1.E.1:
3.A:4.E

Nuclear Physics **34** (1962) 588—592;

DECAY OF Nb^{94} AND Nb^{94m}

L. I. YIN, R E. SUND, R. G. ARNS and M. L. WIEDENBECK
Harrison M. Randall Laboratory of Physics, The University of Michigan, Ann Arbor, Michigan †

Received 26 February 1962

Abstract: Gamma rays in Mo^{94} following the decay of Nb^{94} have been studied using coincidence and directional correlation measurements. The 700 keV transition was found to be in coincidence with the 873 keV gamma ray. The intensity of the crossover transition of 1573 keV was found to be less than 0.1 % of the 873 keV gamma ray intensity. The directional correlation of the 700 keV - 873 keV cascade was measured and the corrected expansion coefficients were found to be $A_2 = 0.0965 \pm 0.0076$ and $A_4 = 0.019 \pm 0.011$. These data indicate spins of 4 and 2 for the 1573 keV and 873 keV levels, respectively. Gamma rays following the decay of Nb^{94m} were studied with proportional and scintillation counters. The conversion coefficient α_K of the 42 keV gamma ray in the decay of 6.6 min Nb^{94m} was measured to be 1600 ± 350 and the branching ratio of the transition from Nb^{94m} to the 873 keV level of Mo^{94} was found to be 0.19 ± 0.03 %. The intensity ratio of the 600 keV beta ray to the 1.3 MeV beta ray in the decay of Nb^{94m} was determined to be 3.0 ± 0.6 %. These measurements support a spin and parity of 3— for the isomeric state.

1. Introduction

The ground state of Nb^{94} decays to Mo^{94} by beta emission with a half-life of about [1–3]) 2×10^4 y. Several authors [1–4]) have studied the gamma transitions following the beta decay. Gamma rays of equal intensity were observed [1–3]) at 700 keV and 870 keV. A transition at 1.57 MeV was shown to be due to summing by Schuman and Goris [3]). The level at 873 keV has been reached through Coulomb excitation [5, 6]), indicating a spin of 2+ for this level. A gamma ray of approximately 873 keV was also observed in the decay of Nb^{94m} to Mo^{94} and in the decay [8]) of Tc^{94} to Mo^{94}. Recently Bernstein and Forster [4]) did a directional correlation measurement on the 700 keV-873 keV cascade. Their measurements were done at 4 angles in each quadrant, and their results indicated level sequences of 4+(Q)2+(Q)0+ or 2+(D, Q)2+(Q)0+.

The metastable state of Nb^{94} has a half-life of [9]) 6.6 min and decays predominantly by the emission of a 42 keV gamma ray [3, 10, 11]). Schuman and Goris [3]) determined the K conversion coefficient of the 42 keV transition to be $\approx$ 400 by comparing the X-ray and 42 keV gamma ray intensities in a scintillation spectrum. The 1.3 MeV beta ray feeding the 873 keV level of Mo^{94} in the decay of Nb^{94m} was found to have a branching ratio of 0.1 % by an absorption experiment [12]). Schuman and Goris noticed a slight enhancement

† Work supported in part by the U.S Atomic Energy Commission and the Michigan Memorial Phoenix Project.

at 700 keV in a scintillation spectrum, indicating the possibility of a 700 keV gamma ray with an intensity of 2 ± 2 % of the 873 keV gamma ray [3]).

2. Experimental Method

2.1. THE Nb^{94} ACTIVITY

A sample of very pure niobium was irradiated with an accumulated flux of 4×10^{20} neutrons per cm^2 in the MTR facility at Idaho Falls. Measurements were taken 33 months after irradiation in order to allow the 115 d Ta^{182} impurity to decay. At the time of the measurements the 1122 keV gamma ray in the Ta^{182} decay had an intensity of about 20 % of the 873 keV transition in the Nb^{94} decay, and the 1.33 MeV transition from Co^{60} impurity had an intensity of less than 1 % of the 873 keV gamma ray from Nb^{94}.

The coincidence and directional correlation measurements employed a fast-slow coincidence circuit with a resolving time of 30 ns. The scintillation counters consisted of 5.1 cm by 5.1 cm NaI(Tl) crystals mounted on R.C.A. 6342A phototubes.

2.2. THE Nb^{94m} ACTIVITY

A highly pure niobium sample was irradiated in a flux of 2×10^{12} neutrons per $cm^2\cdot$ sec for a duration of 2 min in the Ford Nuclear Reactor. In order to obtain good resolution the lower portion of the spectrum which consists of the KX-ray and the 42 keV gamma ray was analyzed via a 10.2 cm diameter cylindrical proportional counter filled with Kr gas at 3 atm pressure with a 0.25 mm thick Be side window. A 99+ % Al absorber of thickness 0.32 cm was placed in front of the Be window to absorb the beta rays and a portion of the KX-ray so that the tail of the X-ray did not completely overwhelm the 42 keV gamma ray in the spectrum. A scintillation counter (5.1 cm $\times$ 5.1 cm NaI(Tl) crystal) was then used to study the complete spectrum of Nb^{94m}, which includes the 873 keV gamma ray. The spectrum of gamma rays in coincidence with the 873 keV gamma ray was obtained by using the fast-slow coincidence method. The summing coincidence method proposed by Hoogenboom [13]) was also used in studying the possible existence of the 700 keV gamma ray in the Nb^{94m} decay. Pulses from the proportional counter as well as the scintillation counter were recorded with a 256-channel analyzer.

3. Results

3.1. THE Nb^{94} DECAY

A gamma ray spectrum was taken with the Nb^{94} source 50 cm from the crystal in order to avoid summing. The spectrum showed gamma rays of 700 keV and 873 keV from the Nb^{94} decay. The crossover transition of 1573 keV was not observed; its maximum possible intensity was found to be 0.1 % of the 873 keV intensity.

In the coincidence measurements, pulses selected by a linear gate were displayed on a 256-channel analyzer. These measurements showed that the 700 keV gamma ray is in coincidence with the 873 keV transition.

The decay scheme is shown in fig. 1. The principal features agree with the decay scheme proposed by Douglas *et al.*[1]). The beta ray energy for the Nb^{94} decay was determined by Douglas *et al.*[1]).

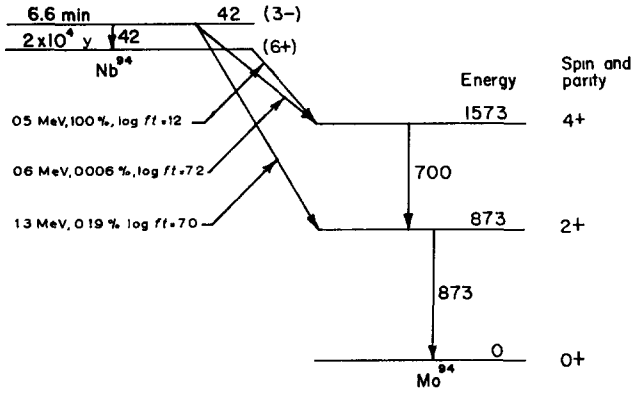

Fig. 1. The decay scheme of Nb^{94} and Nb^{94m}. Energies are given in keV, unless noted otherwise.

The directional correlation data on the 700 keV-873 keV cascade were taken at 7 angles in each quadrant with both crystals at 10 cm from the source. The source was a thin foil of Nb^{94} in a small cylindrical shape. Since the half-life of the 873 keV level is [5,6]) 2.0 p sec, no attenuation of the correlation is expected. Pulse-height analyzers and lateral lead shielding on the crystals provided energy selection. The real coincidence rate was normalized for electronic drift. After making a least squares fit [14]), the expansion coefficients were normalized and corrected for finite resolution [15]). The corrected expansion coefficients were found to be $A_2 = 0.0965 \pm 0.0076$ and $A_4 = 0.019 \pm 0.011$. These data agree well with the theoretical coefficients for a 4(Q)2(Q)0 cascade. The only other cascade which will fit the experimental data is a 2(D, Q)2(Q)0 cascade with a quadrupole content between 0.03 and 0.04 in the 700 keV gamma ray. The 2(D, Q)2(Q)0 cascade is not likely because of the lack of an observable crossover transition at 1573 keV. There is no interference in the directional correlation from the Ta^{182} activity because of the pulse-height analyzers used and the nature of the Ta^{182} decay. In order to check for possible attenuation of the directional correlation due to the solid source, some of the source was dissolved in a solvent consisting of hydrofluoric and nitric acids. A total of about 3000 real coincidences taken at 90° and at 180° with this liquid source indicated, within error limits, the same asymmetry as that of the solid source.

3.2. THE Nb^{94m} DECAY

After having corrected for counter efficiency, the presence of absorbers, and the K fluorescence yield of Nb the conversion coefficient α_K for the 42 keV gamma ray was found to be 1600 ± 350 from the proportional counter spectrum. From the scintillation spectrum the intensity ratio of the 873 keV gamma ray to the 42 keV gamma ray was measured to be 16.0 ± 1.6. By means of this intensity ratio, the value of α_K determined previously, and the K:L:M ratio [11]) of 31 : 100 : 36, the branching ratio of the 1.3 MeV beta ray was determined to be 0.19 ± 0.03 % with a log *ft* value of 7.0.

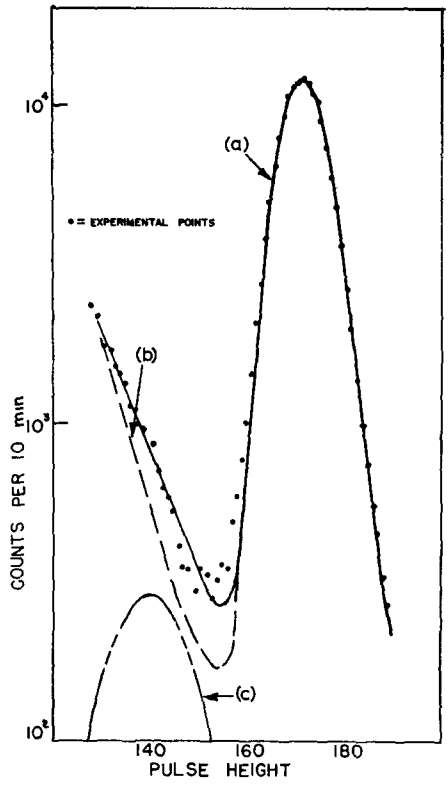

Fig. 2. Comparison of the Nb^{94m} single spectrum with a mono-energetic pulse-height spectrum of 873 keV. The presence of a 700 keV photopeak is evident. (Curve (a) shows the sum of the 700 keV and 873 keV pulse height spectra; the fit was obtained from least square analysis. Curve (b) shows the 873 keV pulse height spectrum and curve (c) the 700 keV photopeak.)

Due to poor statistics, the existence of the 700 keV gamma ray in the spectrum of gamma rays in coincidence with the 873 KeV gamma ray and in the spectrum obtained with the summing coincidence method proved inconclusive. However, a comparison of the Nb^{94m} single spectrum was made with a mono-energetic pulse-height spectrum of 873 keV which was obtained by the extra-

polation [16]) from the measured pulse-height spectrum of Mn^{54} (842 keV). From this comparison it was noted that a gamma ray of approximately 700 keV was present as shown in fig. 2. A least square analysis [16]) showed the intensity of the 700 keV gamma ray to be 3.0 ± 0.6 % of the 873 keV gamma ray. From this intensity ratio the log *ft* value for the 600 keV beta ray was calculated to be 7.2.

4. Discussion

The ground state of Nb^{94} decays to the 1573 keV level of Mo^{94} with a log *ft* value [17]) of 12, which suggests a spin of 2+ or 6+ for Nb^{94}. The spin of 6+ is more probable, since no transitions have been observed from the Nb^{94} ground state to the 873 keV level or ground state of Mo^{94}. Comparing the experimentally obtained conversion coefficient for the 42 keV gamma ray in the Nb^{94m} decay with theoretical values and also taking into consideration its half-life and the K : L : M ratio [11]), the transition should be predominantly E3 in character. This indicates a spin of 3— or 9— for the Nb^{94m} level. The log *ft* values of 7.0 for the 1.3 MeV beta ray and 7.2 for the 600 keV beta ray suggest that both beta transitions are first forbidden, which support the 3— assignment for the isomeric level.

We wish to express our appreciation to J. I. Trombka for doing the least square analysis of the Nb^{94m} single spectrum.

References

1) Douglas, Mewherter and Schuman, Phys. Rev. **92** (1953) 369
2) Rollier, Saeland, Morpurgo and Caglieris, Acta Chem. Scandinavica **9** (1955) 57
3) R. P. Schuman and P. Goris, J Inorg. Nuclear Chem. **12** (1959) 1
4) H. Bernstein and H. H. Forster, Nuclear Physics **24** (1961) 601
5) G. M. Temmer and N. P. Heydenburg, Phys. Rev. **104** (1956) 967
6) P. H. Stelson and F K. McGowan, Phys. Rev. **110** (1958) 489
7) E der Mateosian, Phys. Rev. **83** (1951) 223A
8) Medicus, Preiswerk and Scherrer, Helv. Phys. Acta **23** (1950) 299
9) Sagane, Kojima, Miyamoto and Ikawa, Proc. Phys.-Math. Soc. Japan **22** (1940) 174
10) M. Goldhaber and C. O. Muehlhause, Phys. Rev **74** (1948) 1248A
11) R. L. Caldwell, Phys. Rev. **78** (1950) 407
12) Goldhaber, Muehlhause and Sturm, quoted in Strominger, Hollander and Seaborg, Revs. Mod. Phys. **30** (1958) 667
13) A. M. Hoogenboom, Nuc. Instr. **3** (1958) 57
14) M. E. Rose, Phys. Rev. **91** (1953) 610
15) Arns, Sund and Wiedenbeck, University of Michican Research Institute Report 2375-4-T, Feb. 1959
16) J. I. Trombka, Doctoral dissertation, Univ. of Mich., 1961 I. P. 531
17) Nuclear Data sheets, 58-9-29 (National Research Council, Washington, D. C. 1958)