INVESTIGATION OF SUPPRESSED NUCLEAR ABSORPTION OF RESONANT γ RAYS UNDER LAUE-DIFFRACTION CONDITIONS. EFFECT OF OSCILLATIONS OF THE REFLECTION INTENSITY

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The diffraction of resonant γ rays by an ideal crystal should be accompanied by total or partial suppression of nuclear resonant absorption. This suppression is due to the collective character of the interaction of the γ rays with the crystal [1]. We have already reported observation of this effect under conditions when the diffraction is primarily by electrons [2, 3]. We report here an investigation of the suppression effect for the case of diffraction predominantly by resonant nuclei, i.e., when the ratio of the amplitudes $f_{nuc}^{res}/f_{el} \gg 1$. We investigated Laue diffraction of γ rays by a thick ($(\mu t)^{res} \gg 1$) crystal. Such measurements do not require a small divergence of the incident beam, since only γ rays passing through the crystal in a narrow angle interval are registered; these are precisely the γ rays for which suppression of the absorption is expected.

The suppression of the absorption should become manifest in the dependence of the intensity I of the Laue-diffracted γ rays on the energy of the incident γ rays, i.e., on the relative velocity v of the source and the scatterer. Indeed, if there is no suppression of the absorption, then all the resonant γ rays will be completely absorbed ($(\mu t)^{res} \gg 1$), and the spectrum I(v) will represent a minimum that is symmetrical with respect to the center of the resonance $v = v_{res}$. In the presence of the suppression effect, the crystal does not absorb the resonant γ rays completely, and some of the latter leave the crystal. In this case the form of the spectrum is determined by the amplitude of the coherent scattering, which has an interference structure as a result of the fact that the scattering is both by nuclei and by electrons. Therefore the I(v) spectrum should have a dispersion form that is asymmetrical relative to the center of the resonance. This was indeed observed by us in the present investigation of Laue diffraction of 14.4-keV γ rays of Fe^{57} by a very thick ($(\mu t)^{res} = 210$) ideal crystal of $\alpha\text{-}Fe_2^{57}O_3$ ($f_{nucl}^{res}/f_{el} = 10$).[1] In addition to the expected dispersion form, we observed oscillations of the intensity I(v), which, like the absorption-suppression effect, is a consequence of the collective character of the interaction of the γ rays with the crystal.

Experimental conditions. The experiment was performed with a Mossbauer diffractometer [2]. A beam of 14.4-keV γ quanta with divergence 0.5° in the horizontal plane and 6° in the vertical plane was incident directly from the source (20 mCi of Co^{57} in Pd) on a single crystal of hematite ($\alpha\text{-}Fe_2O_3$) 95 μ thick, enriched to 85% Fe^{57}. The (111) plane emerged on the surface of the crystal. The crystal was mounted in a position of symmetrical Bragg reflection $(10\bar{1})$ in the Laue geometry ($\theta_B = 9°54'$). Control measurements have established that the crystal is close to ideal in its properties, namely, the Borrmann effect is observed when $MoK_{\alpha 1}$ x-rays are diffracted by the $(10\bar{1})$ planes. The experimental conditions were chosen such that only one component of the γ radiation with polarization 1 took part in the effect of suppression of the nuclear absorption (the magnetic vector oscillates perpendicular to the scattering plane). To this end, a magnetic field of ~1 kOe was applied to the crystal perpendicular to the scattering plane and the transition -1/2 → -3/2 was investigated. The crystal absorption factors were as follows: $\mu_e t \approx 2.3$

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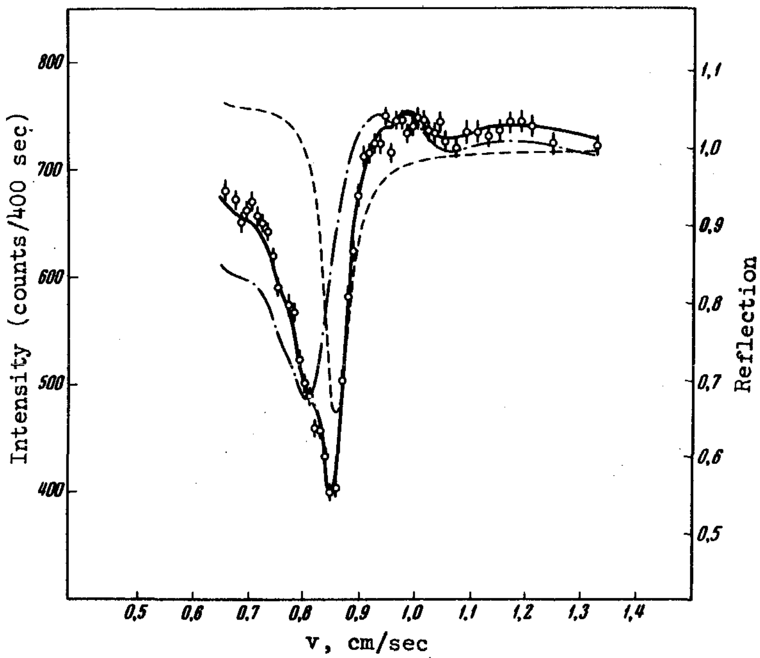
1) For Laue diffraction of γ rays from Sn^{119} by a tin crystal, an analogous experiment was recently performed independently by Voitovetskii et al. [4].

due to the interaction with the electrons, $\mu_{nuc}^{(1)}t = 210$ due to the interaction with nuclei at resonance for the polarization 1, and $\mu_{nuc}^{(2)}t = 6.2$ for the polarization 2.

Results and discussion. The figure shows the results of measurements of the I(v) dependence. The experimental points were obtained after averaging over four measurement runs. The distribution of the experimental points is an asymmetrical curve with dispersion shape. The theoretical curve (solid line in the figure) was calculated on the basis of the dynamic theory of the diffraction of resonant γ rays [1], with account taken of the influence of the neighboring line (corresponding to the transition $-1/2 \rightarrow -1/2$), together with integration over the energy distribution of the γ rays in the incident beam and summation over the polarizations. However, as we already noted, the roles of the polarizations in the suppression effect differ strongly. The good agreement of the experimental points with the theoretical curve makes it possible to analyze the distribution of the experimental points for each polarization separately. For the γ-radiation component with polarization 2, there is no suppression effect, and the corresponding I(v) curve has a practically symmetrical form with respect to $v = v_{res}$ (dashed line in the figure). The center of this line coincides with the center of the line measured by us for the usual Mossbauer absorption. The γ-radiation component with polarization 1 behaved entirely differently. The condition of total suppression of the nuclear absorption is satisfied for this component. We see that I(v) for this component (the dash-dot curve in the figure) has a strong dispersion form, and the center of the minimum is shifted appreciably from the resonance position (indicated by the line corresponding to the polarization 2). Thus, in a narrow range of angles, the crystal changes from strongly absorbing to merely scattering for this γ-radiation component.



Dependence of the intensity of a beam of 14.4-keV γ rays from Fe^{57}, Laue-diffracted by an $\alpha\text{-}Fe_2^{57}O_3$ crystal, on the velocity of the source (relative to the crystal) in the region of the transition $-1/2 \rightarrow -3/2$. The intensity is normalized to the value $I(v = \infty)$ corresponding to the intensity of scattering by electrons only.

In addition, oscillations of the intensity of the Laue beam [1] are observed for the considered component of the γ radiation. This effect is due to the interference of two coherent waves that propagate in the crystal with different refraction coefficients. The path difference of these waves on emerging from the crystal is determined, first, by the thickness of the crystal and, second, by the scattering amplitude (real part). The oscillations of the intensity take place in our case when the path difference changes as a result of the decrease of the amplitude of the scattering on going off resonance. It is interesting to note that the decreased rate of change of the scattering amplitude with increasing distance from the resonance causes the period of the oscillations to increase. The observed effect is a nuclear analog of the "Pendellosung" effect known in x-ray optics [5], but there the oscillations of the intensity are connected only with the change of the thickness. It is important to emphasize that the very presence of these oscillations in our spectrum, as well as the effect of suppression of the nuclear absorption of the γ rays, serves as proof of the collective character of the interaction of the γ rays with the crystal.

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PRODUCTION OF 3-MOe PULSED MAGNETIC FIELDS BY DISCHARGING A CAPACITOR BANK

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The production of magnetic fields of intensity exceeding a million Oersteds, even for a very short time, entails considerable experimental difficulties. The largest magnetic field intensity was registered in magnetic-cumulation experiments [1, 2]. Discharge of a capacitor bank through a solenoid yielded a field of intensity up to 2.5 MOe [3, 4]. The maximum value of the field in the solenoid depends on the rate of growth of the current and on the shape and properties of the solenoid material.

The purpose of the experiments reported here was to choose a solenoid material capable of withstanding pulsed loads in the best fashion and of ensuring maximum field intensity.

The current source in our experiments was a bank of pulsed capacitors with stored energy 25 kJ. The discharge current was in the form of a damped sinusoid with decrement 1×10^5 sec^{-1}. The time of the first current half-cycle was 5.7 μsec, and the maximum amplitude was 1.5 MA.

The experiments were performed with single-turn solenoids made of different materials. The inside diameter of the solenoid was 2.1 mm and its length 2.5 mm. The solenoids were secured in a massive steel frame, which was connected with the current busses of the capacitor bank.

The field intensity was measured with a magnetic probe constituting a four-turn coil 1.1 mm in diameter. The probe was placed in a teflon sleeve and was impregnated with castor oil. The probe was calibrated in a homogeneous field of known intensity. The probes were not damaged and could be used repeatedly even in fields of 2 - 3 MOe.