New Yttrium Isomers of Masses 86 and 90*

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Cyclotron bombardment of Rb with alpha particles and Sr with deuterons have yielded two new yttrium activities. Y^{86m} decays with a half-life of 49.0 ± 1.5 min. The isomer is supported by a highly converted 7.2-kev isomeric transition followed by a 210-kev gamma ray having a conversion coefficient $e/\gamma=0.06\pm0.01$. Y^{90m} has a half-life of 3.19 ± 0.06 hr, decaying to the Y^{90} ground state with emission of two gamma rays: 476 kev, $e/\gamma=0.10\pm0.02$, and 203 kev, $e/\gamma=0.036\pm0.007$. Spin and parity assignments are made for the Y^{90} levels.

INTRODUCTION

DURING recent experiments involving cyclotron production of yttrium isotopes, two unaccountable yttrium activities were observed.[1] These were found to be isomers of Y^{86} and Y^{90}.

EXPERIMENTAL PROCEDURES

Anhydrous RbCl or $SrCl_2$ was evaporated *in vacuo* onto aluminum foil backing, and these targets were then placed in a degrading foil stack. The stack was irradiated with 43-Mev alpha particles or 21-Mev deuterons from the Argonne 60-in. cyclotron. For study, Y^{86m} was most conveniently made with 42-Mev alpha particles on Rb of natural isotopic composition, while Y^{90m} was best produced with 18-Mev alpha particles on separated Rb^{87}.

After bombardment the targets were dissolved in hot, concentrated HCl in the presence of yttrium carrier and strontium holdback carrier. The acid concentration was adjusted to $0.5M$ and the yttrium was extracted into dioctyl phosphate according to the method of Peppard *et al.*[2,3] The radiochemically pure yttrium was then back extracted into $4M$ HCl, the pH of the solution was adjusted to 5–6, and the yttrium precipitated with hot, saturated oxalic acid solution. The precipitate was mounted for counting. For conversion electron measurements no yttrium carrier was added, and the back-extracted, carrier-free yttrium was evaporated onto rubber hydrochloride.

Gamma spectra were taken with 3×3-in. NaI crystals, and beta and conversion spectra with anthracene or stilbene crystals or with a proportional counter. A 200-channel analyzer with appropriate coincidence circuitry was employed.

RESULTS

Y^{86m}

The isomer of Y^{86} was first identified by observation of a gamma ray of 210-kev energy which decayed with a half-life of 49.0 ± 1.5 min. A tentative mass assignment was made from a very crude excitation function derived from data on early bombardments in which the isomer was observed, and was confirmed by watching the growth of 14.6-hr Y^{86} activity as the isomer decayed. Analysis of the growth curve showed that the production ratio for Y^{86m} relative to Y^{86} for 42-Mev alpha-particle bombardment of Rb was 0.85 ± 0.20.

The total conversion coefficient of the 210-kev transition was determined to be 0.06 ± 0.01, and according to Rose's tables[4] corresponds to multipolarity $E2$ or $M1E2$ mixture. The half-life for this transition would be expected to be $\sim10^{-8}$ sec, far shorter than the observed 49 min, and a search for a very low energy transition feeding the 210-kev level was initiated. No conversion line corresponding to this transition was found by scintillation counting. A sample prepared by vacuum volatilization was placed internally in a continuous flow proportional counter. The sample was separated from an externally placed 3×3-in. NaI crystal by a thin window. An electron line with 7.2 ± 0.7 kev energy was observed in coincidence with the 210-kev gamma ray. When the sample was covered with a 1.5-mg/cm² aluminum absorber the electron line disappeared, showing that the transition is highly converted.

Y^{90m}

The Y^{90} isomer showed two gamma lines, one of 203-kev energy, the other of 476-kev, which decayed

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[1] *Note added in proof.* It has been called to our attention that several groups have recently observed the production of Y^{90m} by thermal neutron capture: W. S. Lyon, J. S. Eldridge, and L. C. Bate, *Analytical Chemistry Progress Report*, AEC Report ORNL-2866 (unpublished). R. L. Heath, J. E. Cline, C. W. Reich, E. C. Yates, and E. H. Turk, National Reactor Testing Station, Phillips Petroleum Company, Idaho Falls, Idaho (submitted to Phys. Rev.) and R. Krishnamoorthy and R. F. Buchanan, Argonne National Laboratory (private communication).

[2] D. F. Peppard, G. W. Mason, J. L. Maier, and W. J. Driscoll, J. Inorg. & Nuclear Chem. 4, 334 (1957).

[3] D. F. Peppard, G. W. Mason, and S. W. Moline, J. Inorg. & Nuclear Chem. 5, 141 (1957).

[4] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).

with a half-life of 3.19±0.06 hr. Mass assignment was again tentatively made from an approximate excitation function calculated from data of numerous alpha bombardments. The Y^{90} beta activity was then observed to grow as the Y^{90m} decayed. The two gamma rays were found to be in slow coincidence ($\sim 10^{-6}$ sec resolving time) with each other, and with each other's conversion line, but were not in coincidence with other gammas, betas, or conversion electrons. No crossover transitions from the higher level to the Y^{90} ground state were observed, and may be considered to constitute fewer than 1.5% of all decays. No gamma rays were observed which could be attributed to beta decay of the 3-hr isomeric state to excited states of Sr^{90}. This fact together with the observation that the intensity of the high-energy betas grew rather than decayed shows that the 3-hr state decays principally by isomeric transition.

The total conversion coefficient of the 476-kev transition was found to be 0.10±0.02, and that of the 203-kev transition was 0.036±0.007. Comparison with Rose's tables[3] indicates that the multipolarity of the higher energy transition is $M4$ or possibly $E5$, while that for the lower energy transition is $M1E2$ mixture. K conversion coefficients were also measured and found to be in agreement with the above, but are not reported here as the over-all accuracy of the determinations does not warrant calculation of a $K/(L+M)$ ratio. The predicted half-life[5] for an $M4$ transition is ~ 4 hr, in good agreement with the observed half-life of the isomer, while the predicted half-life for an $E5$ transition is $\sim 10^5$ hr.

DISCUSSION

The decay scheme for Y^{90m} as shown in Fig. 1 was deduced from the above information and is supported by theoretical considerations. The ground state spins[6] of Y^{89} and Y^{91} are both $\frac{1}{2}-$, indicating that the odd proton in Y is in the $3p_{\frac{1}{2}}$ level; the ground state spins of Sr^{89} and Zr^{91} are $\frac{5}{2}+$, suggesting that the odd neutron in the Y^{90} should be in the $4d_{\frac{5}{2}}$ level. According to the coupling rules of Nordheim[7] or of Brennan and Bernstein[8] these nucleons would couple in Y^{90} to give a ground state spin $J=|j_1-j_2|$, or 2−. Comparison of the half-lives of the two excited states as predicted from the multipolarities of the transitions indicates that the energy of the lower excited state is 203 kev above the ground state. The most reasonable spin and parity assignments for that level, which would lead to the observed $M1E2$ transition multipolarity, is 3−; if the spin of this level were smaller, one would expect to observe the crossover transition from the isomeric state to the ground state. The 3− state is easily constructed by recoupling the proton and neutron spins to $J=j_1+j_2$, which from the coupling rules[6,7] one would expect to be higher than the 2− state. The $M4$ transition multipolarity from the 679-kev level to the 203-kev level leads to a probable level assignment of 7+ for the 679-kev level. Promotion of the proton to the higher lying $5g_{9/2}$ which is observed as isomeric states in neighboring odd-mass number yttrium isotopes and recoupling with the $4d_{\frac{5}{2}}$ neutron according to the coupling rules[7] also gives $J=j_1+j_2$, or 7+.

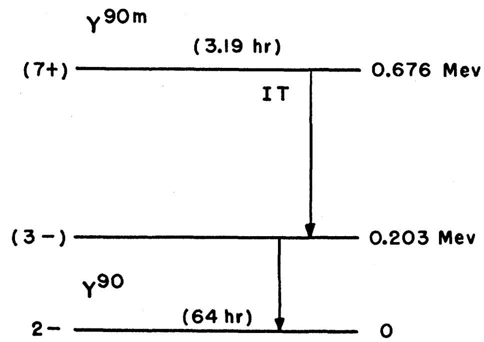

FIG. 1. Proposed decay scheme for Y^{90m}.

The 203-kev state was also observed at 202.4 kev by Bartholomew *et al.*,[9] in studies of the $Y^{89}(n,\gamma)Y^{90}$ reaction. Angular correlation measurements led those investigators also to conclude that this level was 3−. The 676-kev level was not reported by them.

Because of the uncertainty of the Y^{86} ground state spin and the unknown multipolarity of the isomeric transition no level assignment for Y^{86m} is submitted.

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[6] D. Strominger, J. M. Hollander, and G. T. Seaborg, Revs. Modern Phys. **30**, 585 (1958).
[7] L. W. Nordheim, Revs. Modern Phys. **23**, 322 (1951).
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[9] G. A. Bartholomew, P. J. Campion, J. W. Knowles, and G. Manning, Nuclear Phys. **10**, 590 (1959).