Decay of Se^{75} and the Lifetime of the 280-kev State of As^{75}

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The decay of 120-day Se^{75} has been investigated employing NaI(Tl) scintillation spectrometer and coincidence technique. The intensities of the electron capture transitions to the 403-, 572-, and 628-kev states of As^{75} are found to be in the ratio of $1:5.3\times10^{-4}:2.4\times10^{-4}$. On the basis of log$ft$ values of the β and electron-capture transitions the spins and parities of the 477, 572, 628, and 814-kev states of As^{75} are assigned as $\frac{1}{2}^-$, $\frac{5}{2}^-$, $\frac{1}{2}^-$ and $\frac{5}{2}^-$ (or $\frac{7}{2}^-$), respectively. Employing the delayed coincidence method and a time-to-pulse-height converter, the mean lifetime of the 280-kev state is measured as 7.8×10^{-10} sec. The partial $E2$ lifetimes for the 265- and 280-kev levels are estimated to be 1.1×10^{-9} and 5.2×10^{-9} sec, respectively.

INTRODUCTION

THE levels of As^{75} have been studied in detail from the decay of Se^{75} and Ge^{75},[1–8] and by Coulomb excitation.[9,10] Levels at 199, 265, 280, 305, and 403 kev are reported to be excited in the decay of Se^{75}.[2,5] Grigor'ev[5] and Langevin-Joliot[6] have reported the presence of a 572-kev line in the decay of Se^{75}. The states at 199, 280 (and 265), 572, and 814 kev have been observed in the Coulomb excitation experiments[9,10] while the β transitions from Ge^{75} have been shown to excite the 199, 265, 477, and 628 kev levels. The mean lifetime of the 305-kev level is measured by the delayed coincidence method to be[1] 24 msec while that of the 265- and 403-kev states are found by the resonance fluorescence method to be[11] 1.6×10^{-11} sec and[6] 2.1×10^{-9} sec, respectively. On the basis of his conversion coefficient measurements[8] and the Coulomb excitation data,[9,10] Metzger predicts[8] the mean lifetime of the 280-kev state to be 2.4×10^{-10} sec. The spin assignments to the levels of As^{75} up to 403 kev are in good agreement with the angular correlation,[2,7] conversion coefficient[8] and the lifetime measurements.[1,11]

In the present work the gamma-ray spectrum from a Se^{75} source has been examined by a NaI(Tl) crystal spectrometer, and also by coincidence methods. The lifetime of the 280-kev state has been measured by the delayed-coincidence method, employing a time-to-pulse-height converter.

APPARATUS

The gamma-ray spectrum has been studied employing a 4-in. diam×4-in. thick NaI(Tl) crystal mounted on a Dumond 6363 photomultiplier tube. In the coincidence experiments 1.75-in. diam×2 in. thick NaI(Tl) crystals, mounted on RCA 6810A photomultiplier tubes, were employed in a fast-slow coincidence set up with a resolving time of $2\tau=50$ mμsec, and provision of pulse-height selection in the side channels. A twenty-channel pulse height analyzer of the Gatti type built in the laboratory was employed for recording the coincidence spectra.

For the lifetime studies, the pulses from the scintillation spectrometers, after proper shaping to 110 mμsec width and 2 v height in E180F tubes, were fed to a 6BN6 type time-to-pulse-height converter. The time-sorter circuit differed from that of Green and Bell[12,13] in that higher voltage (25 v each) was applied to the plate and the accelerating electrode of the 6BN6 valve. Under this operating voltage it was found that a swing of 1.8 v on the control and quadrature grids was sufficient to saturate the tube current starting from cutoff. These operating conditions result in a better coincidence-to-singles pulse-height ratio and a better stability of the circuit. While taking observations a fixed delay of 55 mμsec was introduced between the pulses from the two counters. There are two advantages of introducing the fixed delay. Firstly the effects due to the rise time of the shaped pulse and also due to the distortions, if any, in the shape near the rising and falling edges are eliminated, since the change in the overlap—due to the delayed coincidences—takes place in a clean, flat region of the shaped pulses. The second advantage is that it affords a simultaneous comparison with the prompt coincidence curve. The slopes on the two sides of the coincidence curve arise due to the jitter in the time of arrival of the pulses from the two detectors, which in turn depends upon the energy of the radiations, the scintillator employed, and the pulse height produced at the grid of the pulse shaping valve. When the time jitter is symmetrical, the prompt-

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coincidence curve would show a symmetrical shape. When a lifetime is present and the delayed radiations are detected only in one of the detectors, the distortion due to the lifetime is imposed on one side of the coincidence curve only. The delayed-coincidence curve would thus have one side with the slope expected for a prompt-coincidence curve for radiations of the same energy, while the other side would have a slope corresponding to the lifetime of the radiations. It should be mentioned that, because of the large decay time of NaI(Tl), the width of the pulses fed to the time sorter have to be about 50 mμsec for the study of mean lifetimes of about one millimicrosecond or less. In the present apparatus a pulse width of 110 mμsec has been used.

The collector pulses from the photomultiplier are negative and up to 150 v high. As the single-channel analyzers accept positive pulses of up to 80 v, the phototube pulses were inverted and attenuated by a factor of about two by increasing the negative feedback in the inverter circuit. These pulses were fed to the single-channel analyzers which selected a suitable pulse height in either counter. The output of the single-channel analyzers were fed to a slow-coincidence circuit, the output of which in turn gated the time-sorter pulses in the twenty-channel analyzer.

Employing two plastic scintillators (decay time $\sim$6 mμsec), detecting Co^{60} gamma rays and biased at about

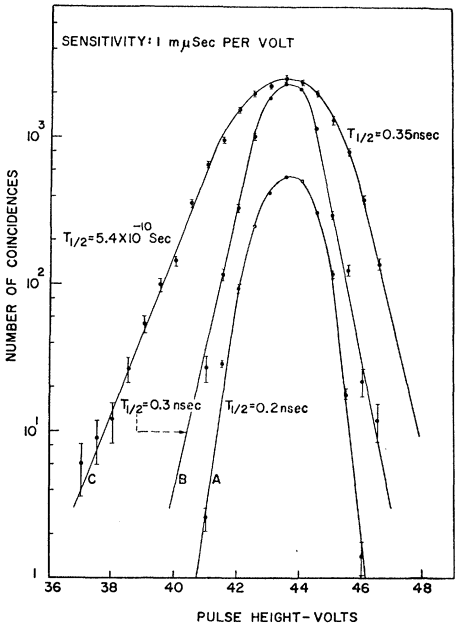

FIG. 1. Experimental data with the time-to-pulse-height converter. Curve (A): the coincidence curve when Co^{60} γ rays are detected in two plastic scintillators biased at 300 kev. Curve (B): the coincidence curve for Co^{60} γ rays employing a plastic scintillator to detect β rays and a NaI(Tl) crystal to detect γ rays. Curve (C): coincidence curve for As^{75}, 120-kev conversion electrons detected in a plastic scintillator and the 280-kev γ ray inNaI(Tl) scintillation spectrometer.

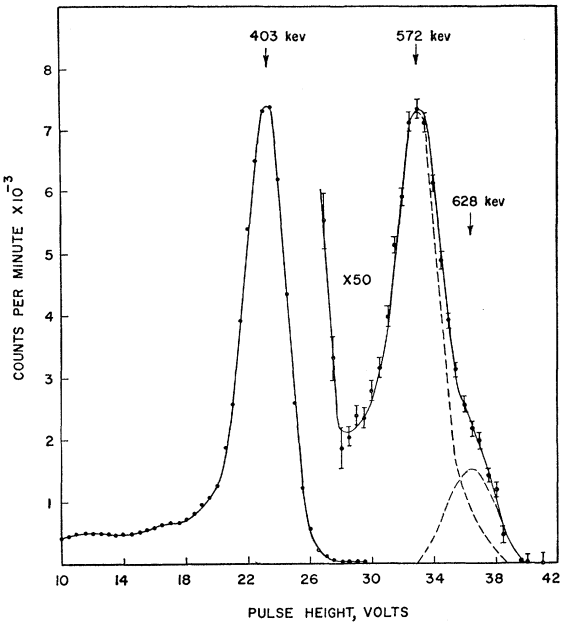

FIG. 2. Pulse-height spectrum in a 4-in. diam$\times$4 in. thick NaI(Tl) scintillation counter, due to the high-energy gamma rays from Se^{75} after passing through 2 cm of lead absorber.

300 kev, the present circuit gave the coincidence curve A shown in Fig. 1. The slopes of the sides are $T_{\frac{1}{2}}=2\times10^{-10}$ sec and the full width at half maximum is 1.9×10^{-9} sec. When a coincidence curve was taken detecting Co^{60} β rays in a thin plastic scintillator and gamma rays in a 1.75-in. diam$\times$2 in. thick NaI(Tl) crystal with 2-v channel selecting one of the peaks at 30 v height, the slopes of the sides become $T_{\frac{1}{2}}=3\times10^{-10}$ sec as shown by curve B of Fig. 1. It is thus possible to measure mean lifetimes up to 4×10^{-10} sec with the present apparatus employing a NaI(Tl) counter.

The time-sorter circuit has been found to be linear in the region of 5 to 100 mμsec. During the experiment the calibration was done by introducing different length cables between the pulses from the two detectors and observing the shift of the Co^{60} γ-ray coincidence curve on the twenty-channel analyzer. The cable employed was type C1T ($Z_0=150$ ohms, capacity 7.3 $\mu\mu$f/ft) having a delay of 1.10 ± 0.02 mμsec/ft as measured with the help of a Tektronics time marker.

MEASUREMENTS

The 120-day Se^{75} was produced by irradiating pure selenium metal in the Apsara reactor (Trombay) for a week and allowed to decay for about three months. In Fig. 2 is shown the pulse-height spectrum in a 4-in. diam $\times$4 in. thick NaI(Tl) crystal due to the high-energy gamma rays from Se^{75} filtered through 2 cm of lead. The background has been subtracted. There is evidence of gamma-ray peaks at 572 and 628 kev. After correcting for absorption in lead and the cross section for pro-

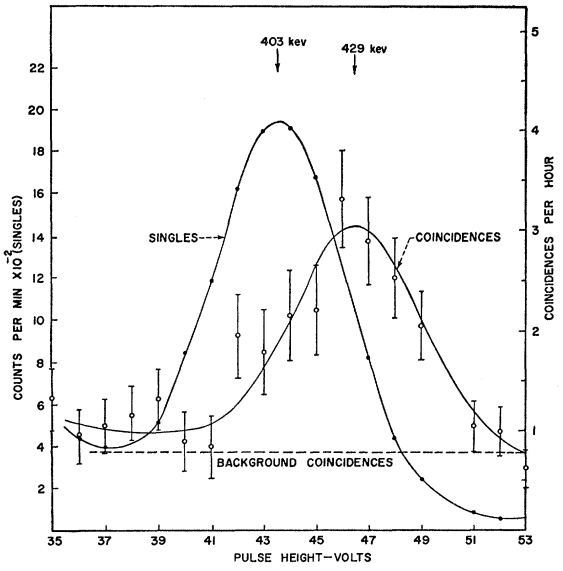

FIG. 3. Gamma-ray spectrum in coincidence with 200-kev gamma-ray peak along with the singles spectrum in the region.

ducing full-energy peaks in the scintillator, the relative intensities of the 403-, 572-, and 628-kev gamma rays are found to be in the ratio $1:3.2\times10^{-3}:5.5\times10^{-4}$. Chemical purification was found to have no effect on the gamma-ray spectrum.

In coincidence experiments in end-on geometry with wide-angle lead cones to suppress backscattering, it was found that the peak at 400 kev gives coincidences with only a gamma ray near 200 kev, which may correspond to the transition from the 199-kev state of As^{75}. To determine correctly the energy of the gamma ray near 400 kev, one channel in the coincidence arrangement was fixed at 200 kev and the gamma-ray spectrum in coincidence was recorded on the multichannel analyzer. There was placed an absorber of 0.74 g/cm² Pb and 1.1 g/cm² Cd between the source and the 200-kev counter and 1.8 g/cm² Pb and 1.1 g/cm² Cd between the source and the counter detecting 400 kev. This was found necessary to suppress coincidences due to 120–135 kev and 265–280 kev gamma rays and their piling up. Figure 3 shows the coincidence and singles peaks observed. The energy of the gamma ray is ~430 kev and should therefore represent a transition from the 628- to the 199-kev state. No other coincidences, except the ones expected on the level scheme known so far, could be detected over a period of several hours, indicating that the 572-kev gamma ray decays in the most part to the ground state. From the coincidence experiment the intensity of the 430-kev gamma ray was found to be 8.9×10^{-4} of the 403-kev gamma ray, which, when compared with the intensity of the 628-kev gamma ray observed in Fig. 2, agrees with the branching ratio of the 628-kev state observed in the β decay.

On the basis of the intensities of the various gamma rays observed here and by others[2,8] and the decay energies, the logft values of the electron-capture transitions to the various levels of As^{75} are calculated and given in Table I. The logft values of the various β-groups from Ge^{75} are also tabulated.

TABLE I. Intensities of the electron capture and β transitions to the levels of As^{75}.

Level of As^{75} to which transition proceeds (kev)	Intensity of electron-capture transitions	Logft for electron capture	Logft for β transitions from Ge^{75}
0	...	...	5.2
199	...	...	7.0
265	~0.05	7.5	5.6
403	0.95	6.1	>8.1
477	$<10^{-4}$	>9.3	6.9
572	5.3×10^{-4}	9.0	...
628	2.4×10^{-4}	9.1	6.2

To measure the lifetime of the 280-kev state a Se^{75} source was put directly on a 2.5 cm diam×0.1 cm thick disk of plastic scintillator which was mounted on a 6810A photomultiplier tube. The peak produced by the conversion electrons of the 120–135-kev gamma rays was selected in a single channel analyzer. In a NaI(Tl) counter placed head-on with the plastic counter a 2 v channel fixed at 30 v selected the high energy side of the 265–280-kev peak. The 120–135-kev gamma rays in this counter were suppressed by 0.7 mm thick Pb and 1 mm thick Cd absorbers. Curve C of Fig. 1 shows the coincidence curve when the fixed delay was in the gamma-ray counter. This curve was repeated (1) by changing the delay to the plastic counter and (2) by changing the fixed delay from 55 mμsec to 65 mμsec. In every case the slopes of the peaks were the same. The slope of the curve after correcting for the contribution of 265-kev gamma-ray (contributing to prompt coincidences only) gives the half-life of the 280-kev state to be $T_{\frac{1}{2}}=(5.4\pm0.5)\times10^{-10}$ sec or a mean lifetime of 7.8×10^{-10} sec. The calibration curve was taken for a region of 11 mμsec on either side of the position of the coincidence peak, in steps of 5.5 mμsec (corresponding to 5 ft of the delay cable). The error in calibration is estimated to be ±5%. Taking the conversion coefficient of the gamma ray into account, the mean life of the level for γ emission is found to be $(8.0\pm0.8)\times10^{-10}$ sec.

DISCUSSION

The complex nature of the excited states of As^{75} is such that the logft values for some transitions in Ge^{75} are much higher than expected. A similar situation arises in the decay of Se^{75}. Only an estimate of the orbitals of the excited states of As^{75} could be made. The logft value of the β transition to the 477-kev state is 6.9 while that of the electron-capture transition to the same level is >9, suggesting spin and parity $\frac{1}{2}\pm$. As the gamma transition leads predominantly to the ground state, the negative parity is favored. The 572-

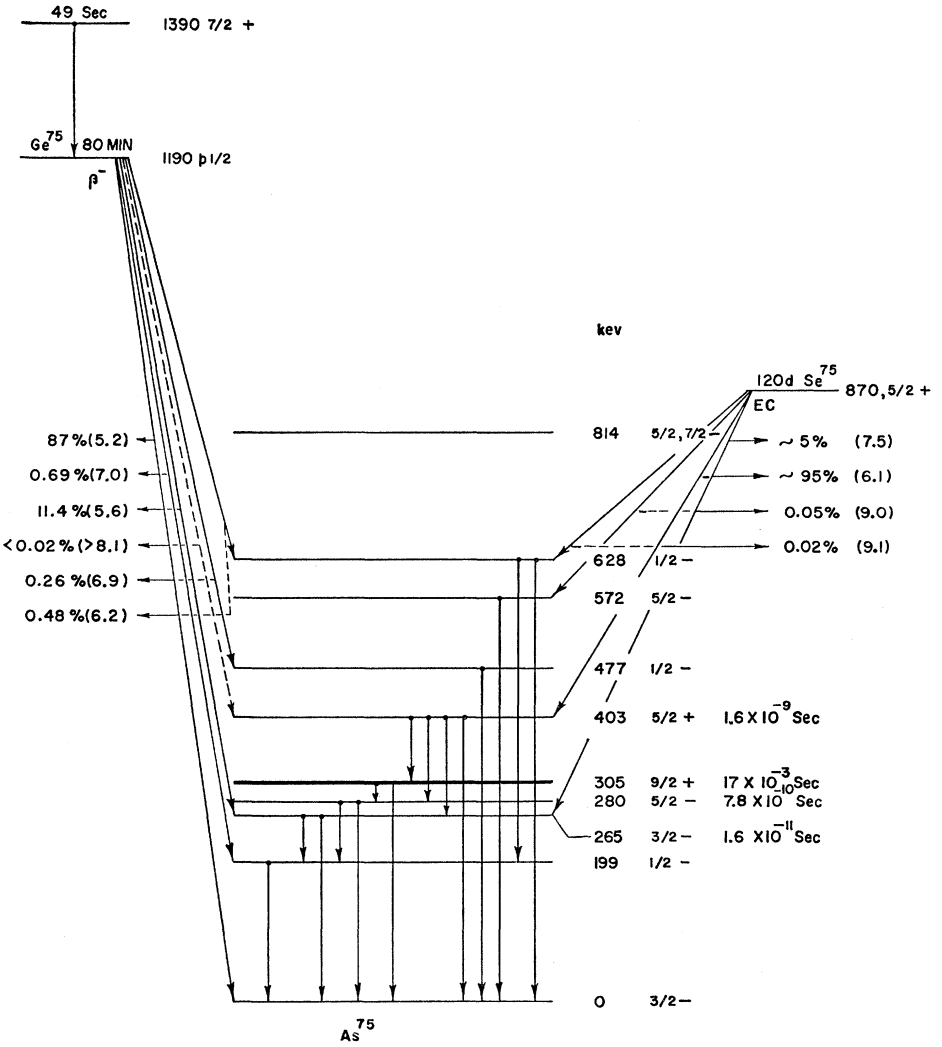

FIG. 4. Level scheme of As^{75} and the decay of Se^{75} and Ge^{75} to it. The intensity and logft value (in parentheses) for the electron-capture and β transitions are also shown.

kev state is seen in Coulomb excitation and in the decay of Se^{75} (logft=9.0) but not in the decay of Ge^{75}. This favors a spin and parity assignment of $\frac{5}{2}^-$ to the state. The electron capture transition seems to have been retarded due to the nuclear configuration. The 628-kev state is observed both in the decay of Ge^{75} (logft=6.2) and Se^{75} (logft=9.1). This favors a spin and parity assignment of $\frac{1}{2}^-$ or $\frac{3}{2}^-$. As the state decays to the $\frac{1}{2}^-$ level at 199 kev and not to the 280-kev ($\frac{5}{2}^-$) or 403-kev ($\frac{5}{2}^+$) state, the assignment of the 628-kev state should most likely be $\frac{1}{2}^-$. The 814-kev state is not excited in the decay of either of the two neighbors. The energy available for electron capture to the 814-kev level is only about 50 kev so that the excitation of the level may be too feeble to observe. Spin and parity $\frac{5}{2}^-$ or $\frac{7}{2}^-$ seem to be a plausible assignment to this level. The spin and parity assignments proposed above are given in Fig. 4 which shows a complete level scheme of As^{75}.

Taking the gamma-ray mean life of the 280-kev state as 8.0×10^{-10} sec and the $E2/M1$ ratio as that obtained by conversion coefficient measurements,[8] one gets the partial lifetimes of the $M1$ and $E2$ transitions as 9.4×10^{-10} sec and 5.2×10^{-9} sec, respectively, giving the reduced $E2$ transition probability $B(E2)=0.014$ (in units of $e^2\times10^{-48}$ cm^4). The value of $B(E2)$ is measured to be 0.071 but, as the authors[9] have pointed out, it is not definite which of the 265- and 280-kev states is excited. If the remaining $B(E2)$ is taken for the 265-kev state, then the partial $E2$ lifetime is given by 1.1×10^{-9} sec. This, with the measured mean lifetime of 1.6×10^{-11} sec, gives $E2/M1=0.015$ which is consistent with the conversion coefficient[8] measurements but disagrees with results of the study of the angular distribution of the resonance-scattered gamma rays.[8,11]

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