RESONANCE SCATTERING OF GAMMA QUANTA BY As^{75}, Sb^{123} AND Re^{187} NUCLEI

Yu. K. SHUBNYĬ, D. K. KAIPOV, and R. B. BEGZHANOV

Institute of Nuclear Physics, Academy of Sciences, Kazakh SSR, and
Institute of Nuclear Physics, Academy of Sciences, Uzbek SSR

Submitted to JETP editor December 21, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) 47, 16-20 (July, 1964)

Resonance scattering of γ quanta on As^{75}, Sb^{123}, and Re^{187} nuclei was investigated by employing Ge^{75}, Sn^{123}, and W^{187} sources. The values obtained for the lifetimes of the excited states are $\tau_\gamma(M1) = (1.7 \pm 0.3) \times 10^{-11}$ for the As^{75} 0.265-MeV level, $\tau_\gamma(M1) = (8.9 \pm 3.0) \times 10^{-10}$ for the Sb^{123} 0.161-MeV level, and $\tau_\gamma(E1) = (4.1 \pm 2.0) \times 10^{-10}$ sec for the Re^{187} 0.686-MeV level.

THE nuclear resonance scattering method was used in this investigation to determine the lifetimes τ_γ of the excited states of As^{75}, Sb^{123}, and Re^{187}, with respective energies 0.265, 0.161, and 0.686 MeV. The sources used were the radioactive isotopes $Ge^{75}(T_{1/2} = 82$ min), $Sn^{123}(T_{1/2} = 41$ min), and $W^{187}(T_{1/2} = 24$ hours). When radioactive isotopes are used for resonance excitation of nuclei the problem arises of compensation for the energy lost by the γ quantum to nuclear recoil in emission and absorption. All the methods used for this purpose are based on the Doppler broadening of the γ line (due to recoil from the preceding β-γ transitions[1,2], to heating of the source[3], or to mechanical motion of the source in the ultracentrifuge[4]). The low transition energies of As^{75} and Sb^{123} make it possible to observe the resonance scattering and determine τ_γ by the thermal method. When solid sources (germanium oxide and metallic tin) are used the time τ_{col} between the collisions of the recoil nuclei with the surroundings is considerably smaller than τ_γ, and the shape of the emission line is determined by the thermal motion of the radiating nuclei. The effective cross section calculated for this case is

$$\sigma(T) = 3.6\cdot 10^{-3}\frac{\Gamma_\gamma^2}{E_\gamma^3\Gamma}\frac{f(\theta)}{4\pi}\frac{g_2}{g_1}\left[\left(\frac{A}{T}\right)^{1/2}\exp\left(-3.1\cdot 10^{-6}\frac{E_\gamma^2}{TA}\right)\right]$$

where g_2 and g_1—statistical weights of the excited and ground states of the nucleus, E_γ—transition energy, Γ_γ—level radiation width connected with the transition to the ground state, Γ—total level width, $f(\theta)$—correlation function, and T—average effective temperature of the source and scatterer. Figure 1 shows the temperature dependence of σ, calculated by means of this formula for 0.161–0.265-MeV γ transitions in Sb^{123} and As^{75}.

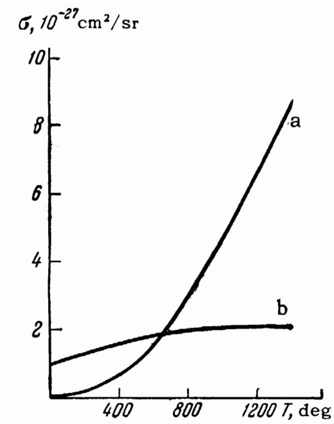

FIG. 1. Dependence of the resonance scattering cross section on the source temperature: a – Ge^{75} source, $\Gamma_\gamma = 4.1 \times 10^{-5}$ eV, b – Sn^{123} source, $\Gamma_\gamma = 6.6 \times 10^{-7}$ eV.

In the case when $\tau_{col} > \tau_\gamma$ (gaseous source), the form of the emission line (microspectrum) is determined by the radioactive decay that leads to the investigated level. The recoil from the preceding 0.63-MeV β transition in Re^{187} brought the γ-quantum energy (0.686 MeV) back to the resonant value. The W^{187} source was used in the form of WO_3, which sublimates above 1000°C.

The cross section of the resonance scattering can be determined from its intensity. It is connected with the level width Γ_γ by the relation

$$\bar{\sigma} = \frac{g_2}{g_1}\frac{\lambda^2}{4}P(E)\Gamma_\gamma\frac{\Gamma_\gamma}{\Gamma},$$

where P(E)—fraction of the resonant γ quanta in the microspectrum.

The isotopes Ge^{75} and Sn^{123} were obtained by irradiating the stable isotopes Ge^{74} and Sn^{122}, enriched to 91 and 80.2% respectively, in a reactor. The Ge^{75} and Sn^{123} activities were 10 and 80 mCi at the start of the measurements. The

W^{187} isotope was obtained by irradiating W^{186} in the form of tungsten oxide enriched to 98.9%, for 20 hours. After the irradiation, the WO_3 was subjected to repeated roasting in air and placed in a quartz ampoule that was thoroughly pumped out and sealed. The measurements yielded the resonant and Rayleigh scattering intensities. The cross section for resonant scattering was calculated both by numerical integration over the volume of the scatterer and by comparison of the resonance effect with the Rayleigh scattering, the cross section of which can be calculated [5].

Figure 2 shows a diagram of the experimental set-up, in which the individual parameters (screen thickness, scattering angle, thickness of absorber ahead of the crystal) were chosen separately for each isotope. In all cases the single-channel pulse analyzer was tuned to the photopeak, and the width of the analyzer window was 5 V.

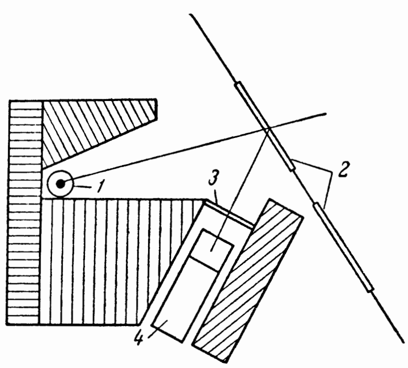

FIG. 2. Diagram of experimental set-up: 1 — electric furnace with source (Ge^{75} or W^{187}), 2 — scatterers, 3 — Pb or Cu filter (Sn^{123}), 4 — FÉU-12B photomultiplier with NaI(Tl) crystal.

a) $Ge^{75} \rightarrow As^{75}$. Figure 1 shows that heating the source to 1000—1200° greatly increases the resonant scattering cross section. During the course of the experiment the source was heated to 1050°C. The scattering substances used were metallic arsenic (in powdered form) and copper (for comparison). The dimensions of the scatterers were $15 \times 15 \times 0.5$ cm, and the scattering angle was 131°. At a source temperature 1050°, the resonance effect increased the scattering from the arsenic by an average of 30 counts/minutes, amounting to ~ 20 per cent of the total counting rate.

Figure 3 shows the scattered radiation spectrum obtained with a 100-channel pulse analyzer. The resonance scattering cross section was found to be $(4.9 \pm 0.6) \times 10^{-27}$ cm²/sr, with account of the absorption of the resonant radiation in the scatterer and of the angular distribution of the resonance-scattered γ quanta for the spin sequence $3/2 - 3/2 - 3/2$:

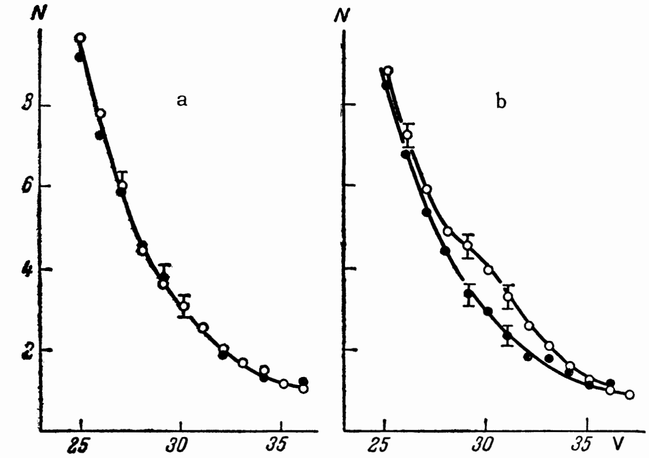

FIG. 3. Resonance scattering by As^{75} nuclei. Spectrum of scattered radiation: a — source at temperature 23°C and b — 1050°C. o — As scatterer, • — Cu scatterer.

in this case $f(\theta) = 1 + 0.16\, P_2(\cos\theta)$. The lifetime of the 0.265-MeV level of As^{75} was found to be $(1.7 \pm 0.3) \times 10^{-11}$ sec. The value obtained for τ_γ is in good agreement with the data of Metzger [6,1] who obtained for τ_γ values $(1.57 \pm 0.10) \times 10^{-11}$ and $(1.6 \pm 0.2) \times 10^{-11}$ sec by the method of nuclear resonance scattering, using Se^{75} as a source.

b) $Sn^{123} \rightarrow Sb^{123}$. The resonance effect was measured at a source temperature of 23°C, with allowance for the temperature variation of the cross section $\sigma(T)$ (Fig. 1) and for the half-life of Sn^{123}. The scattering substances were metallic antimony and tellurium (in powder form). The average scattering angle was 127°. To determine the Rayleigh scattering from Sb, an aluminum scatterer was used, so chosen that the Compton scattering from it and from the Sb scatterer was the same within 0.1 per cent. The efficiency of the antimony and tellurium scatterers under nonresonant conditions was determined by using Ba^{139}($T_{1/2}$ = 80 min) and Ce^{141}($T_{1/2}$ = 28 days) with γ-transition energies 0.165 and 0.145 MeV, respectively.

The average resonance scattering intensity was 20 counts/min, corresponding to 1 per cent of the total counting rate and $1/31$-st of the Rayleigh scattering. The resonance scattering cross section was found to be $(2.5 \pm 0.7) \times 10^{-27}$ cm²/sr. In the determination of τ_γ, account was taken of the relative content of the Sb^{123} nuclei in the natural antimony, and of the angular distribution of the scattered quanta for the spin sequence $7/2 - 5/2 - 7/2$. The lifetime τ_γ for the Sb^{123} 0.161-MeV level was found to be $(8.9 \pm 3.0) \times 10^{-10}$ sec, in satisfactory agreement with the data of Schmorak et al. [7], where the method of delayed coincidences yielded $\tau_\gamma = 10.7 \times 10^{-10}$ sec. The investigated M1 transition between the states $d_{5/2}$ and $g_{7/2}$ is l-forbidden ($\Delta l = 2$). The hindrance factor calculated for this case, with allowance for the statistical factor, amounts to 180.

c) $W^{187} \rightarrow Re^{187}$. A source with activity ~ 20 mCi was used, as already noted, in the form of the compound WO_3. Since the β-transition recoil energy is lower than the binding energy of the WO_3 molecule (~ 9 eV), we can assume that the recoil is experienced by the entire molecule, so that exact calculation of the microspectrum is possible. The lifetime τ_γ of the Re^{187} 0.686-MeV level can be determined from the resonance scattering intensity. The calculated value of P(E) is 0.77 eV^{-1}, without account of β-γ correlation, under the assumption that the recoil due to absorption of the γ quantum is experienced by the Re^{187} nucleus. In the experiment with W^{187} the scattering substances were the compounds $Ba(ReO_4)_2$ and WO_3 (for comparison). The scatterer dimensions were $15 \times 15 \times 1$ cm, and the average scattering angle was 122°. The measurements were made with a single-channel pulse analyzer tuned to the 0.686-MeV photopeak. The sublimability of WO_3 was investigated experimentally.

The measurements were made with six solid and five gaseous sources. The measurements with each source lasted 24 hours. The data reduction (total of 1200 pairs) has shown the additional scattering from the $Ba(ReO_4)_2$ to be insignificant, amounting to (0.7 ± 0.3) pulse every two minutes in the case of the gaseous source. This corresponds to ~ 1 per cent of the total counting rate. Putting $\Gamma_\gamma/\Gamma = 0.5$, the average cross section for resonance scattering was found to be $(5 \pm 2) \times 10^{-28}$ cm^2, corresponding to $\tau_\gamma = (4.1 \pm 2.0) \times 10^{-10}$ sec for the Re^{187} 0.686-MeV excited-state lifetime.

Vartapetyan[8] measured τ_γ for the 0.686-MeV level by the delayed coincidence method and obtained $(3 \pm 1) \times 10^{-10}$ sec. The results obtained here can be compared with the Nilsson-model calculations[9]. The 0.686-MeV level with spin $5/2$ corresponds to Nilsson level $5/2$ [532] No. 36. Calculation yields $\sim 4.3 \times 10^{-11}$ sec for the lifetime relative to the E1 transition to the ground state, This is one order of magnitude less than the time τ_γ obtained in the present work. A similar degree of forbiddeness is characteristic also of the other E1 transitions in the region of heavy nuclei.

1 F. R. Metzger, Phys. Rev. **110**, 123 (1958).

2 N. N. Delyagin, JETP **37**, 1177 (1959), Soviet Phys. JETP **10**, 837 (1960).

3 K. G. Malmfors, Ark. f. Fys. **6**, 49 (1952).

4 P. Moon and A. Storruste, Proc. Phys. Soc. **66**, 585 (1953).

5 W. Franz, Z. Physik **98**, 314 (1935).

6 F. R. Metzger, Phys. Rev. **127**, 220 (1962).

7 Schmorak, Li, and Schwarzschild, Phys. Rev. **130**, 727 (1963).

8 G. A. Vartapetyan, JETP **41**, 1710 (1961), Soviet Phys. JETP **14**, 1217 (1962).

9 S. O. Nilsson, Kgl. Dansk. Vidensk, Selsk. Mat-Fys. Medd. **29**, No. 16 (1955).

Translated by J. G. Adashko
4