# Selective detection of a Mössbauer reflection spectrum

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(Submitted 17 May 1986)
Pis'ma Zh. Eksp. Teor. Fiz. **44**, No. 4, 172–174 (25 August 1986)

Separate detection of resonantly reflected changed-energy and unchanged-energy $\gamma$ rays has been achieved. It is thus possible to observe a change in the hyperfine interaction in the reflector while the nucleus is in an excited state and to determine the probability for recoilless reradiation.

The ratio of the intensities of the spectral lines in the Mössbauer absorption spectrum of a thin polycrystalline sample with an isotropic Lamb-Mössbauer factor is determined by the probabilities for transitions between the corresponding levels. For detection in the usual way, the ratios of the intensities of the spectral lines in the Mössbauer absorption spectrum and the reflection spectrum of thin samples are identical, despite the fact that the different peaks in most reflection spectra contain different fractions of unchanged-energy and changed-energy $\gamma$ rays. The reason is that the intensities of the lines in a reflection spectrum are determined by the first step of the reflection process—the recoilless absorption—since the usual detection methods cannot distinguish between the unchanged-energy and the changed-energy $\gamma$ rays, whose formation occurs during the second step of the reflection—the reradiation. The spectra detected by the usual method do not contain information on the events which occur during the reradiation and which cause the change in the energy of the resonantly absorbed $\gamma$ rays. These events are the reradiation of $\gamma$ rays without or with recoil, the return of the nucleus to that unexcited level from which the excitation occurred or to another level, and a change in the hyperfine field while the nucleus is in an excited state. The change in the energy of the $\gamma$ rays which occurs as a result of the transition of the nucleus to another unexcited level or as a result of a change in the hyperfine field is measured by the selective-excitation double $\gamma$-resonance method,[1] but experimental difficulties have kept this method from being adopted widely, despite its long history.[2] The circumstance that in each particular case the fractions of the unchanged-energy and changed-energy $\gamma$ rays in each peak in the reflected spectrum are determined by the probability for recoilless reradiation, $f'$, and by the rate of change of the hyperfine field (if such a change occurs) makes it possible to work from the spectra of the unchanged-energy and changed-energy $\gamma$ rays to calculate $f'$ and the rate of change of the hyperfine field. Since in measuring the spectra of the unchanged-energy and changed-energy $\gamma$ rays it is necessary only to establish the fact that the energy of the reradiated $\gamma$ ray has not been changed—the magnitude of the change need not be determined—the experiment can be simplified substantially. Many problems in the selective-excitation double $\gamma$-resonance method can be solved by a vastly simpler method: the selective detection of the resonantly reflected $\gamma$ rays.

We have achieved a selective detection of resonantly reflected unchanged-energy and changed-energy $\gamma$ rays in a reflection experiment with the arrangement shown in Fig. 1. The Doppler motion is imparted to the reflector in a direction such that the

  

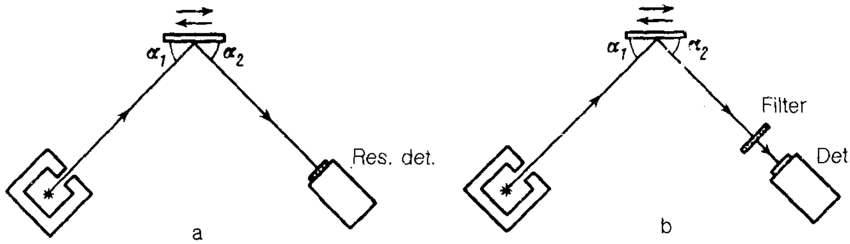


FIG. 1. Layout of the Mössbauer reflection experiment for the detection of (a) unchanged-energy $\gamma$ rays and (b) changed-energy $\gamma$ rays.

signs of the Doppler shift upon absorption and reradiation are opposite. Since the angle of incidence, $\alpha_1$, is equal to the angle of reflection, $\alpha_2$, the Doppler shift in the absorption is cancelled by that in the reradiation, $\pm E_\gamma v/c \cos\alpha_1 \mp E_\gamma v/c \cos \alpha_2 = 0$, and the reflected $\gamma$ rays do not acquire a Doppler shift. The $\gamma$ rays absorbed without recoil and reradiated without recoil have the same energy as $\gamma$ rays emitted from the source without recoil. In such an experimental arrangement, the unchanged-energy $\gamma$ rays are detected by a resonant detector (Fig. 1a), while the changed-energy $\gamma$ rays are detected by filtering the reflected $\gamma$ rays with a "black" resonant absorber (Fig. 1b). In our experiments, this black resonant absorber is made from double ferrocyanide with $^{57}$Fe, whose isomer shift is equal to that of the $^{57}$Co(Cr) source. This filter completely absorbs the unchanged-energy $\gamma$ rays while absorbing almost none of the $\gamma$ rays of other energies.

The selective-detection $\gamma$-resonance spectrum has a characteristic ratio of spectral-line intensities which depends on the elastic and inelastic processes which occur in the reflector during the reradiation. This ratio carries information on these processes. The ratios of the intensities of the ordinary magnetically split spectrum of the $^{57}$Fe nucleus in a thin polycrystalline sample are 3:2:1:1:2:3. During selective detection in the case of a time-independent hyperfine field, the intensity ratios in the unchanged-energy $\gamma$-ray spectrum are described by (we are ignoring the faint Rayleigh and Compton reflections[3])

$$9:4:1:1:4:9, \tag{1}$$

while the ratios in the changed-energy $\gamma$-ray spectrum are described by

$$(9-9f'):(6-4f'):(3-f'):(3-f'):(6-4f'):(9-9f'). \tag{2}$$

The probability for the recoilless reradiation of hematite has been determined from this formula and the measured changed-energy $\gamma$-ray spectrum of $\alpha$-$Fe_2O_3$ (Fig. 2). The result is $f' = 0.75 \pm 0.05$.

The deviation from these intensity ratios indicates that the hyperfine field varies in time (over time intervals comparable to $\tau_0$), and these deviations must be taken into account in each specific problem. For example, in the changed-energy $\gamma$-ray spectrum of hematite the intensity of the sixth split peak begins to increase as we approach the Morin temperature, at which a fluctuation of the electron spin begins,[1] while in the

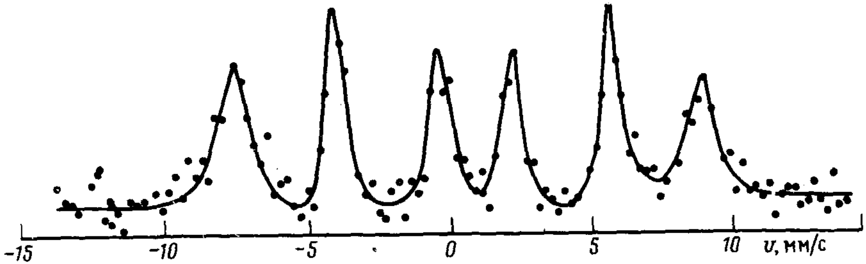


FIG. 2. Mössbauer reflection spectrum of changed-energy $\gamma$ rays from $\alpha$-$Fe_2O_3$ at room temperature.

unchanged-energy $\gamma$-ray spectrum this intensity instead begins to decrease; at the Morin point, where the fluctuation time is at a minimum, $\tau = 1.1 \times 10^{-7}$ s, the peak is nearly indistinguishable. The fluctuation time can be evaluated from the change in intensity.

I wish to thank A. M. Afanas'ev, L. L. Buishvili, and G. S. Smirnov for useful discussions and for encouraging this study. I also wish to thank A. V. Baluev for furnishing the double ferrocyanide for the black resonant absorber.

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[3]J. J. Bara, Phys. Status Solidi **58**, 349 (1980).

Translated by Dave Parsons