Isomeric Transition in Samarium-143

W. L. ALFORD AND D. R. KOEHLER
Army Missile Command, Redstone Arsenal, Alabama
(Received 19 April 1962)

Samarium oxide enriched in Sm^{144} has been bombarded by 14-MeV neutrons to produce the isomeric state of Sm^{143}. The isomeric state was found to decay with a half-life of 65±3 sec by the emission of a 0.75±0.01-MeV gamma ray. Measured relative to a $Cu^{63}(n,2n)Cu^{62}$ cross section of 610 mb, a value of 1670±400 mb was found for the total $(n,2n)$ cross section of Sm^{144}. The ratio of the cross section for production of the isomeric state to the total $(n,2n)$ cross section was determined to be approximately 0.5.

THE isomeric state of Sm^{143}, which has been reported by James and Bingham[1] and by Kotajima and Morinaga,[2] has been produced by 14-MeV neutron irradiation of samarium oxide enriched[3] in Sm^{144}. This isomeric state was found to decay with a half-life of 65±3 sec by the emission of a 0.75±0.01-MeV gamma ray in agreement with the results given in reference 2.

The experimental procedure was essentially the same as that previously described.[4] A series of 10-min activations of the samarium samples was made by neutrons produced in the $T(d,n)He^4$ reaction. Immediately following the irradiations, gamma-ray spectra were recorded on an RCL 256-channel analyzer fed by a scintillation counter employing a NaI(Tl) crystal 3 in. in diameter by 3 in. in height. These spectra showed gamma-ray photopeaks at 0.75 MeV and 0.51 MeV attributed to the decay of Sm^{143m} and Sm^{143g}, respectively. The half-life of the isomeric state was determined by following the output of a single-channel analyzer set to pass counts in the 0.75-MeV photopeak. The results are compared with previous measurements in Table I. The decay of the ground state was found to follow an 8.9±0.3-min half-life which was determined by counting the positron annihilation radiation as a function of time.

To give added validity to the assignment of the 0.75-MeV gamma activity to an isomeric transition in Sm^{143}, an attempt was made to determine the production cross section. The counts in the 0.75-MeV photopeak were compared with those at 0.51 MeV from the positron annihilation following the decay of Sm^{143} ground state. The ratio of the cross section for production of the isomeric state to the total $(n,2n)$ cross section of Sm^{144} was found to be approximately 0.5. Using a Sm_2O_3 sample of natural samarium, copper monitor foils, and a $Cu^{63}(n,2n)Cu^{62}$ cross section[5] of 610 mb, a value of 1670±400 mb was found for the total $Sm^{144}(n,2n)Sm^{143}$ cross section at a neutron energy of 14.7±0.7 MeV. This result compares with 1484±119 mb and 1200±300 mb obtained by Rayburn[6] and by Wille and Fink,[7] respectively. A part of the disparity between these results and those of the present work is due to a difference in the value taken for the $Cu^{63}(n,2n)Cu^{62}$ cross section. In making the cross section calculations, account was taken of the crystal efficiency,[8] gamma-ray photopeak to total ratios,[8] saturation factors, decay factors, branching ratios,[9] and gamma-ray attenuation factors. In calculating the yield of the isomeric state of Sm^{143}, the internal conversion coefficients[10] were taken as those for an $M4$ transition[1,2] of 0.75 MeV.

The yield of the 0.75 MeV-gamma ray is consistent with the assumption that it results from a $Sm^{144}(n,2n)$ reaction. Considering gamma-ray energies and half-lives, any activity due to the isomeric state[1,2] of Nd^{141}, produced in the $Sm^{144}(n,\alpha)Nd^{141m}$ reaction, would not have been distinguishable from the activity observed. However, the yield of the activity attributed to the $Sm^{144}(n,2n)Sm^{143m}$ reaction was two or three orders of magnitude larger than would be expected for reactions involving alpha-particle or other charged-particle emission. A check was also made by bombarding the samarium with neutrons of energy less than 6 MeV from the $Be^9(d,n)B^{10}$ reaction. The failure to produce the activity gave evidence against its origin in an (n,γ) or (n,n') reaction. These results give added proof of the

TABLE I. Gamma-ray energy and half-life for the decay of Sm^{143m}.

	Present work	Reference 1	Reference 2
Energy	0.75 MeV	0.68 MeV	0.748 MeV
Half-life	65 sec	137 sec	64 sec

[1] Ralph A. James and Carleton D. Bingham, Phys. Rev. **117**, 810 (1960). These workers discuss briefly isomeric states which occur in nuclei having 81 neutrons and which decay by $M4$ transitions. Also see reference 2.
[2] K. Kotajima and H. Morinaga, Nucl. Phys. **16**, 231 (1960).
[3] Samarium, enriched to 94.6% in Sm^{144}, was obtained in the form of an oxide from the Stable Isotopes Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
[4] W. L. Alford, D. R. Koehler, and C. E. Mandeville, Phys. Rev. **123**, 1365 (1961).
[5] J. L. Fowler and John E. Brolley, Jr., Rev. Mod. Phys. **28**, 103 (1956).
[6] L. A. Rayburn, Phys. Rev. **122**, 168 (1961).
[7] R. G. Wille and R. W. Fink, Phys. Rev. **118**, 242 (1959).
[8] R. L. Heath, Phillips Petroleum Company AEC Research and Development Report IDO-16408, 1957 (unpublished).
[9] Nuclear Data Cards (National Academy of Sciences—National Research Council, U. S. Government Printing Office, Washington, D. C., 1958 and 1960). The percentages of decays resulting in positron emission were taken to be 43% and 98.2% for Sm^{143g} and Cu^{62}, respectively.
[10] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).

correctness of Kotajima's[2] work and conclusions which were based on the $Sm^{144}(\gamma,n)Sm^{143}$ reaction and on shell model considerations. No reason appears immediately evident for the difference between these results and those of James[1] whose work was based on the reaction of 20.6-MeV protons with samarium oxide enriched in Sm^{144}.

We would like to thank Robert G. Polk for his assistance in making the neutron bombardments.

PHYSICAL REVIEW VOLUME 129, NUMBER 2 15 JANUARY 1963

Levels in Y^{89} Excited by the $Y^{89}(n,n'\gamma)$ Reaction*

S. M. Shafroth, P. N. Trehan,† and D. M. Van Patter
Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania

(Received 14 May 1962; revised manuscript received 4 September 1962)

Gamma-ray spectra from the $Y^{89}(n,n'\gamma)$ reaction have been studied using a ring geometry for fifteen $Li^7(p,n)$ neutron energies ranging from 0.78 to 3.36 MeV. Ground-state gamma-ray transitions arising from levels in Y^{89} at 0.908±0.003, 1.506±0.005, 1.745±0.006, 2.84±0.02, and 3.05±0.03 MeV, as well as cascade gamma rays of 0.71±0.01, 1.31±0.01, and 1.62±0.01 MeV arising from levels in Y^{89} at 2.22±0.01 and 2.53±0.01 MeV, have been observed. Spin and parity assignments of $3/2^-$ and $5/2^-$ have been made for the 1.51- and 1.75-MeV levels, primarily as a result of comparisons of ratios of experimental cross sections for these two levels with theory. Tentative assignments are made for higher levels. Theoretical level excitation cross-section calculations for various values of spin and parity are done with a computer using the Hauser-Feshbach method and optical-model transmission coefficients obtained from various theories. The 1.75-MeV gamma-ray angular distribution was calculated using Satchler's theory and the corresponding level excitation cross section was corrected accordingly.

A new level scheme is presented for Y^{89} which takes into account all known data up to the present time. It is suggested that some of the levels excited in the present work may be due in part at least to coupling of a $p_{1/2}$ proton to the 2^+, 3^-, and (2^+) excited levels of a Sr^{88} core.

I. INTRODUCTION

As the theory of nuclear level structure becomes increasingly refined, more precise and extensive knowledge concerning individual nuclei becomes necessary. Level structures of nuclei in the 50-neutron region have been the subject of several recent theoretical investigations.[1–3] In one of these,[1] the positions of three levels in Y^{89} having various spins and parities were calculated and the $g_{9/2}-p_{1/2}$ splitting was predicted very accurately. Studies of beta-decay energy systematics[4] have led to the suggestion of a new $9/2^+$ level in Y^{89}. Recently, de-Shalit[5] has suggested that in certain cases levels of odd nuclei may be formed by coupling the odd nucleon to excited states of the even core. The Y^{89} nucleus with one $p_{1/2}$ proton outside the 38-proton shell and a strongly closed 50-neutron shell might be such a nucleus. Some examples of isomerism involving very high spin levels such as the $21/2^+$ level[6,7] in Mo^{93} find simple explanations on the basis of the core excitation model.

Most of the knowledge up to 1960 concerning the level structure of Y^{89} has been compiled by the Nuclear Data Group.[6,8] Only three levels in Y^{89} are known to be fed by radioactive decay.[6–9] An investigation of the $Y^{89}(p,p')$ reaction, which was done by Cohen and Rubin[10] as part of a survey of about 35 nuclei, revealed the presence of five proton groups which were thought to correspond to five or more additional levels in Y^{89}. A similar study of the $Y^{89}(d,d')$ reaction by Cohen and Price[11] revealed deuteron groups corresponding to the five proton groups and two more deuteron groups which roughly corresponded to levels in Y^{89} which had already been established.[6,8] However, the excitation energies in Y^{89} corresponding to the proton and deuteron groups differed from energies of levels in Y^{89} reported from radioactivity studies and $(n,n'\gamma)$ studies by up to 100 keV.

With the exception of the early work of Swann and Metzger[12] concerning the excitation curve for produc-

* Assisted by the U. S. Atomic Energy Commission.
† Present address: Panjab University, Chandigarh, Panjab, India.

1 L. S. Kisslinger and R. A. Sorensen, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. **32**, No. 9 (1960).
2 I. Talmi and I. Unna, Nucl. Phys. **19**, 225 (1960).
3 V. E. Asribekov, J. Exptl. Theoret. Phys. (U.S.S.R.) **41**, 171 (1961) [translation: Soviet Phys.—JETP **14**, 123 (1962)].
4 F. Everling, Nucl. Phys. **36**, 228 (1962).
5 A. de-Shalit, Phys. Rev. **122**, 1530 (1961).
6 K. Way, N. B. Gove, C. L. McGinnis, and R. Nakasima, *Landolt-Börnstein New Series*, edited by K. H. Hellwege (Springer-Verlag, Berlin, 1961), Group I, Vol. 1, Sec. 2.
7 *Nuclear Data Sheets*, compiled by K. Way, A. Artna, G. H. Fuller, N. B. Gove, R. Nakasima, R. van Lieshout, and M. A. Waggoner (Printing and Publishing Office, National Academy of Sciences–National Research Council, Washington 25, D. C., 1958–61).
8 K. Way, F. Everling, G. H. Fuller, N. B. Gove, C. L. McGinnis and R. Nakasima, *Nuclear Data Sheets* (Printing and Publishing Office, National Academy of Sciences–National Research Council, Washington 25, D. C., 1960), Set 3.
9 S. Monaro, G. B. Vingiani, and R. van Lieshout, Physica **27**, 985 (1961).
10 B. L. Cohen and A. G. Rubin, Phys. Rev. **111**, 1568 (1958).
11 B. L. Cohen and R. E. Price, Phys. Rev. **123**, 283 (1961).
12 C. P. Swann and F. R. Metzger, Phys. Rev. **100**, 1329 (1955).