

# COLLECTIVE INTERACTION OF NUCLEI WITH RESONANT $\gamma$ -RADIATION

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**Abstract**

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*PHYSICS*

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## **COLLECTIVE INTERACTION OF NUCLEI WITH RESONANT $\gamma$ -RADIATION**

*(Presented by Academician A. P. Aleksandrov on 13.IX.1968)*

Under ordinary conditions, the interaction of nuclei with incident particles proceeds independently. But when the wavelength of the particles or radiation with which the nuclei interact is comparable with interatomic distances, the simultaneous participation of a large number of nuclei in the reaction is possible. This should also be true for resonant nuclear reactions, if the corresponding resonant interaction possesses the property of coherence. In a nuclear process of this type, the collective character of the interaction should lead to a change in the resonance parameters and substantially affect the entire course of the reaction, including the decay of the excited nucleus formed as a result of the reaction. The features of collective interaction should be manifested most sharply for a strictly regular distribution of nuclei—in perfect single crystals.

In <sup>(1-4)</sup> a dynamical theory was developed for the resonant scattering of  $\gamma$ -radiation and neutrons in ideal crystals, which not only confirms that, in scattering by regular systems of identical nuclei, the resonance parameters must change substantially, but also predicts new phenomena based on the collective interaction of nuclei: the formation of a collective nuclear level <sup>(1, 2)</sup>, the suppression of the inelastic channel of a nuclear reaction <sup>(3, 4)</sup>, and others.

The effect of suppression of the inelastic channel of a nuclear reaction should occur in an ideal crystal when the Bragg condition is satisfied: the probability of formation of the compound nucleus becomes equal to zero (in the simplest cases this is caused by the electric or magnetic field strength becoming zero), and a substance that is strongly absorbing becomes transparent.

We outlined a broad program for studying the collective interaction of nuclei with resonant  $\gamma$ -radiation and carried out the first experiments to investigate the diffraction of resonant  $\gamma$ -radiation in tin single crystals (the isotope Sn<sup>119</sup> has a Mössbauer transition with energy 23.8 keV).

The coherence of the process of resonant  $\gamma$ -ray scattering was experimentally confirmed by us in studies of Bragg diffraction in mosaic tin crystals containing 88% Sn<sup>119</sup>. In these experiments interference was clearly observed between reso-

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

nant and Rayleigh scattering, as well as Bragg diffraction of radiation resonantly scattered by nuclei <sup>(5)</sup>.

An experimental study of the resonant interaction of  $\gamma$ -rays with a regular system of nuclei was carried out with perfect single crystals of tin of natural isotopic composition. (The observation of the Borrmann effect in these crystals testifies to their sufficiently perfect structure <sup>(6)</sup>.) Bragg diffraction and Laue diffraction of resonant  $\gamma$ -radiation by nuclei and electrons were investigated.

The experimental apparatus consisted of a two-crystal  $\gamma$ -ray spectrometer combined with a Mössbauer spectrometer with

at constant velocity. The radiation selected by a monochromator\* with energy 23.8 keV (radiation source  $\text{Sn}^{119m}\text{O}_2$ ) was scattered by a tin single crystal of thickness  $400\ \mu$ . The scattered beams and the beams of  $\gamma$ -rays transmitted through the crystal were detected by a scintillation counter.

The Mössbauer scattering spectrum (the dependence of the intensity of the scattered radiation on the relative velocity of the source and scatterer) under

**Fig. 1.** Scattering spectrum in Bragg diffraction of  $\gamma$ -radiation in a single crystal of tin of natural isotopic composition. 1—calculated scattering spectrum for an ideal single crystal; 2—calculated scattering spectrum for an ideally mosaic crystal. Scatterer temperature  $100^\circ\ \text{K}$ . Crystal thickness  $400\ \mu$ . Reflecting planes (020)

Bragg diffraction from the (020) plane is shown in Fig. 1. The experimental spectrum differs from the theoretical dependence for crystals of ideally mosaic structure by a sharp decrease in the resonant absorption and agrees with the calculation carried out on the basis of the dynamical theory for an ideal crystal <sup>(7)</sup>. The agreement of the experimental spectrum with the results of the dynamical theory proves that Bragg reflection from a thick ideal crystal is determined by the dynamical character of scattering and is indirect evidence for the existence of the dynamical effect of suppression of the inelastic channel of the nuclear reaction.

**Fig. 2.** Dependence of the intensity of transmitted  $\gamma$ -radiation on the angle of rotation of the crystal about the Bragg angle in Laue diffraction in a tin single crystal of natural isotopic composition. *I*—at a relative velocity of the source and scatterer of 10 mm/sec; *II*—at the resonant velocity (2.55 mm/sec). Scatterer temperature  $120^\circ\ \text{K}$ . Crystal thickness  $400\ \mu$ . Reflecting planes (200)

The effect of suppression of the inelastic channel of the nuclear reaction was directly observed by us in the study of Laue diffraction of resonant  $\gamma$ -radiation by nuclei and electrons in a perfect tin single crystal. Figure 2 shows the dependence of the intensity of the beam of  $\gamma$ -rays transmitted through the crystal on the angle of rotation of the crystal about the Bragg angle. The scatterer temperature was 120° K.

Curve *I* was obtained at a relative velocity of the source and scatterer far from resonance and corresponds to anomalous transmission of  $\gamma$ -rays by the electron shells of atoms. Curve *II* was obtained at the resonant velocity (2.55 mm/sec, which corresponds to the chemical shift for Sn<sup>119</sup>O<sub>2</sub>). Each point of the experimental curves represents the total intensity of the radiation transmitted through the crystal.

\* Angular divergence of the  $\gamma$ -ray beam  $\sim 5'$ .

When the angles between the directions of the incident radiation and the reflecting crystallographic plane differ substantially from the Bragg angle, the resonant absorption in the crystal amounts to 38.5%. The Mössbauer component of the radiation passing through the crystal anomalously (part of this radiation is represented on the curves by the peak) is absorbed much more weakly. In the range of angles corresponding to the peak on the curves (this range is bounded by deviations of the mean angle of incidence of the beam from the Bragg angle lying within the beam divergence), even for all the radiation incident on the crystal the decrease of resonant absorption reaches, on average, 10%.\* The weakening of resonant absorption for such a position of the crystal, when the Bragg condition is satisfied for some part of the radiation incident on the crystal, is direct proof of the existence of the effect of suppression of the inelastic channel of a nuclear reaction.

It should be noted that suppression of the inelastic reaction channel has been observed in a tin single crystal possessing anisotropy of the Mössbauer effect. In such a crystal, when the Bragg condition is fulfilled, the nuclei do not become nodes of the magnetic field (the transition in Sn<sup>119</sup>-M1), but for  $\gamma$ -quanta with one polarization the amplitudes for formation of the excited state of the nuclei in the primary and diffracted waves prove to be equal in magnitude and opposite in sign and, owing to the coherence of these waves, the probability of forming an excited nucleus is zero. The observed effect does not occur in disordered systems and, consequently, it has been shown experimentally for the first time that the result of a nuclear reaction depends essentially on how the nuclei are arranged in space.

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\* With an angular divergence of  $\sim 5'$ , the greater part of the radiation falls on the crystals at angles far from the Bragg angle and passes through, being absorbed normally, which sharply lowers the effective value of the weakening of absorption. The effect of suppression of the inelastic channel should appear much more sharply with improved collimation of the incident beam, and also in the diffracted beam independently of the degree of collimation.

*Note: Figure translations are in progress. See original paper for figures.*

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