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BRAGG SCATTERING OF MOSSBAUER GAMMA RADIATION BY AN IDEAL CRYSTAL

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Submitted 10 July 1968
ZhETF Pis. Red. 8, No. 6, 295 - 300 (20 September 1968)

Yu. M. Kagan and A. M. Afanas'ev have recently developed a thoery of coherent phenomena occurring upon resonant interaction of gamma quanta with nuclei in a regular crystal. It was shown that the excitation of nuclei in such crystals has a chollective character, thus bringing about a number of interesting phenomena [1 - 3].

For an experimental investigation of these phenomena it is necessary to have crystals with a high degree of perfection on the basis of nuclei of the Mossbauer type. The isotope Fe^{57} is highly suitable for this purpose. Indeed, as is well known, it is possible at present to obtain almost ideal single crystals of iron doped with silicon. On the other hand, the low energy of the gamma quantum in the case of Fe^{57}, in conjunction with the large probability of the Mossbauer effect, greatly facilitate the conditions for the observation of coherent effects.

As the first stage of the study, we investigated the Bragg scattering of 14-keV Mossbauer radiation of Fe^{57} nuclei by an ideal crystal Fe + 3% Si of natural iron. We succeeded in demonstrating experimentally that the scattering of Mossbauer gamma radiation by an ideal crystal differs greatly from scattering by a mosaic crystal, in agreement with the prexictions of the theory [2][1)].

Three samples were prepared for the investigation. The first was cut from a single crystal obtained by crucible-less zone melting followed by prolonged annealing at t = 1420°C [9, 10]. The second and third were cut from one grain obtained by second recrystallization. To produce the mosaic structure, the surface of the third sample was subjected to mechanical damage. In all samples, the surface was the (110) plane. From the point of view of the absorption factor, all three samples were thick ($\mu t > 10$). The degree of perfection of the obtained samples was determined with a two-crystal x-ray spectrometer based on the DRON-1 diffractometer. Mo $K\alpha_1$ and quartz monochromator crystal $(10\bar{1}1)$ were used. We measured the integral intensities for (110) reflection and the widths of the swing curves. The measurement

1) Scattering by a mosaic crystal was thoroughly investigated, mainly from the point of view of revealing the interference between the resonant nuclear and Rayleigh electron scattering, by Black et al. [4 - 7], and later by Voitovetskii et al. [8], where a clear-cut interference pattern was revealed during the course of an investigation of scattering by tin crystals.

results are summarized in a table, where they are compared with the theoretical values calculated assuming ideal and mosaic structure of the crystals.

Sample No	Integral intensities *, 10^6		Oscillation-curve width	
	Calculated	Measured	Calculated*	Measured
1	51	50 ± 1	17.2"	19"
2	-	113 ± 2	-	3'
3	315	202 ± 4	-	2°

*With allowance for the fact that the quanrtz monochromator is not ideal.

It is seen from the table that the interaction of the MoKα_1 (λ = 0.709 Å) with sample 1 has a clearly pronounced dynamic character. A similar situation should arise also for the investigated Mossbauer radiation (λ = 0.86 Å). It follows therefore that sample 1 can be regarded, with good approximation, as a regular system of scatterers. It should be added also that in a thinner sample (μt = 2.5) cut from the same single crystal together with sample 1, we were able to observe the Bormann effect in Laue diffraction by (11) planes. Figure 1 shows the obtained oscillation curves for the transmitted and reflected beams.

The behavior of sample 3 was analogous in many respects with the behavior of a mosaic crystal.

In sample 2, the elements of the substructure are disoriented and have sufficiently large dimensions to permit the primary extinction to play a noticeable role. With respect to the degree of perfection, this sample occupies a position between ideal and mosaic.

To investigate the diffraction of the Mossbauer radiation, a vibrator customarily used in a Mossbauer spectrometer operating at constant velocity was mounted on the DRON-1 diffracto-

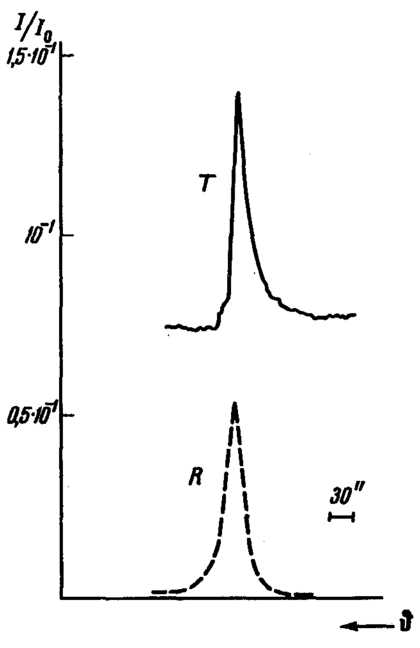

Fig. 1. Laue diffraction of Mo Kα_1 x-rays by (110) planes of an Fe + 3% Si crystal:
- - - - - - reflected radiation,
——— transmitted radiation

meter. The vibrator moved a Co^{57} source ina a Pd matrix measuring 10 x 1 mm, with activity 20 μCi, producing an unsplit line. All the measurements were made at room temperature.

A gamma-quantum beam with horizontal divergence 0.5° and vertical divergence 6° was incident on the investigated sample. The Mossbauer spectrum for our scatterers consists of six magnetic hyperfine structure lines. We selected the lines corresponding to the transitions Δm = 0. In order to intensify these lines, the samples were placed in a magnetic field directed perpendicular to the scattering plane, the direction of the easy magnetization axis in the crystal, [100], coincideing with the field direction. To determine the degree of magnetic order of the samples, the Mossbauer spectra were obtained in a 90° scattering geometry [11]. Figure 2 shows the four internal lines of the spectrum for sample 1. The ratio of the intensities of the transitions with Δm = ±1 and Δm = 0 amounts to 3.9 ± 1.0. Samples 2 and 3 produced similar spectra, within the limits of the experimental accuracy. This is evidence of the high degree of magnetic ordering of the samples.

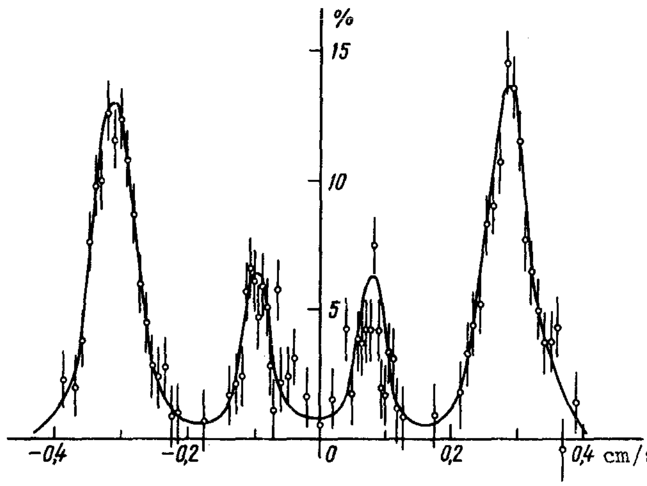

Fig. 2. Central part of Mossbauer spectrum of ideal Fe + 3% Si crystal (sample 1) placed in a magnetic field. Measurement in 90° scattering geometry. Outer lines correspond to Δm = 0 transitions.

On going over to a scattering angle equal to the Bragg angle 12°20' for reflection (110), the picture is radically altered. The Mossbauer spectra obtained for transitions with Δm = 0 are shown in Fig. 3. The counting rate was 3 - 4 pulses per minute, and the time required to plot the spectrum at the required statistical accuracy ranged from 100 to 300 hours. The low value of the effect in Fig. 3a did not allow us to determine the line shape within a reasonable time. The value of the effect at resonance was measured with good accuracy.

For all cases, the integral intensity of the Bragg peak reaches a minimum value when the nuclear interaction is turned on near resonace, owing to the increased nuclear absorption. However, the depth of the minimum is five times larger for a mosaic crystal than for an ideal one, in good agreement with the theory. This means that the role of the nuclear absorption in scattering at the Bragg angle is greatly reduced compared with the case of scattering from a mosaic crystal. It can be stated that the resultant yield of the nuclear reaction depends strongly on whether the system of scatterers in which the nuclear radiation propagates is regular or irregular.

The solid curves superimposed on the spectra have been calculated on the basis of [2]

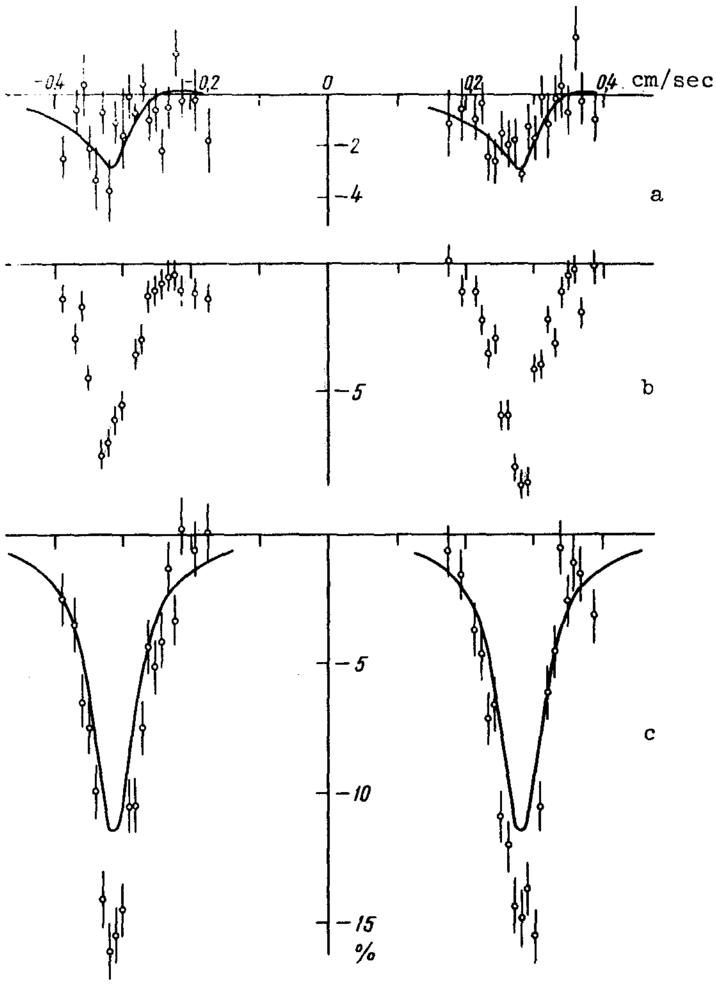

Fig. 3. Mossbauer spectra ($\Delta m = 0$ lines) obtained in scattering at the Bragg angle 12°20' for various samples of Fe + 3% Si placed in a magnetic field: a - ideal crystal (sample 1); b - real crystal (sample 2); c - mosaic crystal (sample 3)

for concrete experimental conditions[1)]. The spectrum for sample 2 corresponds to an intermediate position of the sample from the point of view of perfection.

We are preparing crystals enriched with Fe^{57}, on which the investigations will continue.

The authors thank A. P. Aleksandrov, I. K. Kikoin, and B. N. Samoilov for cooperation a and interest, Yu. M. Kagan, A. M. Afanas'ev, and I. P. Perstnev for a discussion and help with the calculations, and A. M. Volkov and S. G. Kutukov for help with the measurements.

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1) The causes of certain discrepancies between theory and experiment for the case of scattering from mosaic crystals are still unclear.