The authors are sincerely grateful to M. I. Elinson for continuous interest in the work, N. B. Brandt and Ya. G. Ponomarev for a discussion of the results, and S. V. Novikov for help with the experiments.

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NUCLEAR DIFFRACTION OF RESONANT γ RADIATION BY AN ANTIFERROMAGNETIC CRYSTAL

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Submitted 11 November 1968
ZhETF Pis. Red. 9, No. 2, 123-127 (20 January 1969)

This is a continuation of our earlier investigations [1] of coherent effects predicted by Kaganov and Afanas'ev [2,3] and occurring in the diffraction of resonant γ radiation by nuclei. Obviously, these investigations can be performed most effectively under conditions when the Rayleigh scattering by the electrons is suppressed or completely excluded. The first attempt to suppress Rayleigh scattering was made in [4], where they succeeded in choosing the Bragg position upon reflection from a crystal of potassium ferrocyanide ($K_4Fe(CN)_6 \cdot 3H_2O$), such that the Rayleigh scattering from the nonresonant atoms extinguished almost completely the Rayleigh scattering from the iron atoms. The separation of nuclear diffraction in such a manner is possible only in rarely encountered particular cases.

There exists another more interesting and more promising possibility of separating nuclear diffraction, based on the spin dependence of the amplitude of nuclear scattering of resonant γ rays. As shown recently by Belyakov and Aivazyan [5], it follows from this dependence that the diffraction of resonant γ rays by magnetically ordered crystals should be sensitive to the magnetic structure. The situation is here analogous in many respects to that obtained in the case of diffraction of neutrons and used in magnetic neutron diffraction analysis [6]. If the periods of the magnetic and the crystal structures are different, then diffraction of the resonant γ rays should give rise to additional Bragg maxima, connected with the magnetic structure and produced as a result of resonant scattering by nuclei only.

If the magnetic and crystal structures coincide, then, generally speaking, both the nuclear resonance and the Rayleigh electron scattering of the γ rays contribute to the Bragg maximum, and interference between them should be observed.

However, as shown in the present paper with hematite as an example 1), pure nuclear diffraction maxima can exist even in the case when the magnetic and crystal structures coincide.

Such a maximum was observed experimentally by us upon reflection of Mossbauer γ radiation of Fe^{57} from the system of (111) planes of hematite.

Figure 1 shows schematically the reflection case under consideration. The unit cell consists of four iron ions located on the [111] axis, and six oxygen ions (not shown). It is

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1) Hematite is cited in [5] as an example of the case considered there, where the magnetic and crystal structures differ. In fact, according to [7], the magnetic and crystal cells of hematite are identical.

known that in the case of Rayleigh scattering from the system of (111) planes, the scattering from the oxygen ion is suppressed and, independently, the scattering from the iron ions is suppressed. The amplitudes of scattering from the two upper and two lower iron ions (Fig. 1) in the unit cell of the hematite are then equal in magnitude but opposite in direction.

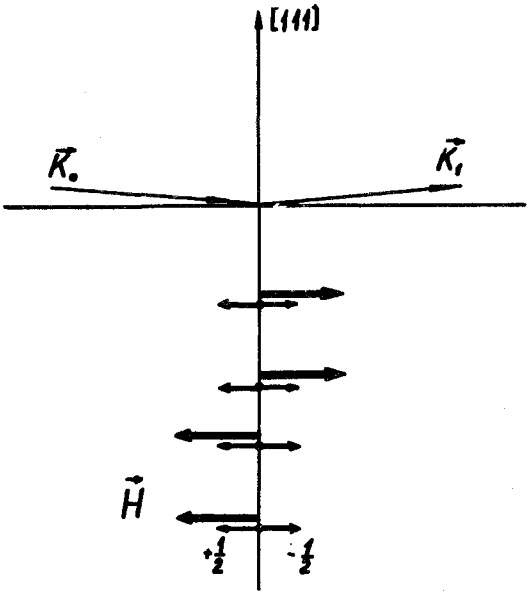

Fig. 1. Diagram of Bragg scattering of resonant γ quanta by iron ions contained in the hematite cell ((111) plane): $\vec{K}_0$, $\vec{K}_1$ - wave vectors of incident and scattered quanta, $\vec{H}$ - magnetic field at the nucleus, +1/2, -1/2 - projections of spin of the nucleus in the ground state on the magnetic field.

We consider now the case of nuclear resonant scattering of γ rays. As shown in Fig. 1, the magnetic fields at the iron nuclei are perpendicular to the [111] axis, and the fields at one pair of nuclei are practically antiparallel to the fields at the other pair (at room temperature). The small arrows denote the equally-probable projections of the nuclear spin on the field direction in the ground state. If one transition is excited, say for concreteness the -1/2 → -3/2 transition, then quanta of one polarization (left-hand circular) are necessary to excite the upper pair of nuclei, and quanta of the other polarization (right-hand circular) are needed for the excitation of the lower pair. This means that each quantum from the beam is scattered by only two nuclei out of four, and there is no suppression in this case, and consequently a Bragg peak should be observed.

The experiment was performed with a Mossbauer diffractometer [1]. 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 (Co^{57} in Pd) on a single crystal of hematite enriched to 85% with the isotope Fe^{57}. The crystal was grown from a solution in a flux of $Bi_2O_3 + Na_2CO_3$ [8]; the (111) plane emerged to the surface. The weak ferromagnetism of the hematite was used to orient the angular momenta of the sublattices in the direction corresponding to the scheme of Fig. 1, i.e., a magnetic field perpendicular to the scattering plane was applied to the crystal. All measurements were made at room temperature.

The measurement results are shown in Fig. 2. Figures 2a and b show the dependences of the scattering intensities of the γ rays on the angle of rotation of the crystal in the region of two Bragg angles: 5°20' (reflection (111)) and 10°50' (reflection (222)). The curves of Fig. 2a are plotted under the conditions when $v \neq v_{res}$ (v - γ-ray source velocity), i.e., in the absence of resonant interaction of the γ rays with the Fe^{57} nuclei in the hematite, when only Rayleigh scattering from electrons can take place. As expected, there is no scattering for the first Bragg angle, owing to the suppression, whereas for the second angle (for which there is no extinction), a Bragg peak is observed. The curves of Fig. 2b are plotted at

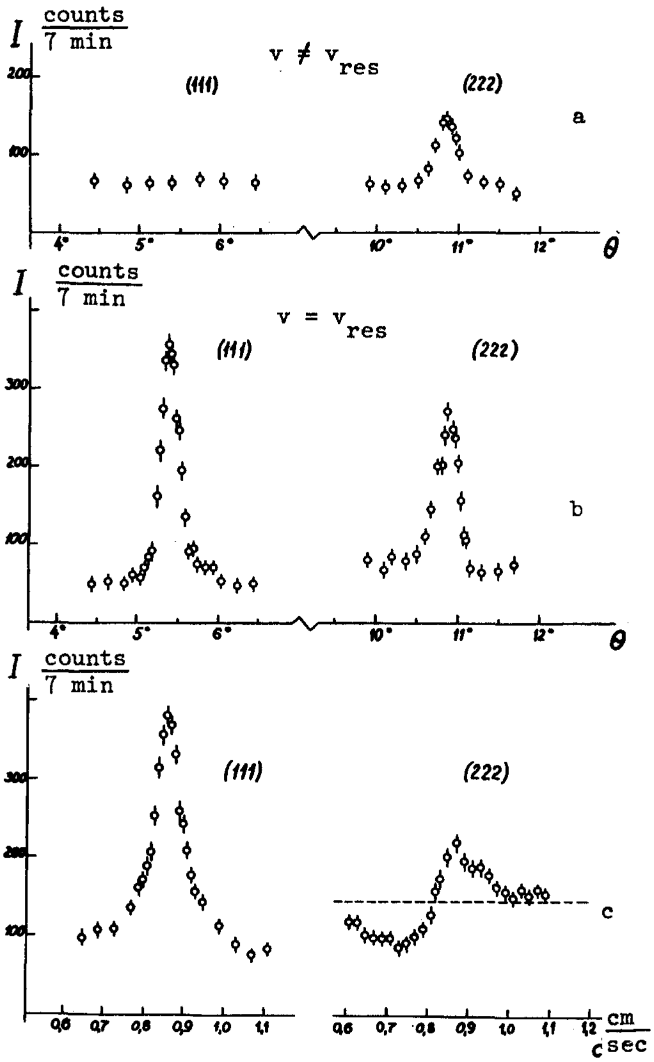

Fig. 2. a - Diffraction spectra measured in Bragg scattering of 14.4-keV γ radiation from Fe^{57} by a hematite crystal (85% Fe^{57}) in the vicinity of the Bragg angles 5°20' (111) and 10°50' (222) far from nuclear resonance ($v_{true} \neq v_{res}$); b - diffraction spectra for the same angles, measured at $v_{true} = v_{res} = 0.86$ cm/sec (the $-1/2 \rightarrow -3/2$ transition is excited); c - Mossbauer lines corresponding to the $-1/2 \rightarrow -3/2$ transition measured in the scattering of γ radiation from Fe^{57} by the same crystal at two fixed angles, 5°20' (111) and 10°50' (222). Dashed line - level of intensity far from resonance. (The maximum value of the intensity on the right-hand curve c is somewhat smaller than on the right-hand curve b, because the crystal was not set exactly in the Bragg position during the plotting of the first curve.)

$v = v_{res}$, when the velocity of the source ($v = 0.86$ cm/sec) corresponds to the $-1/2 \rightarrow -3/2$ transition between the magnetic sublevels in the hematite. In this case, a second coherent scattering mechanism is turned on, namely the nuclear resonant mechanism and, as seen from Fig. 2b, a Bragg peak formed only as a result of the diffraction of the γ rays by the nuclei appears in the position (111).

In position (222), the Bragg peak is formed as a result of scattering of the γ rays by both nuclei and electrons.

Figure 2b shows the dependence of the intensity of the scattered γ rays on the velocity of the source relative to the scatterer in the region of resonant velocity, corresponding to the $-1/2 \rightarrow -3/2$ transition. These dependences were measured at two fixed Bragg positions of the crystal, (111) and (222). The symmetrical form of the line in the first position offers evidence that it contains no admixture of Rayleigh scattering, whereas the clearly pronounced dispersion form of the line in the second position reveals the interference between the nuclear resonance and the Rayleigh electronic scattering processes. We note the larger value of the resonance effect $(\epsilon = (N(v_{res}) - N(\infty))/N(\infty))$ for the first position, corresponding to $\sim$400%.

Attention is called to the anomalous form of the Mossbauer line (Fig. 2b, left): a smoother decrease of intensity than in the case of a Lorentz line and a certain broadening, in qualitative agreement with the predictions of the theory [5].

In conclusion, we wish to note that we could determine in the present investigation in a direct manner the orientation of the magnetic moments in the hematite cell, in analogy with the result of the neutron-diffraction method [7].

The authors thank B. N. Samoilov, Yu. M. Kagan, and A. M. Afanas'ev for interest in the work and a discussion of the results, V. A. Balyakov, E. P. Stepanov, V. I. Ozhogin, and I. P. Perstnev for valuable advice, and M. A. Volkov for help with the measurements.

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PHOTOFISSION OF EVEN-EVEN NUCLEI AND STRUCTURE OF THE FISSION BARRIER

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Submitted 12 December 1968
ZhETF Pis. Red. 9, No. 2, 128-132 (20 January 1969)

We present in this paper experimental data on the cross sections and angular distributions of photofission fragments; some of them were published earlier [1]. They are analyzed in connection with the problem of the double-hump barrier. This hypothesis, now under intense discussion [2,3], apparently explains certain experimental facts which are in sharp disagreement with the traditional picture.

Measurements of the angular distributions of the fragments of photofission of Th^{232}, U^{238}, Pu^{238}, Pu^{240}, and Pu^{242} were made with the 12-MeV microtron of the Institute of Physics Problems in the interval of end-point energies $E_{max} = 5 - 8$ MeV, with the aid of glass fragment detectors.

The anisotropy of the scattering of the fragments results from the fact that the height and the form of the fission barrier depends on the angular momentum I, on the parity π^-, and on the K-projection of the angular momentum on the symmetry axis of the nucleus, along which the fragments are scattered. In our case, the compound nucleus is apparently produced only in the states 1^- and 2^+ as a result of dipole and quadrupole photoabsorption respective-