A STUDY OF THE MÖSSBAUER EFFECT ON Sm^{149}

V. P. ALFIMENKOV, N. A. LEBEDEV, Yu. M. OSTANEVICH, T. RUSKOV,[1] and A. V. STRELKOV

Joint Institute for Nuclear Research

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The experimental arrangement and results of measurements of the Mössbauer effect on the 22.5-keV γ line of Sm^{149}, using source and absorber of Sm_2O_3, are described. In the resonance absorption spectrum a single line was seen, broadened by a factor of 2.3 at 300°K. Estimates are given for the probability of recoilless emission and absorption and of the internal conversion coefficient of the 22.5-keV transition.

1. MEASURING TECHNIQUE AND APPARATUS

UP to now most work on the application of the Mössbauer effect to the solution of various physical problems has been carried out using the "good" Mössbauer γ transitions in Fe^{57}, Sn^{119}, and Au^{197}. We have studied the 22.5 keV γ transition of Sm^{149},[1-3] which with some development of the experimental technique can also serve as a good instrument for solving physical problems.

The 22.5-keV level in Sm^{149} is excited by K capture in Eu^{149} and has a lifetime of 1.1×10^{-8} sec.[6] The radioactive Eu^{149} was obtained from a spallation reaction by irradiating a Ta target with 660 MeV protons. Since most of the Eu^{149} nuclei are formed from the decay of Gd^{149} ($T_{1/2}$ = 9.3 days), the chromatographic separation of the europium fraction[7,8] was done a month after the irradiation. To introduce the Eu^{149} into the Sm_2O_3 crystal lattice we added 3-4 mg of samarium nitrate to a solution of ammonium lactate containing carrier-free Eu^{149}; the solution was then evaporated and the residue heated in air at 600°C for an hour. The samarium oxide thus obtained, which contained Eu^{149}, was fixed to a quartz backing with polyvinyl alcohol. The source activity in the 22.5-keV line was about 5×10^4 quanta/sec.

The 22.5 keV line is apparently highly converted, and its resolution from the apparatus γ spectrum is made difficult by the nearby x-ray of samarium ($\sim$41 keV). A satisfactory apparatus γ spectrum could be obtained (Fig. 1) using a proportional counter. The main characteristics of our counter are: diameter of working volume-

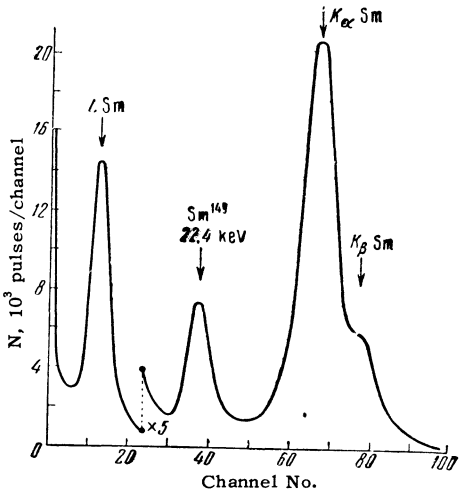

FIG. 1. Apparatus γ spectrum from Eu^{149} source. Detector is a proportional counter.

70 mm; length- 150 mm; side window of beryllium; working mixture- argon plus 10% methane, pressure 3-5 atm; for purifying the gas the counter was fitted with a continuously operating calcium purifier.

The resonance absorption spectrum was obtained by the usual method of Doppler shift using an electromagnetic vibrator. The vibrator (Fig. 2)

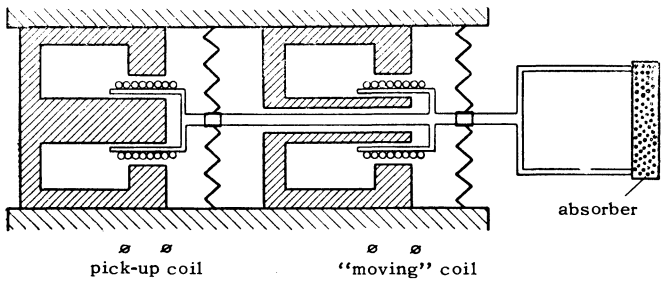

FIG. 2. Schematic of electromagnetic vibrator.

[1]Now at the Physics Institute of the Bulgarian Academy of Sciences, Sofia.

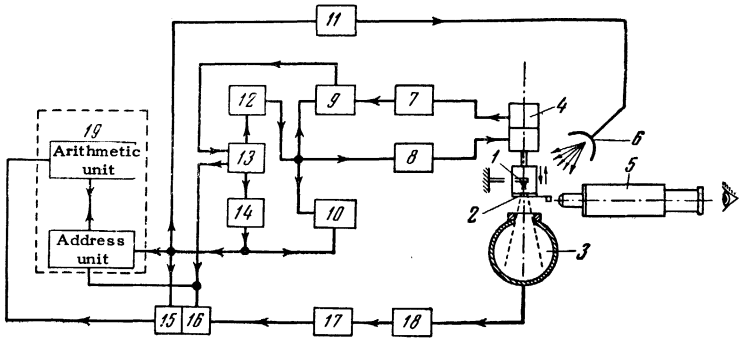

FIG. 3. Block diagram of electronic equipment and experimental apparatus: 1–source, 2–absorber, 3–proportional counter, 4–vibrator, 5–microscope, 6–pulsed light source, 7–nonlinear signal amplifier with "pickup" coil, 8–power amplifier, 9–device for measuring phase of motion, 10–measurer of phase of output of memory bank, 11–input to pulsed light source, 12–first scaler, 13–trigger pulse generator, 14–second scaler, 15, 16–blocking circuits for switching address on and off, 17–single channel analyzer, 18–broadband amplifier, 19–multichannel memory bank.

consisted of two standard loud speaker magnets. Two moving coils were placed in the magnet gaps and coupled by an aluminum rod. The windings were centered in the gaps by phosphor bronze diaphragms. The absorber was mounted on a frame, rigidly attached to the coils, the source was placed inside the frame on an independent support and was kept fixed during the measurements. The coils of the vibrator together with the absorber were set in harmonic motion with the resonance frequency of the vibrator (30—40 cps).

To get the dependence of the counting rate in the detector on the velocity of the motion, and to excite the vibrator, we used the following scheme (Fig. 3). We had a generator of trigger pulses with frequency n times[2)] the natural frequency of the vibrator, and the frequency of the vibrator could be controlled within limits using an external voltage. Pulses from the generator were fed into a scaling circuit with scaling factor n, giving a rectangular voltage pulse at the output. After power amplification this voltage was fed to the "moving" coil of the vibrator. The sinusoidal voltage from the "pickup" coil, induced by the motion, was fed, after nonlinear shaping to rectangular form, to one arm of an electronic phase meter. The other arm of the phasemeter was fed by the voltage exciting the vibrator. The constant voltage from the output of the phase meter, which is proportional to the phase difference between the driving force (supply voltage) and the velocity of the motion (the voltage from the "pickup" coil) controlled the frequency of the trigger pulse generator, thus giving a feedback which stabilized the generator frequency. This system assured long term stability of the frequency and amplitude of the vibrator motion over a range of velocities from a fraction of a millimeter to tens of centimeters per second. The unscaled trigger pulses from the generator went to the address unit of the memory, switching all n channels after one vibration period.

The γ radiation passing through the absorber was recorded by the proportional counter; the interesting region of the pulse amplitude spectrum was selected by an AADO-1 single channel analyzer. After passing through a blocking and shaping circuit, the pulses from the AADO-1 were recorded in the arithmetic unit of the memory. Each channel of the memory corresponded to a definite interval of values of the absorber velocity relative to the source. The channel number i and the average value of the velocity V were related as follows:

$$V_i = V_{max} \cos\left(\frac{2\pi}{n} i + \varphi\right). \qquad (1)$$

To fix the starting phase of the memory output (the value of φ) we used a second scaling circuit with scaling factor n; a pulse from its output sets the address of the arithmetic unit to zero. With the first counting circuit set to zero, one could introduce any number into the second from 0 to n-1, which enabled the establishment of n discrete phase values of the output of the memory within a single period. But this control was used only for convenience, since the decoding of the apparatus spectrum is not difficult with any value of the starting phase. In fact any point of the velocity spectrum (for example, the point of maximum absorption) appears twice during one period of the motion. Thus the apparatus spectrum of velocities consists of two parts which are mirror

[2)] n is the number of channels in the memory. We used two, with 100 (AI-100) and 200 channels.

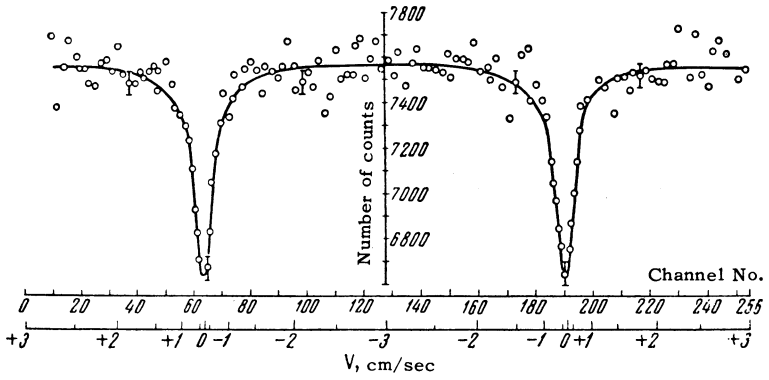

FIG. 4. Apparatus velocity spectrum, absorber of 50 mg/cm² Sm_2O_3.

images (Fig. 4). For example, the value of the velocity V_a corresponding to the maximum absorption can be calculated from the apparatus spectrum using the following formula:

$$V_a = -V_{max}\cos\frac{(i-i')\pi}{n}, \qquad (2)$$

where V_{max} is the velocity amplitude, i and i′ are the channel numbers in which the maximum is observed, and n is the number of channels in the memory.

Direct control of the law of motion of the vibrator and a definite V_{max} were obtained using a stroboscope with a pulsed light source IFB-300. The flashing of the lamp was done by a pulse from the second counting circuit, and consequently could be synchronized with the operation of any of the n channels. The measurement of displacement of the vibrator was done with a microscope. The accuracy in determining the velocity was not worse than 3—5%.

2. DISCUSSION OF RESULTS

The measured velocity spectra at room temperature showed that, in the resonance absorption spectrum of Sm^{149} in Sm_2O_3, up to velocities of 6 cm/sec there is a single component whose shape is close to Lorentzian. Assuming a single line in emission and absorption, using least squares we found for the width of the emission and absorption line a value $\Gamma_e = (1.35 \pm 0.1) \times 10^{-7}$ eV, or 1.8 mm/sec, which is in satisfactory agreement with the data of [1,4,5]. The shift between the emission and absorption lines, as expected, was practically equal to zero ($\Delta E < 0.2 \times 10^{-7}$ eV).

The line width corresponding to the lifetime is less than this by a factor of 2.3. Thus the value found for Γ_e should rather be regarded as the effective value for Sm_2O_3.

The spin of the ground state of Sm^{149} is $^7/_2$, the spin of the 22.5 keV level is unknown, but from the data of Harmatz et al [3] it can differ from that of the ground state by no more than one. Under these conditions a quadrupole splitting should give at least eight components. The observed line width is too small for this structure to be resolved, which also explains the Lorentzian shape of the absorption line as a function of relative velocity.

Assuming that the multicomponent spectra in emission and absorption can be replaced to sufficient accuracy by a single emission and absorption line of width Γ_e, we can use for the dependence of maximum absorption on absorber thickness the familiar formula

$$\varepsilon(n) = f[1 - \exp(-{}^1/_2 n\sigma_0 f')\, I_0({}^1/_2 n\sigma_0 f')], \qquad (3)$$

where n is the absorber thickness, and f and f′ are the probabilities for recoilless emission and absorption,

$$\sigma_0 = \frac{2J^*+1}{2J+1}\frac{\lambda^2}{2\pi}\frac{1}{1+\alpha}. \qquad (4)$$

Treating the data by least squares (Fig. 5), using expression (3), gave the following results:

$$f = (38 \pm 4)\cdot 10^{-2}, \qquad f'\sigma_0 = (3.2 \pm 0.7)\cdot 10^4 \text{ b}. \qquad (5)$$

Setting f = f′, we get for σ_0 the value

$$\sigma_0 = (8.4 \pm 2.5)\cdot 10^4 \text{ b}.$$

In the work of Harmatz et al,[3] two values are suggested for the spin J* of the excited state: $^5/_2$ or $^7/_2$. From (5) the internal conversion coefficients

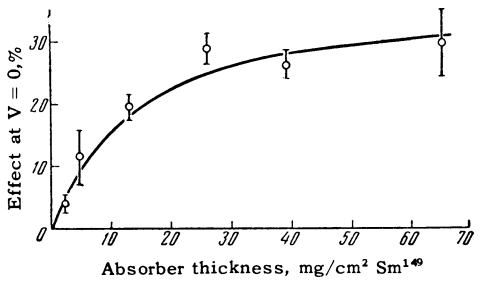

FIG. 5. Dependence of resonance absorption at zero velocity on absorber thickness.

are: $\alpha = 41 \pm 12$ for $J^* = 5/2$, $\alpha = 56 \pm 17$ for $J^* = 7/2$. In this same work they found the value 0.011 for the ratio of the probabilities of E2 and M1 transitions which, using the computed values of the conversion coefficients,[9] gives $\alpha = 38$. In the work of Sychikov et al,[10] which is apparently more accurate, they give a probability ratio of $(31 \pm 0.3) \times 10^{-4}$, which gives $\alpha = 28$. Our result is in satisfactory agreement with these data with an excited state spin of $5/2$, although the accuracy is not yet good enough for a reliable determination of the spin.

The low acticity of the source unfortunately did not permit us to improve the results and make other measurements of interest. Work with Sm^{149} will be continued after we obtain stronger sources.

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