RESONANCE SCATTERING OF GAMMA RAYS BY Se^{76}

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The lifetime of the first excited state of Se^{76} (0.56 Mev) was measured through the resonance scattering of gamma rays from a gaseous As^{76} source in the form AsH_3. $(1.3 \pm 0.2) \times 10^{-11}$ sec was obtained for the lifetime. The absence of resonance scattering of 1.21-Mev quanta, representing the ground-state transition from the second excited state of Se^{76}, indicates that the corresponding partial lifetime of the second excited Se^{76} state is greater than 6×10^{-12} sec.

1. INTRODUCTION

RECENT investigations[1,2] have shown that the beta decay of As^{76} is accompanied by gamma radiation corresponding to transitions between at least seven levels of Se^{76}. More than 90% of these beta decays go to the ground level and first two excited levels of Se^{76} (0.56 and 1.21 Mev). Both excited states have the spin and parity assignment 2^+, and electric quadrupole transitions are observed from these levels to the ground level of Se^{76} (see the decay scheme of As^{76} in the preceding article[2]). The end-point energies of the beta transitions to the 0.56- and 1.21-Mev levels of Se^{76} are 2.41 and 1.76 Mev, respectively. Favorable conditions thus exist for the observation of the resonance scattering of 0.56- and 1.21-Mev gamma rays by Se^{76} nuclei using the method of cascade transitions.[3-5] Following the beta decay of As^{76}, gamma rays are emitted by excited Se^{76} recoil nuclei which are in motion. The Doppler effect changes the magnitude of the emitted quanta, a certain fraction of which are increased by the amount of energy required to compensate for recoil losses during emission and absorption; this is a necessary condition for the observation of resonance scattering. In this type of experiment, it is usually necessary to use gaseous sources of gamma rays to insure a sufficiently long mean free time for the recoil nuclei. Otherwise, following the beta decay, collisions with neighboring atoms of the source material would slow the recoil nuclei down before radiating and the described compensation mechanism could not come into play.

The resonance scattering cross section is associated with the width of the excited level; observation of this process therefore enables us to determine the width and, consequently, the lifetime of the level. Temmer and Heydenburg,[6] as well as Alkhazov et al.[7] have obtained 1.7×10^{-11} sec and 1.3×10^{-11} sec, respectively, for the first excited level (0.56 Mev) of Se^{76} by means of Coulomb excitation. Coulomb excitation has led to conflicting values for the partial lifetime of the second excited state (for the direct transition to the ground state of Se^{76}). Reference 7 gives 2.5×10^{-12} sec, while the preliminary result given in reference 8 is of the order 10^{-11} sec.

2. RESONANCE GAMMA-RAY SCATTERING PROBABILITY

The calculation of the resonance scattering probability resembles earlier calculations by the present author[5] and by Metzger.[9] The resonance scattering probability can be expressed as a function of the excited level width. Constants are determined from the characteristics of the As^{76} decay scheme and from the parameters of the scatterer. The total scattering probability for a given experimental geometry is obtained by numerical integration over the volume of the scatterer. It is necessary to know the energy distribution $N(E)$ of the gamma rays and its density at the resonance value of E.

The decay-scheme data which are required for the calculation are given in the preceding paper;[2] the uncertainties in the decay scheme have no essential effect.

$N(E_p)$ depends on the type of beta interaction. Despite recent progress in the study of beta decay, we have advanced no specific hypothesis regarding the type of interaction. The resulting uncertainty is included in the overall experimental error.

3. EXPERIMENTAL PROCEDURE

As already mentioned, the observation of resonance scattering requires the use of a gaseous gamma-ray source. It would be simplest for this purpose to use metallic arsenic containing As^{76}, which sublimes at a relatively low temperature. However, in arsenic vapor As_4 molecules are formed, so that the recoil atoms resulting from beta decay are not, strictly speaking, free. Although the energy of the recoil atoms considerably exceeds the atomic binding energy in the As_4 molecule, in some instances the bonds might not be broken (for example, when the recoil atom is moving toward the center of the molecule). Recoil energy may also be partially lost through other processes such as molecular rotation. Since such processes cannot be taken into account exactly, the gaseous source must either be a monatomic gas or a compound of As and a very light element such as hydrogen. In the latter case the molecular mass would be practically that of the As atom and the uncertainty associated with the chemical bonds would be unimportant.

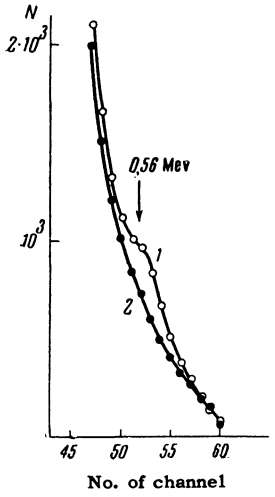
In the present work arsine (AsH_3) was used as the gaseous source. About 5 mg arsenic metal was irradiated with thermal neutrons in a reactor for a period of 40 hours and was then used to prepare the alloy As_2Zn_3. The arsine produced by the interaction between this alloy and 30% sulfuric acid was collected in a 9-cm^3 glass ampoule and was solidified by cooling with liquid air. During this process the ampoule was evacuated and then sealed. Evacuation was required since collisions between recoil atoms and air molecules would otherwise reduce the resonance scattering effect. The pressure of the AsH_3 source gas did not exceed 0.02 atm, thus entirely excluding the possibility that collisions would affect the experimental results. The total activity of the source was of the order 10 mC, but only about 35% and 5% of the total number of decays is accompanied by the emission of 0.56-Mev and 1.21-Mev gamma rays, respectively.

The experimental geometry and the method of determining the resonance scattering cross section are described in reference 5. The scatterer was a hollow thin-walled aluminum cylinder filled with 99.5% pure selenium powder. The cylinder was 13.5 cm long and had an outside diameter of 30 cm. The selenium formed a layer 1.45 cm thick with a total weight of 6185 g. An arsenic scatterer of similar dimensions was used for comparison; the two scatterers were interchanged every 2 minutes. Similar measurements were also performed with a solid As^{76} source whose activity was equal to that of the gaseous source. When the solid source was used the counting rate of scattered radiation was identical for both scatterers. In conjunction with the gaseous source the counting rate for the selenium scatterer increased due to resonance scattering by Se^{76}. The experimental results were corrected for decay during the 70-hour period of continuous measurements.

Preliminary measurements were obtained with a source in the form of arsenic metal vapor produced by heating to ~ 500° C. Comparison with the results obtained with the AsH_3 source shows that the above-mentioned chemical-bond effect actually occurs; the resonance scattering cross section was 10 — 15% less in the first case. The experimental results that are discussed in the following section were obtained with the gaseous AsH_3 source alone.

4. RESULTS AND DISCUSSION

The average counting rate of resonance-scattered 0.56-Mev gamma rays was 0.52 ± 0.02 pulse/sec. This was 6% of the total counting rate, which represented mainly the laboratory background and elastic nonresonance gamma-ray scattering. A multichannel pulse-height analyzer was used to measure the scattering spectrum shown in the figure. Scattering by arsenic is represented by a smoothly falling curve while scattering by selenium exhibits a resonance peak at 0.56 Mev. The lifetime of the first excited Se^{76} state was found to be $(1.3 \pm 0.2) \times 10^{-11}$ sec, which is in excellent agreement with the Coulomb excitation value of 1.32×10^{-11} sec given in reference 7. The difference between these two results and 1.7×10^{-11} sec, which is given in reference 6 on the basis of Coulomb excitation, is within experimental error.



Gamma-ray scattering spectrum. 1 — Se scatterer; 2 — As scatterer; N — pulse counting rate in arbitrary units.

We did not observe resonance scattering of 1.21-Mev gamma rays, corresponding to the ground-

state transition from the second excited state. In any event the counting rate of resonance scattering was under 0.002 pulse/sec, thus making it possible to measure only the lower limit of the lifetime. The partial lifetime of the second excited Se^{72} state for direct ground-state transitions must therefore be greater than 6×10^{-12} sec. This disagrees with the 2.5×10^{-12} sec lifetime given in reference 7, but agrees with reference 8, where a lifetime of the order 10^{-11} sec was obtained.

When we used the intensity ratio of the direct and cascade transitions from the second excited Se^{76} state, which is given in the preceding paper, we found that the partial lifetime for the cascade transition is also greater than 6×10^{-12} sec.

In references 6 and 7 Coulomb excitation was used to determine the reduced probabilities for electric quadrupole transitions from the first excited states of even-even selenium isotopes with mass numbers A = 76, 78, and 80. A relationship is found between these reduced probabilities and the excitation energies similar to that previously noted in references 5, 10 and 11 for even-even isotopes of several elements; an increase of excitation energy is always accompanied by a decrease of the reduced transition probability.

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Note added in proof (March 4, 1960). New measurements of the lifetimes of excited Se^{76} states produced by Coulomb excitation were published after the present paper had gone to press. Alkhazov, Andreev, Grinberg, Erokhina, and Lemberg obtained 1.8×10^{-11} sec for the lifetime of the first excited Se^{76} state (Abstracts of the Tenth Conference on Nuclear Spectroscopy, Moscow, 1960, p. 95). The review article by Van Patter [Nuclear Phys. **14**, 42 (1959)] gives results obtained by McGowan and Stelson: $(1.62 \pm 0.15) \times 10^{-11}$ sec for the lifetime of the first excited state and $(1.2 \pm 0.4) \times 10^{-11}$ sec for the partial lifetime of the second excited state. These results are in agreement with our present work.

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