INVESTIGATION OF THE MÖSSBAUER SPECTRUM OF RESONANTLY-SCATTERED NUCLEAR RADIATION OF Fe^{57}

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The Mössbauer spectrum of resonance γ radiation of Fe^{57} was investigated. A method is proposed for measuring the relaxation time of nuclei in the excited state. This method is also useful in the simplification of interpretation of complex Mössbauer spectra.

THE Mössbauer effect has allowed us, for the first time, to observe directly and to investigate the hyperfine structure of nuclear levels. Figure 1 shows an energy level scheme of Fe^{57} in the lattice of iron metal.[1] If the energy of γ quanta incident on an iron scatterer corresponds to a transition of a nucleus from its ground state with the spin projection $+1/2$ to an excited state with the spin projection $-1/2$, the scattered radiation should include γ quanta of energies corresponding to transitions from an excited sublevel with the spin projection $-1/2$ to sublevels of the ground state having the spin projections $+1/2$ and $-1/2$. However, if during the lifetime of a nucleus in the excited state, some of the spins change their orientation and partly populate other excited sublevels, then the scattered radiation should include not only the lines corresponding to transitions from the excited sublevel but also other hyperfine structure lines.

Measurement of the Mössbauer spectrum of radiation scattered resonantly by a substance can give information on the relaxation of the spin of a nucleus in the excited state provided the relaxation times do not differ by more than an order of magnitude from the lifetime of the excited nucleus.

We attempted to carry out such measurements on nuclei of the Mössbauer isotope Fe^{57}. Figure 2 shows the experimental layout. Co^{57}, in stainless steel, of about 1 μCi activity, was used as the source. The scatterer was an iron foil 5 μ thick enriched to the extent of 20% with Fe^{57}. The radiation of the source, scattered by the iron foil, was analyzed by means of an absorber made of stainless steel (10 μ thick) enriched by 20% with Fe^{57}; the absorber and the source had the same Mössbauer line.

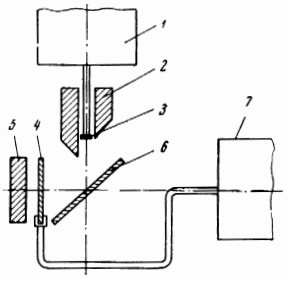

FIG. 2. Experimental layout: 1 – source vibrator; 2 – collimator; 3 – source; 4 – absorber; 5 – detector; 6 – scatterer, 7 – absorber vibrator.

The scatterer was fixed rigidly. The source and the absorber (analyzer) were attached to electrodynamic vibrators. The source and the absorber vibrated at the same constant frequency but the amplitudes of their motion (and, consequently, their velocities) could be varied independently. The motion could be in phase or in antiphase. (The motion was regarded as in phase when $V_{source\text{-}scatterer} > 0$ and $V_{absorber\text{-}scatterer} > 0$.) A photomultiplier with a NaI crystal was used as the detector. The recording system was based on a constant-velocity Mössbauer spectrometer, described in[2].

Figure 3 shows the dependence of the intensity of the 14.4-keV γ radiation, which had passed through the absorber, on the velocity of the absorber when the velocity of the source relative to the scatterer was -0.08 cm/sec. (This velocity of the source corresponded to the excitation of Fe^{57} nuclei in the scatterer from their ground state with the spin projection $+1/2$ to

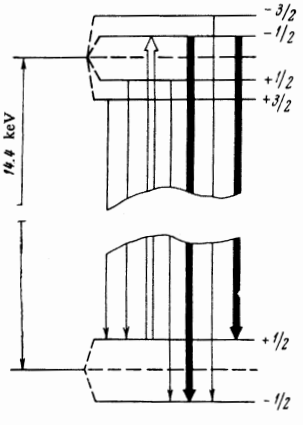

FIG. 1. Splitting scheme of the levels of the $3/2 \rightarrow 1/2$ transition of 14.4 keV energy in Fe^{57}. The double arrow represents the excited transition and the thick black arrows represent the transitions, observed in the spectrum of the scattered radiation.

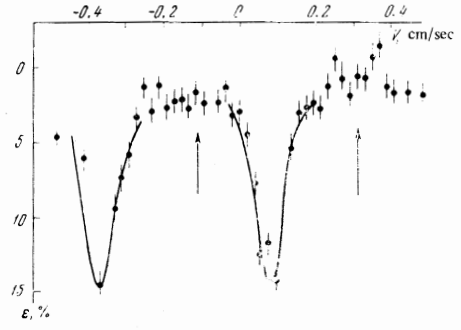

FIG. 3. Mössbauer spectrum of the scattered radiation. The right-hand peak represents the $-1/2 \rightarrow +1/2$ radiative transition, while the left-hand peak represents $-1/2 \rightarrow -1/2$. The arrows indicate the expected positions of the peaks corresponding to the transitions from the +1/2 sublevel.

an excited state with the spin projection $-1/2$; this transition is represented by a double arrow in Fig. 1.) The peaks in the spectrum, located at velocities of +0.08 and −0.37 cm/sec, represent transitions from the $-1/2$ sublevel to the $+1/2$ and $-1/2$ sublevels. These transitions are represented by thick black arrows in Fig. 1. It is interesting to note that the energy of the γ quanta emitted in the $-1/2 \rightarrow -1/2$ transition is higher than the energy of the incident radiation. The vertical arrows in Fig. 3, located at velocities of +0.32 and −0.11 cm/sec, represent the points at which we should observe peaks corresponding to the $+1/2 \rightarrow -1/2$ and $+1/2 \rightarrow +1/2$ transitions.

Unfortunately, the insufficiently strong activity of the source prevented us from obtaining a higher static accuracy in a reasonable time (~100 h). For the same reason, we were unable to investigate the edges of the spectrum since the broadening of the extreme peaks was very large for the solid angles used in the present investigation. Therefore, our measurements could yield only the lower limit of the relaxation time. Using the spectrum in Fig. 3 we estimated the upper limit of the ratio of the areas under the peaks corresponding to the $+1/2 \rightarrow -1/2$ and $-1/2 \rightarrow +1/2$ transitions. This estimate showed that the sensitivity of the method under our conditions was $\sim 3 \times 10^{-7}$ sec, i.e., that we could measure relaxation times $\tau \lesssim 3 \times 10^{-7}$ sec. Obviously, sources of activity of the order of tens of millicuries are required for more accurate measurements.

The method described may be useful in experiments with Mössbauer nuclides when the preparation of a source with a single narrow line is for some reason difficult but a one-line absorber is available. A narrow emission line can be obtained using such an absorber as a scatterer in conjunction with a sufficiently strong source. Moreover, such measurements give us an opportunity to simplify considerably the interpretation of complex and poorly resolved spectra and to make this interpretation more reliable. By exciting separate transitions in a many-line spectrum, we can separate it into a number of spectra, each of which represents transitions from only one excited level.

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[2] K. P. Aleshin, I. I. Lukashevich, B. N. Samoĭlov, V. V. Sklyarevskiĭ, A. P. Stepanov, and N. I. Filippov, PTÉ, No. 4, 43 (1964).

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