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SUPERALLOWED BETA DECAY IN Z = N NUCLIDE $^{74}_{37}$Rb

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Abstract

The new nuclide $^{74}_{37}$Rb has been observed at the ISOLDE-2 facility using a novel metal powder target operated at 2200°C, and a ΔE-E beta telescope. Calculations support the conclusion that the observed half-life of 59 ± 2 msec is superallowed beta decay from a $T = 1$, $I = 0^+$ ground state in this heaviest $Z = N$ nuclide known.

1. Introduction

Great interest is attached to the study of nuclei along the $N = Z$ line and, in particular, to their beta decay. Thus the family of isospin triplets with $I = 0^+$, which are characterized by pure Fermi-type beta decays, have played an important role in determining the strength of the weak interaction[1]) and may even contribute to our understanding of the structure of the nucleon[2]). In this family of nuclei with mass number $4n + 2$, the heaviest known member until now has been ^{62}Ga [1,3]); in the present paper is reported the observation of the new nuclide $^{74}_{37}$Rb, also, as it turns out, characterized by a $T = 1$ ground state.

The cross-sections for the production of extremely neutron-deficient species are low, and for this reason on-line isotope separation (which selects A *and* Z) has been used to provide sufficient selectivity. A search for the $T = 1$ state of ^{74}Rb, however, presents special problems because of the short half-life (predicted value 57-60 msec, see Section 4) and because of the expected decay by essentially pure beta radiation albeit with a very high end-point energy. These problems have been resolved through new experimental techniques, which are summarized below, followed by the new results and a comparison with the theoretical predictions.

2. Experimental techniques

2.1 Target and ion-source

Neutron-deficient isotopes are produced at the ISOLDE installation at the CERN Synchro-cyclotron through spallation reactions induced by 600 MeV protons. Details of these techniques have been given elsewhere[4-6]). In previous work with the rubidium isotopes the target was a liquid alloy of Y + La, operated at 1400°C, and element selectivity was ensured through the use of a surface-ionization source. The relatively long average delay-time of this system (∿ 50 sec, Ref. 6), however, reduces the yield of a 60 msec isotope by a factor of the order of 10^{-3} from decay losses alone. Recently, a new target concept[6]) involving metallic powders at very high temperatures has offered greatly improved release rates, which originate in a new rate-determining process, namely solid-state diffusion in the grains. In the present work, pure niobium metal powder with an average grain size of 20 microns was operated at a temperature of 2200°C. Measurements of release rates[6]) combined with calculations based on standard diffusion theory[7]) show that the release yield for a 60 msec isotope should be as high as 5%.

2.2 Detection system

Owing to the contamination of the mass-separated beam with small amounts of other masses, and also to the background, it was essential to use a detection system with high selectivity. As the odd-odd light Rb isotopes are characterized by Q_{EC} values in the vicinity of 10 MeV, much above those of likely contaminants and daughter products, the main detector was an 80 mm dia. × 50 mm plastic scintillator (NE 110). In order to reduce the background, this detector was operated in coincidence with a ΔE detector[8]), 1 mm thick and with an area of 100 mm^2; the two detectors acting as a telescope counter with an over-all efficiency of 20% determined for 3.5 MeV betas. The full system comprising two detector telescopes is shown in Fig. 1.

With an expected half-life for ^{74}Rb possibly as low as 60 msec, it became necessary to use electrostatic deflecting of the beam instead of the usual

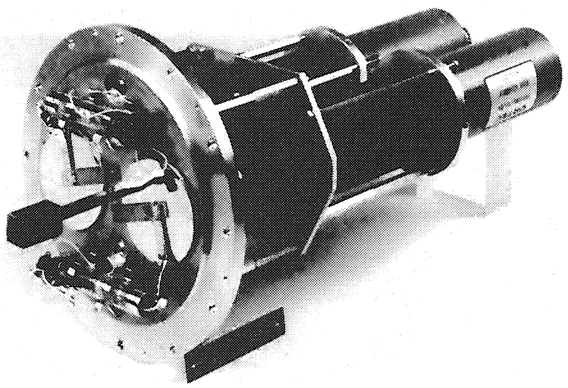

Fig. 1 Dual ΔE-E beta telescope as described in the text. The thin (10 mm × 10 mm) ΔE scintillator is positioned between an aluminized mylar collector foil and the large, cylindrical E detector, and mounted onto a light guide, attached to the small phototube.

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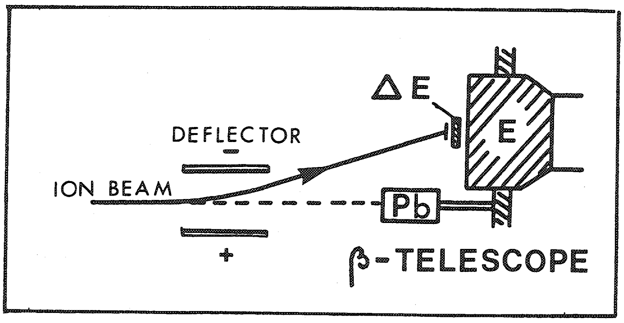

Fig. 2 A schematic representation of the ΔE-E beta telescope system, showing the path of the ion beam from the separator, both with and without deflection.

mechanical (tape-transport) systems. The arrangement shown in Fig. 2 allows the radioactive ion beam to be directed onto a stationary collector foil of aluminized mylar placed in front of the telescope. The timing of the collection and the counting sequence were determined as a pre-set cycle, and data were recorded in a multi-analysis mode as well as by multi-scaling with fixed discriminator settings in the beta spectra.

3. Experimental results

The first and the last of a sequence of eight beta spectra, recorded at intervals of 60 msec for 4400 cycles, are shown in Fig. 3. There is clearly a fast decay component at high energies; we find (see the inset of Fig. 3) that the betas of energies greater than 5 MeV decay with a half-life of 59 ± 2 msec. The high-energy betas have an end-point energy of 10.0 ± 1.5 MeV, a value which agrees with the expected one (see Section 4). The production rate for ^{74}Rb corresponds to 450 atoms/sec at the collector foil for a proton beam of 0.8 μA on the niobium target. The low-energy betas at the mass 74 position originate from the 12 min 9) daughter product ^{74}Kr, as well as from a slight contamination from the much more abundant neighbouring mass ^{75}Rb. As a by-product in the present study, the same experimental arrangement was used for a re-determination of the ^{75}Rb half-life, which was found to be 17.0 ± 1.0 sec in agreement with the previous value 4) of 21 ± 3 sec.

The isotope ^{74}Rb is expected to have two low-lying levels, one with isospin 1 and $I^{\pi} = 0^{+}$, and a second with isospin 0. The short half-life observed in this experiment clearly must come from the former state, but if isomerism occurs, we might hope to observe also the beta decay of the $T = 0$ level. According to the calculations of Takahashi et al. 10) this decay would be characterized by a half-life of approximately 1 sec. A brief search for this activity allows us to put an upper limit of 1% to the production cross-section of an assumed isomeric $T = 0$ state, relative to that of the $T = 1$ state. It therefore seems most likely that the $T = 0$ state lies higher, and that it de-excites to the $T = 1$ state by electromagnetic transitions.

4. Predicted properties of the T = 1 state of ^{74}Rb

In order to draw conclusions about the Fermi transition matrix element from the measured half-life, it is necessary to know the Q_{EC} value. In

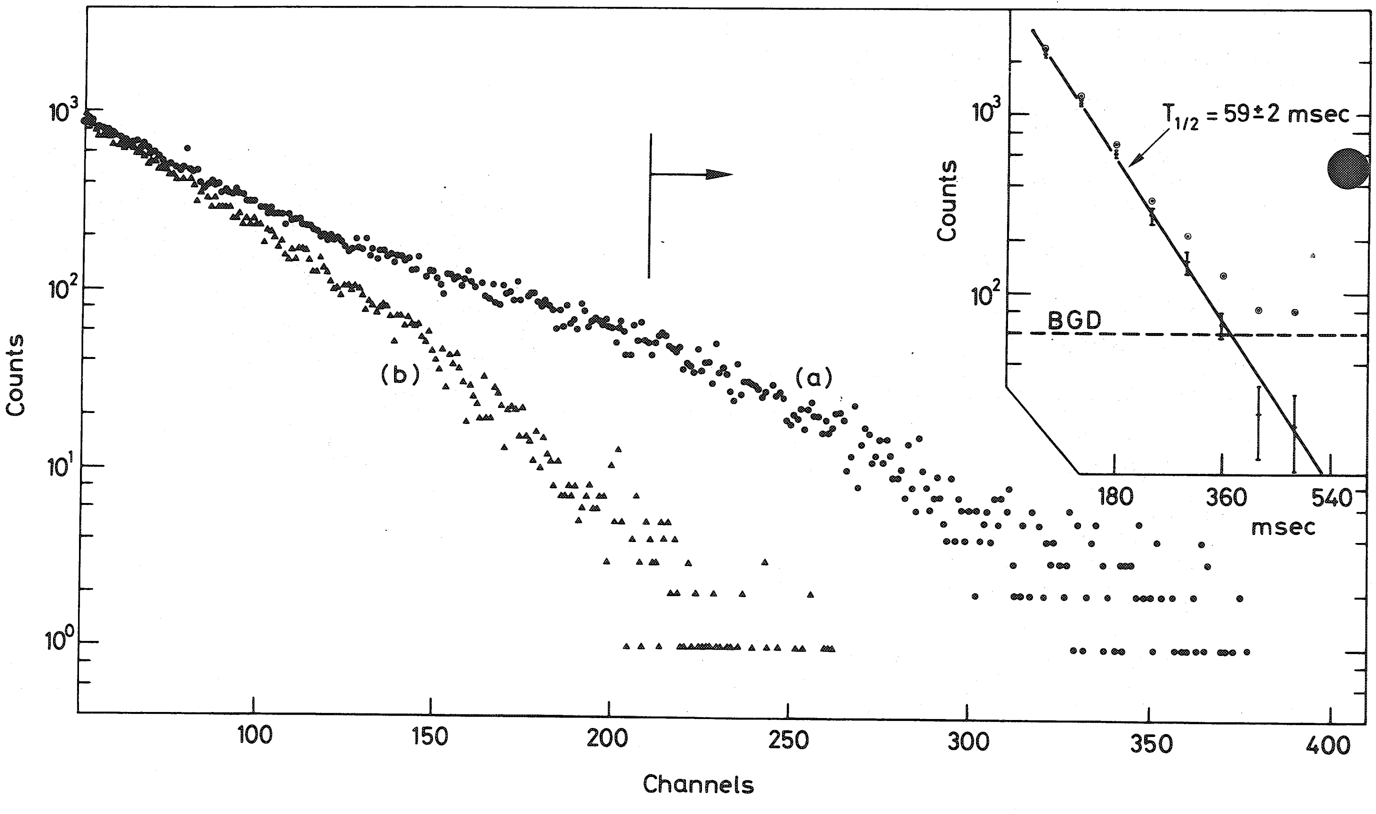

Fig. 3 The first (a) and last (b) of a sequence of eight beta spectra of ^{74}Rb, recorded at intervals of 60 msec for about 4400 cycles. The cycle sequences were 200 msec collecting, 5 msec waiting, and 700 msec counting periods. The solid vertical line indicates the point above which counts were summed in each spectrum to give the decay curve indicated in the inset.

the absence of precise experimental data the Q_{EC} has been estimated from the semi-empirical systematics of Coulomb displacement energies (ΔE_C) within the isobaric triplets. Two formulae for ΔE_C, used by Jänecke$^{11)}$, and including the n-p mass difference, can reproduce the Q_{EC} values from ^{26m}Al to ^{54}Co with a precision of typically 100 keV; the predictions for the case of ^{74}Rb are 10,642 and 10,546 keV, respectively.

For the superallowed beta decay of ^{74}Rb we expect that any branching to excited levels in ^{74}Kr will be extremely weak. The half-life of ^{74}Rb can therefore be calculated from the expression

$$ft(1+\delta_R) = K/[G_V^2|M_V|^2(1+\Delta_R)(1-\delta_C)] \,, \qquad (1)$$

in which t is the partial half-life, G_V the vector coupling constant, M_V the nuclear matrix element, and δ_R, Δ_R, and δ_C are the outer and inner radiative correction terms and the isospin purity correction term. Following Hardy and Towner$^{1)}$ we assume for the quantitiy $ft(1+\delta_R)(1-\delta_C)$ the value 3081.7 ± 1.9 sec. Using extrapolated values of 1% and 2.3% for δ_C and δ_R, respectively$^{3)}$, and the Q_{EC} values given above, we predict values of 57 and 60 msec for the half-life of ^{74}Rb.

5. Concluding remarks

The isotope ^{74}Rb represents the heaviest self-conjugate nucleus observed until now. The experimental half-life of 59 ± 2 msec agrees well with the theoretical predictions for a superallowed Fermi transition in an isospin triplet; in the absence of a precise experimental Q_{EC} value and before the precision on the half-life has been improved, it is, however, not possible to draw conclusions about the magnitude of the correction terms in Eq. (1). It has not been possible to observe beta decay from the expected $T=0$ state; the inference is that it lies above the $T=1$ state to which it decays electromagnetically. An improved precision has been obtained for the ^{75}Rb half-life: 17.0 ± 1.0 sec.

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11a) J. Jänecke *in* Isospin in nuclear physics (ed. D.H. Wilkinson) (North-Holland Publ. Co., Amsterdam, 1969), chapter 8, Eq. (8.97).

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