Suppression effect under conditions of purely nuclear Laue diffraction of resonant γ rays

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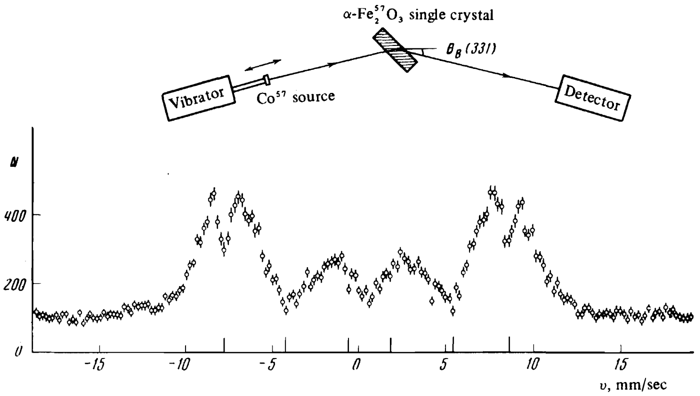
Suppression of inelastic channels of the nuclear reaction in a thick ($\mu t > 100$) α-Fe_2O_3 single crystal is studied under conditions of purely nuclear diffraction of 14.4 keV resonant γ-rays by the (331) planes of the crystal. A distinct weakening of the resonant intensity is observed. This is manifest in an enormous broadening of the peaks up to $45\,\Gamma_{nat}$. The troughs in the resonance maxima are ascribed to residual absorption due to the fact that the suppression conditions are not obeyed rigorously and the crystal is not perfect.

The effect of suppression of inelastic nuclear-reaction channels under conditions of diffraction of resonant γ rays both by nuclei and by electrons, predicted by Yu. Kagan and Afanas'ev[6], was investigated in a number of studies[1-5]. In the present paper we study this effect for the first time under conditions of purely nuclear diffraction[7] in a Laue geometry; this has made it possible, in particular, to observe a suppression of the resonant dependence of the intensity of the γ-ray reflection; this suppression is not trivial for nuclear resonant interaction. The experiment was performed at room temperature with a Mössbauer diffractometer[8]. A beam of 14.4-keV γ rays with divergence $\sim 15'$ from a Co^{57} source in chromium (200 μCi) was incident on an α-Fe_2O_3 single crystal (2×3 mm, 85% Fe^{57}) mounted in the position of the asymmetrical Laue reflection (331) at $\theta_B = 17°\,11'$. (The experimental setup is illustrated in the upper part of the figure.) The crystal was situated in a magnetic field of ~ 1 kOe perpendicular to the scattering plane. The crystal thickness, 60 μ, corresponded in the case of (331) diffraction to $\mu^{\pi}_{res}t = 215$ and $\mu^{\sigma}_{res}t = 120$ for π and σ polarized components of the incident beam. For the (331) planes, the γ rays are diffracted only by nuclei, since the diffraction by electrons is identically extinguished. When measuring the angular dependence off resonance ($v_{source} = \infty$), there was no diffraction, whereas under resonance conditions (the $+1/2 \rightarrow +3/2$ transition was excited), a clearly pronounced peak was observed. We note that this is the first observation of purely nuclear Laue diffraction of resonant γ rays from a thick crystal, and serves in itself as proof of the existence of the effective suppression of inelastic nuclear-reaction channels.

In the fundamental experiment, we measured the dependence of the intensity of the diffracted γ rays on the source velocity, i.e., on the energy of the γ rays incident on the crystal. The source moved with constant acceleration, and the information was accumulated in a multichannel analyzer. The total measurement time was ~ 700 hours. The spectrum obtained (see the figure) shows four broad maxima corresponding to four nuclear transitions with $\Delta m = \pm 1$. The two lines of the spectrum with $\Delta m = 0$ are missing, since they are likewise extinguished.

The first singularity of the obtained spectrum is the tremendous broadening of the resonances—the widths of the uppermost lines are equal to $\sim 45\,\Gamma_{nat}$. This phenomenon is easiest to explain for the case of ideal collimation of the incident beam ($\theta = \theta_B$ and $\Delta\theta = 0$). The γ quanta interact with the nuclei only in a certain thin layer of the entrance surface of the crystal, forming a diffracted beam. The intensity I_d of this beam reaches a maximum value at the end of the transition layer, and it remains unchanged in its further passage through the crystal by virtue of the suppression effect. The thickness d_{tr} of the transition layer is determined by the amplitude of the γ-quantum scattering, which depends on the energy. Deviation from resonance causes the amplitude to decrease and d_{tr} to increase, but so long as $d_{tr} \gg d_c$ (d_c is the crystal thickness), the value of I_d remains constant at its maximum value. Under the real conditions of our experiments, the collimation $\Delta\theta$ was equal to the angle interval in which diffraction took place. This caused the intensity I_d to be no longer constant, but to decrease slowly with increasing ΔE. Even in this case, however, the effective line width was determined by the condition $d_{tr} \lesssim d_c$. It follows therefore that when the crystal thickness is increased, the width of the resonance maxima should increase without limit. This effect should be treated not as a broadening of the resonance line under diffraction conditions, but as a sharp decrease or suppression of the resonant dependence of the intensity of the γ rays passing through the crystal under diffraction conditions.

A second distinguishing feature of the spectrum is the presence of dips on the centers of the resonant maxima (they are quite distinct on the extreme peaks, but did not appear on the internal lines as a result of the lower statistical accuracy). These dips are connected with residual absorption due to at least two causes: 1) deviation from rigorous satisfaction of the conditions for the suppression of the inelastic channels of the nuclear reaction for the investigated reflection (331) (the nuclear structure factor F_{nuc} per nucleus differs from unity and equals 0.9956) leads to effective residual absorption factors $\mu_{res}t = 0.7$ at $\mu^{0}_{res}t = 0.25$. (We recall that rigorous satisfaction of the condition for the suppression of the inelastic channels yields $\mu^{\pi,\sigma}_{res} = 0$.); 2) the fact that the crystal employed is not ideal. It must be particularly emphasized that the shapes of the dips can serve as a sensitive indicator of the degree of perfection of the crystal.



Intensity of the Laue reflection of 14.4-keV γ rays of Fe^{57} vs. the source velocity. N is the total number of counts in the analyzer channel. The strokes denote the positions of the nuclear resonances as measured in the absorption experiment. The upper part of the figure shows the experimental setup.

Small deviations from monotonicity on the internal slopes of the outermost resonances can apparently be due to an effect that we observed earlier, namely oscillations of the intensity of the Laue-reflected beam [5].

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