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RESONANCE SCATTERING OF GAMMA QUANTA IN Te^{125}

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By recording the x rays following internal conversion in the resonance absorption in Te^{125}, we have observed the Mössbauer effect for the 35.5 keV γ rays of Te^{125m}. For TeO$_2$, we found the values $f = 0.12 \pm 0.03$ at $-190°C$ and $f = 0.067 \pm 0.008$ at room temperature. The half-life of the 35.5-keV level was measured to be $(1.4 \pm 0.2) \times 10^{-9}$ sec, which agrees with the result from measurements of delayed coincidences.

1. INTRODUCTION

WE have studied the resonance for the 35.5-keV γ rays emitted by Te^{125m}, whose decay scheme is shown in Fig. 1.

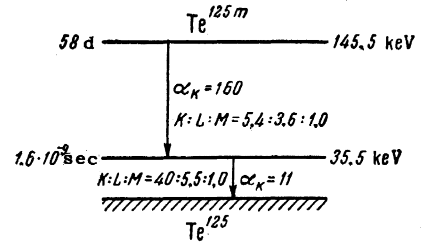

FIG. 1. Decay scheme of Te^{125m}.

The usual resonance absorption method cannot be used in this case since the 35.5-keV transition is highly converted and the weak γ line of this transition cannot be separated by the scintillation spectrometer from the intense x rays at 27.4 and 31.2 keV, which cannot be filtered out. We therefore used the procedure of counting x rays following conversion in the resonance on the scattering nuclei.

2. DESCRIPTION OF APPARATUS AND EXPERIMENT

The Te^{125m} was obtained by neutron irradiation in a reactor of metallic tellurium enriched to 86% Te^{124}. The irradiated tellurium was in the form of the dioxide, TeO$_2$, from which a 20 mg/cm^2 source was prepared. The scatterers were prepared by precipitating the dioxide TeO$_2$, enriched to 92% in Te^{125}, onto an aluminum backing 5 μ thick.

The source 1 (Fig. 2), which is cooled by liquid nitrogen in a Teflon container, is set in reciprocating motion at constant speed by an appropriately shaped cam. The speed of the source is changed by means of multi-step pulleys and a variable speed drive, to which the motion is transmitted from an electric motor via a worm gear. The scatterer 2 is placed inside the NaI (Tl) detector crystal 3, which is a hollow cylinder with i.d.27 mm, wall thickness 4.6 mm, and height 12 mm, halfway up the cylinder. The crystal is placed on an FÉU-13 photomultiplier. The lead collimator 4, placed over the crystal, shields the direct radiation from the source. To reduce scattering from the inner walls of the collimator, the walls are grooved. Below the scatterer, on the end face of the photomultiplier there is a lead plate 5 which shields the crystal from radiation scattered by the walls and other parts of the photomultiplier. The plate itself scatters quite weakly because of the deep cut made in it.

The scintillation spectrometer records the x rays emitted by the scatterer, together with a small admixture of resonantly scattered γ quanta, on a background of radiation which is scattered nonresonantly by the material of the scatterer, as well as the backing, the lead, etc. The filter 6, of 400 μ copper foil, serves to increase the fraction

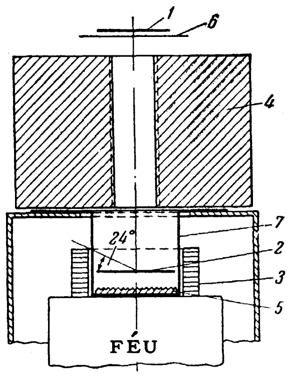

FIG. 2. Geometry of the experiment.

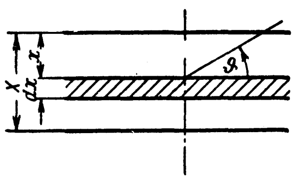

FIG. 3.

of γ quanta in the radiation incident on the scatterer and to reduce the background. The spectrometer is shielded from light by the black paper can 7.

Pulses from the photomultiplier pass through an amplifier and a single-channel discriminator to two PS-1000 counting circuits, one of which operates while the source moves toward the scatterer, the other while it moves in the opposite direction. During the reversal of the direction of motion (in the transition sections of the cam profile), both counting circuits are switched out. Control of the operation of the counting circuits is accomplished by a pair of relays which are set in operation by a sliding contact which is attached to the same shaft as the cam. The instability of the recording equipment did not exceed 0.3%.

3. COMPUTATIONS OF THE SIZE OF THE EFFECT AND RESULTS OF MEASUREMENTS

We introduce the relative intensity of the recorded x rays resulting from resonance absorption of the γ rays (we neglect the contribution of the resonantly scattered γ quanta):

$$S = I/I_0, \tag{1}$$

where I is the number of recorded x rays, which appear as a result of resonance absorption (determined from the difference in counting rate at zero speed and at high speed), I_0 is the number of γ quanta incident on the scatterer.

Consider an elementary layer dx of the scatterer at a distance x from the surface (Fig. 3). The relative intensity of the x rays produced in it as a result of the resonance absorption of γ rays is given by the formula (the first integral gives the x-ray intensity for zero speed, the second for very high speeds):

$$\begin{aligned} dS &= \Big[\int e^{-(\mu_{\mathrm{n}}+\mu_{\mathrm{e}})x}\Big(\frac{\alpha_K\omega_K}{\alpha+1}\mu_{\mathrm{n}} + \omega_K\mu_{\mathrm{p}}\Big)\Phi(E)\,dE \\ &\quad - \int e^{-\mu_{\mathrm{e}}x}\omega_K\mu_{\mathrm{p}}\Phi(E)\,dE\Big]B'\,dx = \Big[\int e^{-(\mu_{\mathrm{n}}+\mu_{\mathrm{e}})x}\frac{\alpha_K\omega_K}{\alpha+1} \\ &\quad \times \mu_{\mathrm{n}}\Phi(E)\,dE + \omega_K e^{-\mu_{\mathrm{e}}x}\int (e^{-\mu_{\mathrm{n}}x} - 1)\,\mu_{\mathrm{p}}\Phi(E)\,dE\Big]B'\,dx, \end{aligned} \tag{2}$$

where μ_{e} is the coefficient of total electronic absorption of γ quanta in the scatterer, μ_{n} is the coefficient of resonance absorption of γ quanta by nuclei of the scatterer, α_{K} is the K-shell conversion coefficient, α is the total conversion coefficient, ω_{K} is the fluorescence yield of the x rays ($\omega_{\mathrm{K}} = 0.85$)[1], μ_{p} is the absorption coefficient for the photoeffect, $\Phi(E)$ is the energy distribution of γ quanta emitted by the source without recoil, and B′ is the probability of detecting an x ray produced in the scatterer. Furthermore,

$$B' = \frac{1}{4\pi}\int_{\Omega} \exp(-\mu_R x/\sin\vartheta)\,d\Omega, \tag{3}$$

where μ_{R} is the absorption coefficient of the scatterer for x rays, Ω is the solid angle within which the x rays from the scatterer impinge on the detector crystal. For small values of μ_{R}, we can replace x in (3) by its average value X/2.

For $\mu_{\mathrm{n}}x \ll 1$ (thin scatterer), the second term in the final formula (2) can be neglected. Introducing

$$B = B'\alpha_K\omega_K/(\alpha + 1) \tag{4}$$

and integrating dS with respect to x, we obtain

$$S = B\int_0^X e^{-\mu_{\mathrm{e}}x}\Big[\int e^{-\mu_{\mathrm{n}}x}\mu_{\mathrm{n}}\Phi(E)\,dE\Big]dx. \tag{5}$$

The x integral in (5) describes the resonance absorption of γ quanta in the scatterer, and consequently[2]

$$S = Bf\exp(-\mu_{\mathrm{e}}X)\,[1 - \exp(-f'N\sigma_0X/2)\,J_0(if'N\sigma_0X/2)], \tag{6}$$

where f and f′ are, respectively, the probabilities of recoilless emission and absorption of γ quanta. From (6) and (1) we get

$$f[1 - \exp(-f'N\sigma_0X/2)\,J_0(if'N\sigma_0X/2)] = I/I_0B\exp(-\mu_{\mathrm{e}}X). \tag{7}$$

The quantities on the right of (7) can be found from the geometry of the experiment and the results of the measurements. The values of B for the scatterer thicknesses used by us are: 1) X = 3.5 mg/cm², B = 0.23; 2) X = 5.0 mg/cm², B = 0.22; 3) X = 8.5 mg/cm², B = 0.20.

To determine I_0 we must compute the fraction of γ quanta in the radiation incident on the scatterer. From the decay scheme of Te^{125m} we find that the ratio of the intensity of the x rays (27.4 and 31.2 keV) to the intensity of the γ radiation is 18.5 ω_{K} = 15.7.

Taking account of the difference in absorption of the source material for the various radiations (the absorption coefficient is 8 cm²/g for x rays and 25.8 cm²/g for γ rays), we find for the ratio the value 19.1. The attenuation of the radiation by a copper filter in the experimental geometry was measured using a flat NaI (Tl) crystal placed at

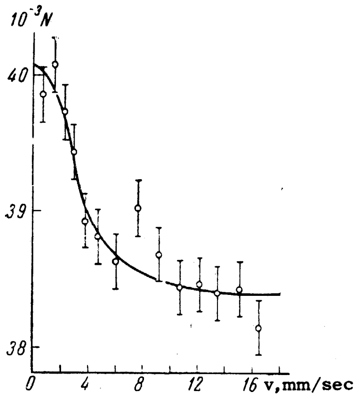

FIG. 4. Dependence of recorded radiation intensity on source velocity v (results for positive and negative velocities combined).

the position of the hollow cylinder crystal. To measure the attenuation of the γ rays we used the cerium x ray (34.5 keV) which has almost the same energy. It was found that the copper filter transmits 3.2% of the x rays and 12.9% of the γ quanta. Thus the ratio of the x ray and γ intensities after passing through the filter becomes 4.8 ± 0.4. By measuring the total number of quanta incident on the flat crystal, we find the value of I_0.

From measurements of the effect with the source uncooled and cooled to liquid nitrogen temperature (in both cases the scatterer was not cooled) it was found that $f = (1.7 \pm 0.17) f'$.

Computing the value of $C = I/I_0 B \exp(-\mu_e X)$ for the scatterer thicknesses X used, and using the graph of the function in square brackets in (7), one can easily find the appropriate values of f′.

The computations gave:

X, mg/cm²	3.5	5.0	8.5
C, %	1.3±0,2	1.65±0.25	2.5±0.4
f'	0.070±0,009	0.065±0.008	0.065±0.008

The average was $f' = 0.067 \pm 0.008$; $f = 0.12 \pm 0.03$.

The half-width of the curve (Fig. 4), taken for X = 3.5 mg/cm² and a source temperature of −190° C, gives for the half-life of the 35.5-keV level the value $(1.4 \pm 0.2) \times 10^{-9}$ sec (taking account of the fact that the observed width of the line is 2.15 times the natural width, as a result of self-absorption in the source and the finite thickness of the absorber), which agrees with the result obtained by Graham and Bell[3] using delayed coincidences: $(1.58 \pm 0.15) \times 10^{-9}$ sec.

Measurements using a scatterer of metallic tellurium (4 mg/cm²), with the same enrichment as for the TeO_2, showed no significant effect at room temperature. Thus in this example we again see that the presence of a light atom in the lattice increases the probability for recoilless emission of γ quanta. A theoretical basis for this effect has been given by Kagan.[4]

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