where $\tau_1 = 80$ μsec and $\tau_2 = 330$ μsec. From (6) it follows that in our model

$$V = V_0 \exp(-t/\tau_0), \tag{8}$$

where $\tau_0 \simeq [1.2\sqrt{\pi}(\gamma_e H_1/\omega_n)^2\delta]^{-1} \simeq 100 - 300$ μsec. We emphasize that the difference between (7) and (8) is due to the assumed model of random homogeneous distribution of the proton spins about the paramagnetic center.

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DIRECT DETERMINATION OF THE STRUCTURE FORMED BY CRYSTAL MAGNETIC FIELDS AT NUCLEI HAVING MOSSBAUER ISOTOPES

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We show in this paper that the character of the interference in Mossbauer scattering of γ quanta by a crystal depends on the structure formed by the crystal magnetic fields at the nuclei of the Mossbauer isotope, and depends by the same token on the magnetic structure of the crystal. An analysis of the picture of the diffraction and polarization of the Mossbauer radiation at the Bragg maxima makes it possible to determine the structure formed by the magnetic fields at the crystal lattice sites containing the Mossbauer nuclei. The physical cause of the influence of the magnetic structure on the character of the Mossbauer scattering lies in the dependence of the amplitude of the Mossbauer scattering on the direction of the magnetic field at the scattering nucleus.

Assume that a monochromatic γ-quantum beam is resonantly scattered by a single crystal containing a Mossbauer isotope, and let the magnetic ordering in the crystal produce at the nuclei magnetic fields sufficiently strong to split the Mossbauer radiation into individual Zeeman components. We shall assume that the crystal is ideal, the content of the Mossbauer isotope is 100%, and the nuclei have zero spin in the ground state and are rigidly secured at the crystal sites. These assumptions signify that the elastic scattering is fully coherent and that the Mossbauer factor is f = 1. Assuming also that the crystal is sufficiently thin, we neglect extinction. In the case of a fully polarized beam of primary γ quanta, the polarization of which is defined by a polarization vector $\vec{n}$, the cross section for elastic resonant scattering corresponding to a finite polarization defined by a polarization vector $\vec{n}'$ is of the form

$$\frac{d\sigma(\mathbf{k}, \mathbf{n}; \mathbf{k}'\mathbf{n}')}{d\Omega\mathbf{k}'} = A\left|\sum_m f_m(\mathbf{k}, \mathbf{n}; \mathbf{H}_m; \mathbf{k}', \mathbf{n}')e^{i(\mathbf{k}-\mathbf{k}')\mathbf{r}_m}\right|^2, \tag{1}$$

where $\vec{k}$ and $\vec{k}'$ are the wave vectors of the initial and scattered γ quanta, respectively,

$\vec{H}_m$ is the magnetic field at the nucleus in the m-th site of the lattice, f_m is the amplitude of the Mossbauer scattering of the γ quantum for the m-th site, and A is a factor of no further consequence. The summation in (1) is over the sites containing the Mossbauer isotope. Expression (1) can be transformed by a well-known method into

$$\frac{d\sigma}{d\Omega} = A' \left| \sum_m f_m e^{i(\vec{k} - \vec{k}')\vec{r}_m} \right|^2 \sum_r \delta(\vec{k} - \vec{k}' - \vec{r}), \tag{2}$$

where $\vec{\tau} = 2\pi\vec{b}$, $\vec{b}$ is the reciprocal-lattice vector of the crystal, and A' differs only by a factor from A in (1). Now m in expression (2) denotes the index of the summation over the sites containing the nuclei of the Mossbauer isotope, within the limits of one unit cell of the crystal, and $\vec{r}_m$ is the vector defining the position of the m-th site. Let us stop to discuss the case when the magnetic fields at the Mossbauer nuclei can differ only in direction, i.e., $|\vec{H}_m|$ does not depend on m. If the amplitude f_m were independent of the magnetic field, as is the case for x-ray scattering, then the diffraction pattern described by (2) would be determined by the unit cell of the crystal structure, regardless of whether or not the magnetic fields at the nuclei are ordered. In the presence of ordering of the magnetic field at the nuclei, with a period different from that of the crystal, formula (2) gives, owing to the dependence of f_m on the direction of the magnetic field, additional interference maxima corresponding to magnetic ordering. We note that the positions of these maxima do not coincide with the positions of the maxima of the Rayleigh scattering.

We now write out the explicit form of the amplitude of the Mossbauer scattering by a nucleus situated in a magnetic field, for the case of a split scatterer line. Using the results of [1,2], we express the amplitude of the Mossbauer scattering in the form

$$f(\vec{n}, \vec{k}; \vec{H}; \vec{n}', \vec{k}') = C(\vec{n}^* \cdot \vec{n}_0)(\vec{n}' \cdot \vec{n}_0'^*) \sqrt{I \cdot I'}, \tag{3}$$

where $\vec{n}_0$ and $\vec{n}_0'$ are the polarization vectors of the γ quanta with wave vectors $\vec{k}$ and $\vec{k}'$, emitted by the scattering nucleus in the field $\vec{H}$ in a transition opposite to the absorbing one, I and I' are the radiation intensities of the corresponding γ quanta, and C is a factor of no importance to us. The right side of (3) depends on $\vec{H}$ via $\vec{n}_0$, $\vec{n}_0'$, I, and I'. At the Bragg maximum we obtain with the aid of (2) and (3) for the polarization vector of the γ quantum scattered by the crystal in pure Mossbauer fashion

$$\mathbf{n}' = \frac{\sum_m \mathbf{n}'_{m0} (\mathbf{n} \cdot \mathbf{n}^*_{m0}) \sqrt{I_m I'_m}\, e^{-i(\vec{k} - \vec{k}')\vec{r}_m}}{\left| \sum_m \mathbf{n}'_{m0} (\mathbf{n} \cdot \mathbf{n}^*_{m0}) \sqrt{I_m I'_m}\, e^{-i(\vec{k} - \vec{k}')\vec{r}_m} \right|}. \tag{4}$$

The notation in (4) is the same as in (1) - (3), and the index m singles out the quantities pertaining to the m-th direction of the magnetic field. As follows from (4), information concerning the magnetic ordering is contained also in the polarization of the scattered radiation. In the scattering of an unpolarized beam, the polarization density matrix of the scattered radiation can be obtained from (4) by suitable averaging.

Let us stop to discuss the Mossbauer scattering of the γ radiation by a crystal with antiferromagnetic ordering of the magnetic fields at the Mossbauer nuclei (for example, a collinear antiferromagnet). In this case formula (2) for the scattering cross section takes the form

$$\frac{d\sigma}{d\Omega} = A\left|f_{\uparrow} + f_{\downarrow} e^{i(\mathbf{k}-\mathbf{k}')(\mathbf{r}_{\downarrow}-\mathbf{r}_{\uparrow})}\right|^2 \sum_{\tau} \delta(\mathbf{k}-\mathbf{k}'-\tau), \tag{5}$$

where $\vec{\tau}$ is the vector of the reciprocal lattice of the magnetic structure, and the symbols $(\uparrow,\downarrow)$ are introduced since there are only two mutually opposite non-equivalent direction of the magnetic field at the Mossbauer isotopes in this case. For the polarization vector of the scattered radiation, neglecting Rayleigh scattering, we can obtain from (5) (see (2) and (3))

$$\mathbf{n} = \frac{\mathbf{n}'_0(\mathbf{n}\cdot\mathbf{n}_0^*) \mp \mathbf{n}_0^*(\mathbf{n}'\cdot\mathbf{n}_0)}{\left|\mathbf{n}'_0(\mathbf{n}\cdot\mathbf{n}_0^*) \mp \mathbf{n}_0^*(\mathbf{n}'\cdot\mathbf{n}_0)\right|}, \tag{6}$$

where the upper sign pertains to the pure magnetic maxima and the lower one to the crystalline ones. We considered above only cases of fully coherent scattering. As is well known, allowance for factors that lead to a partial incoherence (crystal defects, crystal thermal vibrations, nonzero ground-state spin of the scattering nuclei, etc.) will not change the results qualitatively.

In conclusion, to illustrate the foregoing example of a collinear antiferromagnet, we present the values of the Bragg angles at which magnetic maxima occur for the scattering of Mossbauer radiation with energy 14.4 keV from Fe^{57} by antiferromagnetic single-crystal Fe_2O_3. The first two crystal maxima are at the Bragg angles ~16 and 23°, and the first two magnetic maxima at ~11 and 20°.

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E R R A T U M

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The last two lines of the article read "The first two crystal maxima are at the Bragg angles ∿16 and 23°, and the first two magnetic maxima at ∿11 and 20°." They should read: "The first two crystal maxima are at the Bragg angles ∿7.5 and 9°, and the first two magnetic maxima at ∿5 and 6°." This was pointed out to the authors by G. V. Smirnov.