INFLUENCE OF ULTRASONIC EXCITATIONS IN CRYSTALS ON THE PROBABILITY OF THE MOSSBAUER EFFECT

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We show in the present paper that the excitation of acoustic oscillations in an absorber containing Mossbauer nuclei leads to a change in the parameters of the Mossbauer absorption spectra and to the appearance of strong anisotropy of the probability of the Mossbauer effect. This apparently makes it possible to investigate certain subtle physical phenomena occurring in crystals. Let us consider the influence of standing ultrasonic waves on the probability and anisotropy of recoilless absorption and emission of γ quanta by Mossbauer nuclei in a crystal. We assume that a standing acoustic wave is excited in one of the normal directions [1] of a crystal, and that the crystal contains an excited Mossbauer atom. Under the influence of the standing acoustic waves and thermal phonons, the excited atom shifts from its equilibrium position $\vec{r}_0$ in accordance with the law

$$\mathbf{r}(t) = \mathbf{r}_0 + \mathbf{A}\cos\mathbf{qr}\cos\Omega t + \mathbf{R}(t). \tag{1}$$

Here $\vec{A}$ is the vector of displacement of the atom under the influence of the acoustic oscillations with wave vector $\vec{q}$ and frequency Ω, and $\vec{R}(t)$ is the displacement due to the thermal oscillations with allowance for the weak variation of the phonon field by the standing acoustic waves. The probability of the Mossbauer emission of γ quanta by an excited nucleus can be calculated classically, in analogy, for example, with the procedure used in [2]. Recognizing that the perturbation of the phonon field as the result of the interaction with the acoustic oscillations is small, and neglecting the term in which $n\Omega + \Sigma n_m\Omega_m = 0$, in the general expression for the phase of the wave, where Ω_m are the natural frequencies of the crystal and n and n_m assume the following integer values: $n = \pm 1, \pm 2, \pm\ldots$, $n_m = 0, \pm 1, \pm 2, \pm\ldots$ [2], we obtain from the probability of the nucleus emitting a γ quantum with wave vector $\vec{k}$

$$F = f_1 f_2, \tag{2}$$

where f_1 is the probability of recoilless emission of γ quanta in the absence of the ultrasound, and $f_2 = I_0^2(a\cos\vec{q}\cdot\vec{r})$ is a factor describing the change of the probability of the effect due to acoustic oscillations. In the expression for f_2 we have $a = \vec{A}\cdot\vec{n}/\lambda\!\!\!^{-} = A\cos\alpha/\lambda\!\!\!^{-}$, $\lambda\!\!\!^{-\,-1} = 2\pi/\lambda$, where λ is the wavelength of the Mossbauer γ quantum and α is the angle between the vector $\vec{A}$ and the direction of emission of the γ quantum (vector $\vec{n}$, $|\vec{n}| = 1$).

As seen from (2), the probability of the Mossbauer effect depends on the points at which the excited nucleus is located. To determine the experimental average Mossbauer-effect probability, expression (2) must be averaged over the volume of the crystal. As a result of such an averaging, we obtain from (2)

$$F = f_1\bar{f}_2, \quad \bar{f}_2 = \frac{1}{\pi}\int_0^{\pi/2} I_0^2(a\cos z)\,dz = \sum_{j=0}^{\infty}(-1)^j a^{2j}\frac{[(2j-1)!!]^2}{[(2j)!!]^2}. \tag{3}$$

The average probability of the Mossbauer absorption of a γ quantum in an absorber is obviously equal to $\bar{F}' = f_1'\bar{f}_2'$, where $\bar{f}_2' = \bar{f}_2$ and f_1' is the probability of recoilless absorption of γ quanta in the absorber in the absence of

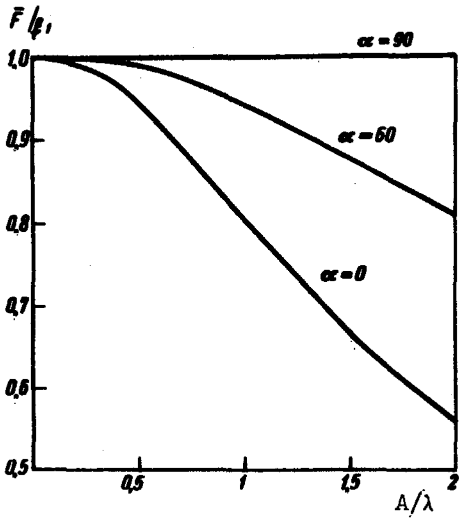

Fig. 1

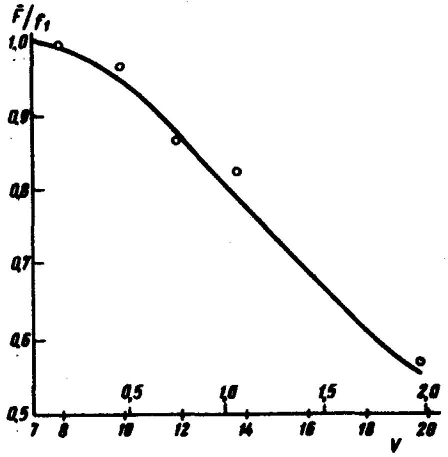

Fig. 2

Fig. 1. Theoretical plots of the average Mossbauer-effect probability against the parameters A/ƛ and cos α.

Fig. 2. Mean value of the Mossbauer-effect probability in $LiNbO_3$ (0.5% Sn^{119}) vs. the voltage on the converter. The experimental data are compared with the theoretical curve (Fig. 1). The ultrasound propagation direction coincides with the crystal C axis (cos α = 1). The voltage at which the generation begins depends on the thickness of the oil cushion between the quartz crystals and the $LiNbO_3$ and amounts to 7 V in this case.

ultrasound. Figure 1 shows plots of $\bar{F}'/f'_1$ as a function of the parameters A/ƛ and α, as obtained from formula (1). We see from Fig. 1 that the probability of the Mossbauer effect depends strongly on the angle α and on A/ƛ.

To verify the foregoing results, we carried out an experimental investigation, by the γ-quanta absorption method, of the dependence of the probability of the effect on the parameter A/λ (the effective voltage V* on the converter) in the ferroelectric crystal $LiNbO_3$ (the space group of the lithium niobate is C_{3v} [3]), containing 0.5 mol.% Sn^{119}.

The spectra were obtained with an electrodynamic-type spectrometer, the γ-ray source was Sn^{119m} in the form of $Sn^{119m}O_2$ with activity 5 mCi.

The experiments were performed at 300°K with single-crystal plates of lithium metaniobate with polished surfaces. The plate thickness was 0.39 ± 0.03 mm. A standing acoustic half-wave along the C axis of the crystal was excited at a frequency 4.19 MHz. The γ-quanta propagation direction coincided with the C axis.

The experimental results for $LiNbO_3$ are shown in Fig. 2, which shows for comparison also the calculated curve for cos α = 1 from Fig. 1. From a comparison of these curves we see that the calculated curve of the Mossbauer-effect probability, as a function of A/ƛ (see Fig. 2), coincides, within the limits of the experimental error, with the experimental curve of F' at a definite value of the proportionality coefficient C, $A/ƛ = CV^*$, $V^* = V - V_0$, where V is the voltage on the converter and V_0 is the voltage at which generation begins. We note that C can in principle be determined by calculation (see, e.g., [4]).

Thus, excitation of ultrasonic oscillations in crystals makes it possible to change the average probability of the Mossbauer effect, and the appearance of a strong dependence of f_2^1 on the angle between the direction of propagation of the γ quanta and the displacement of the atoms under the influence of the acoustic oscillations can find wide use in research on physical phenomena in crystal physics.

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EXCITATION OF ULTRASONIC WAVES BY PASSAGE OF FAST ELECTRONS THROUGH A METAL

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Askar'yan has predicted [1] the emission of ultrasonic waves when charged particles pass through a liquid, and noted that such radiation should take place in solids and in compressed gases, but its intensity there would be much less than in liquids.

Kaganov et al. [2] indicated that interaction between electrons and the lattice, for electrons having a velocity larger than the velocity of propagation of sound in the medium, leads to "Cerenkov" radiation of phonons.

Beron and Hofstadter [3] observed experimentally mechanical oscillations arising in ceramic piezoelectric pickups through which relativistic electrons with E_0 = 1 GeV pass.

Using the electron accelerator of the Physico-technical Institute of the Ukrainian Academy of Sciences, with E_0 = 300 MeV, experiments were undertaken aimed at observing ultrasonic oscillations in solids excited by passing electrons. The beam of electrons was normally incident on the center of a plate made of the investigated material and measuring $50 \times 10 \times h$ cm^3, where the thickness h was varied during the experiment. At one end of the plate there was fastened a detector of ultrasonic oscillations, made of a plate of rochelle salt and operating at 65 kHz. The plate together with the detector and preamplifier was placed in acoustic and electric screens. The signal from the cascade emitter repeater of the preamplifier was fed through a coaxial cable to a matched attenuator and a terminal tuned amplifier. The signal amplitude was registered on the screen of an oscilloscope I0-4, the delayed sweep of which was triggered by a synchropulse from the accelerator. The bandwidth of the entire detecting system was Δf = 4 kHz. The sensitivity of the detection system made it possible to measure displacement $\Delta\lambda \approx 10^{-12}$ cm at a twofold distance of the signal amplitude from the noise level of the preamplifier.

In the experiments we registered the amplitude U of the electric signal from the ultrasound detector, and the value of the average amplifier current. The sound force was calculated from the formula

$$J = \frac{U^2}{R_s S}, \qquad (1)$$

where $R_S = 1.88 \times 10^1\ \Omega$ is the "acoustic" resistance of the detector and of the