  is the density of the material.

As a result, it follows that for  $H/T \ll 10^4$  and  $T \ll \theta^2/\theta_c$ , the dissipation function and the sound absorption coefficient  $\Gamma$  are determined by the relaxation time  $\tau^{(1)}$ :

$$\Gamma = C\omega^2 (\lambda_{ij} \dot{u}_{ij}) \ln^2 \frac{w + 2\beta H}{T},$$

where  $\dot{u}_{ij}$  is the change in the deformation tensor of the crystal,  $\lambda_{ij}$  is some tensor,  $C$  is a constant, and  $\omega$  is the sound frequency. In this case,

the magnetic field increases the sound absorption.

For  $H/T \gg 10^4$  and  $T \ll \theta^2/\theta_c$ , the spin-spin interaction has a small probability, and the principal contribution to the distribution function is made by the interaction of the spin waves with the phonons. The absorption coefficient in this case is determined by the time  $\tau_k^{(2)}$  and has the form

$$\Gamma = C'\omega^2 (\lambda_{ij} \dot{u}_{ij}) \exp(\theta^2/4\theta_c T).$$

In a sufficiently large magnetic field, the sound absorption depends exponentially on the temperature and not on the field.

In both cases, we can show that  $\tau_f \ll \tau_k$  for  $T \ll \theta^2/\theta_c$ , and, consequently, the phonons play a small role in the sound absorption.

The author thanks Prof. A. I. Akhiezer for discussion of the problem.

<sup>1</sup>A. I. Akhiezer and L. A. Shishkin, J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, Soviet Phys. JETP **8** (in press).

<sup>2</sup>A. I. Akhiezer, J. Phys. (U.S.S.R.) **10**, 217 (1946).

Translated by R. T. Beyer

44

### INFLUENCE OF ACOUSTIC VIBRATIONS ON THE PARAMETERS OF THE BANDS OF IMPURITY ABSORPTION IN CRYSTALS

V. L. VINETSKII and M. F. DEIGEN

Physics Institute, Academy of Sciences,  
Ukrainian S.S.R.

Submitted to JETP editor April 1, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 287-289  
(July, 1958)

In a previous paper<sup>1</sup> the authors considered a system of an ionic crystal and an F-center in a macroscopic approximation and obtained expressions for the energies of the ground and excited states of the system and for the parameters of the corresponding absorption bands. These expressions depend, according to reference 1, on the sums  $q_1 = \sum \cos^2 \theta_\alpha / f_\alpha^2$  and  $q_2 = \sum \cos^2 \theta_\alpha / f_\alpha$ , where  $\theta$  is the angle between the displacement vector of the medium  $u$  and the wave vector  $\kappa$  for the  $\alpha$ -th branch of the elastic vibrations of the crystal ( $\alpha = 1, 2, 3$ );  $f_\alpha$  determines the angular dependence in the dispersion law for the fre-

quencies of the elastic vibrations  $\omega_{\kappa\alpha} : f_\alpha = \omega_{\kappa\alpha} / |\kappa|$ .

In reference 1 we used for the evaluation of the sums  $q_1$  and  $q_2$  the results of a paper by Tolpygo<sup>2</sup> where the consideration was based on a microscopic approximation. It turned out, however, that it was possible to perform, in general form, a consistent macroscopic consideration for a large group of crystals for which the anisotropy was not too large (for crystals which did not satisfy this condition it was necessary to resort to numerical calculations).

The quantities  $f_\alpha$  are, as is well known, the solutions of the characteristic determinant

$$n_1^2/(n_1^2 - \gamma_1) + n_2^2/(n_2^2 - \gamma_2) + n_3^2/(n_3^2 - \gamma_3) = 1, \quad (1)$$

where

$$\gamma_i = (A - C) n_i^2 + C - x; \quad A = \lambda_{1111}/(\lambda_{1122} + \lambda_{1212});$$

$$C = \lambda_{1212}/(\lambda_{1122} + \lambda_{1212});$$

$$x = \rho f_\alpha^2 / (\lambda_{1122} + \lambda_{1212});$$

$\lambda_{ijk}l_m$  are the elasticity moduli of a cubic crystal;  $n_i$  a unit vector in the direction  $\kappa$ , and  $\rho$  the crystal density. It is convenient to rewrite Eq. (1) in the form