Effective variation of hyperfine interaction as a result of collective excitation of nuclei

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A shift of the Mössbauer lines in the absorption spectrum of a perfect $^{57}FeBO_3$ crystal was observed experimentally when the Bragg condition was satisfied. This shift is attributable to a variation of the hyperfine splitting of collective nuclear levels as a result of interaction of resonance γ radiation with the crystal.

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A diffraction of resonance γ radiation in thick, perfect crystals may produce effects which can be attributed to the collective interaction of Mössbauer radiation with a regular system of nuclei: suppression of inelastic channels of a nuclear reaction,[1] variation of nuclear parameters (of the location of resonance levels and lifetime of the excited state).[2]

We can assume that as a result of formation of the collective state, the hyperfine splitting of nuclear levels must change primarily because of possible variation of the magnetic moments of nuclei.

Experimental evidence of this occurrence would prove the existence of a "nuclear exciton" which has parameters that are different from those of an isolated nucleus.

A collective state can be formed if the crystal has a high degree of perfection.

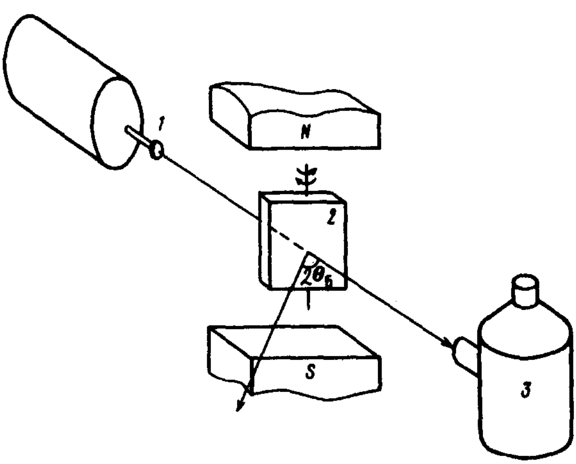

FIG. 1. Experimental setup.

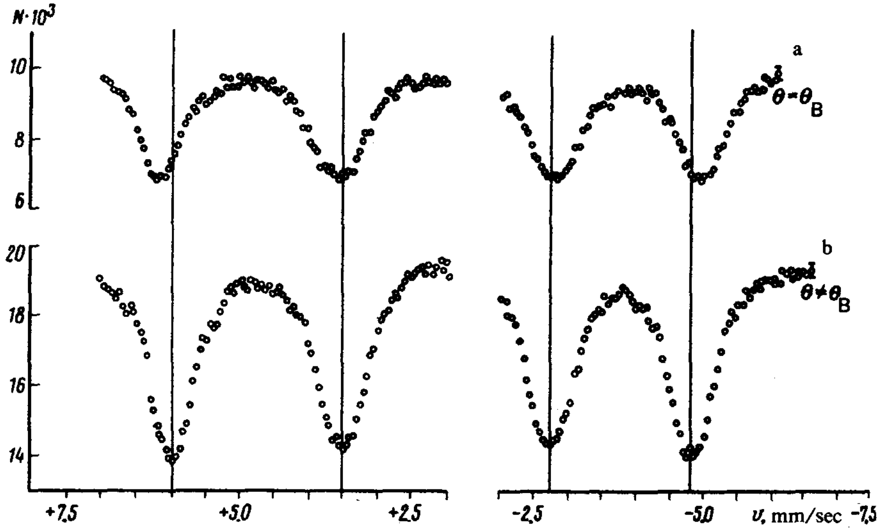

FIG. 2. Mössbauer absorption spectra. (a) $\theta=\theta_B$ and (b) $\theta \neq \theta_B$.

Because of a recently developed process of synthesizing perfect $^{57}FeBO_3$ single crystals,[3] it is possible to set up experiments in which the collective effects can be observed in a direct beam in a single-crystal geometry. The experimental setup is shown in Fig. 1.

A beam of γ-ray quanta from a ^{57}Co source (1) was focused on a $^{57}FeBO_3$ crystal (2) enriched with ^{57}Fe isotope to 87%, which was placed in a Laue-reflecting position [$(32\bar{1})$ reflection]. Adjustment to the diffraction peak was accomplished according to the method described in Ref. 4, which uses an x-ray tube bremsstrahlung. To improve the signal-to-background ratio, we recorded the γ-ray beam that was transmitted through the crystal using Si(Li) detectors (3) with a 300-eV resolution on the line FeK_α ($E = 6.4$ keV). The magnetic field applied to the crystal in the base plane converted it to a single-domain state. This had to be done in order to remove the elastic strain associated with the presence of domain walls.[5]

Figure 2a shows the Mössbauer absorption spectrum [the transitions $\frac{3}{2}\rightarrow\frac{1}{2}(1)$, $\frac{1}{2}\rightarrow\frac{1}{2}(2)$, $-\frac{1}{2}\rightarrow-\frac{1}{2}(3)$ and $-\frac{3}{2}\rightarrow-\frac{1}{2}(4)$] when the crystal was placed at the Bragg angle with respect to the γ-ray beam incident on the crystal. Figure 2b shows the same spectrum when the crystal was no longer in the Bragg position, i.e., when the condition for the collective state was violated.

We can see in Fig. 2 that the lines in the spectrum a (Bragg condition is satisfied) are shifted relative to the lines in the spectrum b. The location of the lines of spectrum b also coincides with the location of the lines of the absorption spectrum obtained by using a thin, powdery absorber made from this crystal. This indicates that the hyperfine splitting of the nuclear levels has changed. One reason for this change can be a variation of the magnetic moment of nuclei as a result of collective interaction of resonance γ radiation with the crystal.

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