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THE N = Z NUCLIDE ^{74}Rb WITH T, I^{π} = 1, 0^{+}

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ABSTRACT

Improved experimental techniques have permitted the observation of new nuclide ^{74}Rb with a half-life of 64.9 ± 0.5 msec, which represents the heaviest self-conjugate nucleus detected until now. The absence of a long-lived isomer indicates that the T = 0 state of ^{74}Rb lies above the T = 1 state. An upper limit of 10^{-3} relative to ^{74}Rb can be placed on the yield of the (unobserved) mirror nucleus ^{73}Rb, and it appears likely that the limit of particle stability has been reached. The half-life of ^{75}Rb is 17.0 ± 1.0 sec.

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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 $I^{\pi} = 0^{+}$ has played an important role in the determination of the strength of the weak interaction and may even contribute to our understanding of the structure of the nucleon [1,2]. In the present paper we report a new member of this series [3], the isotope ^{74}Rb. An early report based on less precise data was given elsewhere [4].

Spallation reactions induced by 600 MeV protons were used to produce neutron-deficient rubidium isotopes, which were ionized by surface ionization and mass-separated in the ISOLDE-2 on-line facility at CERN [5-8]. Several improvements in the experimental techniques were necessary in order to permit the detection of the expected 60 msec T = 1 state characterized by a cross-section of only a few tens of nanobarns. The production yields of rubidium isotopes and the spallation cross-sections [9] are illustrated in fig. 1.

As the light odd-odd rubidium isotopes are characterized by Q_{EC} values close to 10 MeV, it was possible to reduce the effects of background and the interference of contaminants in the separated mass spectrum by detecting the high-energy betas in a telescope similar to that used by Beck [10]. The experimental arrangement is shown schematically in the inset of fig. 2. The collection and counting sequences were operated externally and cycled continuously. Data were recorded in a multi-spectral mode with a computer-based system and, in parallel, in a multi-scaling mode with the discriminator set at 5 MeV. The results of the latter measurement are displayed in fig. 2.

Analysis of the data of fig. 2, using the CLSQ computer code [11] and assuming a single component with a constant level of background, yielded a half-life of 64.9 ± 0.5 msec for the decay of ^{74}Rb. The effects of possible systematic errors appear to be negligible. The method of Wilkinson [12] indicates that *pile-up* should introduce an error of less than 0.005 msec given the observed initial count rate of 200 counts/sec. *Radioactive contamination* with other short-lived activities is quite unlikely, as a surface ionization source was used, followed by mass analysis of the rubidium beam. Experiments conducted at adjacent masses indicated clearly the lack of such interferences. Nevertheless a decrease of only 0.13 msec would be introduced if the entire long-lived component (fig. 2) were assumed due to the presence of the abundantly produced isotope ^{80}Rb ($T_{1/2}$ = 30 sec).

The isotope ^{74}Rb is expected to have two low-lying levels, one with T = 1, $I^{\pi} = 0^{+}$ which is clearly the one reported above, and another with T = 0. From the systematics of Takahashi et al. [13], a half-life of about 2 sec may be estimated for the latter level. A search for a mass-74 activity in this half-life range proved negative, and an upper limit of about 1% can be placed on the production cross-section of a T = 0 activity relative to that of the T = 1 activity. This estimate includes the delay corrections indicated in fig. 1. The half-life for the decay of the previously observed nuclide ^{75}Rb [5] was remeasured to be 17.0 ± ± 1.00 sec, in good agreement with the previous value of 21 ± 3 sec.

Finally, about 12 hours of counting was devoted to a search for the $T_Z = -1/2$ nucleus ^{73}Rb, which is expected to have almost the same beta end-point energy and approximately the same beta half-life as ^{74}Rb. (The heaviest known $T_Z = -1/2$ nucleus, ^{55}Ni, has a half-life of 183 msec [14].) No short-lived activity was observed at mass 73, and we may put an upper limit on the yield at 1 atom/sec.

In conclusion, let us turn briefly to the main results obtained in the present work and to their interpretation.

a) The half-life of ^{74}Rb is 64.9 ± 0.5 msec. In the absence of a precise measurement of Q_{EC}, a discussion of the Fermi matrix element is not possible; still it is interesting to utilize the estimate for Q_{EC} based on the formulae for the Coulomb displacement energy given by Jänecke [15], which lead to a value of 10594 keV. (Applied to the lighter isospin triplets, these formulae agree typically to within 100 keV.) Following Hardy and Towner [1] we use the value 3081.7 ± 1.9 sec for the quantity "corrected $\mathcal{F}t$", and taking $\mathcal{F}$ and the correction terms from Wilkinson and Macefield [16] and Towner and Hardy [17] we calculate a half-life for ^{74}Rb of 58.5 msec. The 10% deviation from the experimental value could be explained by a decrease in Q_{EC} of about 200 keV.

b) The non-observation of a T = 0 state in ^{74}Rb is a strong indication that the ground state has T = 1 and is populated by electromagnetic transitions from the T = 0 state. This is in agreement with the general tendency for the 0^+ T = 1 state to lie lowest in ^{34}Cl and all heavier $T_Z = 0$ nuclei except ^{38}K, and ^{58}Cu. The systematics has recently been discussed by Zeldes and Liran [18].

c) The low limit on the cross-section for the production of ^{73}Rb, which is in disagreement with the semi-empirical spallation yield formula (fig. 1), indicates that low proton separation energies are now setting a limit to the production of more neutron-deficient rubidium nuclei. An analysis [19] of the proton separation energies of odd-Z nuclei in this region has been performed on the basis of the systematics of masses and Coulomb-displacement energies, and indicates that the ground state of ^{73}Rb will be unstable towards proton emission. It thus seems very probable that the present experiment has reached the limit of particle stability.

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REFERENCES

[1] J.C. Hardy and I. Towner, Nuclear Phys. A254 (1975) 221.

[2] D.H. Wilkinson, Nature 257 (1975) 189.
D.H. Wilkinson and D.E. Alburger, Phys. Rev. C 13 (1976) 2517.

[3] S. Raman, T.A. Walkiewicz and H. Behrens, Atomic Data and Nuclear Data Tables 16 (1975), 451 and references therein.

[4] J.M. D'Auria, L.C. Carraz, P.G. Hansen, B. Jonson, S. Mattsson, H.L. Ravn, M. Skarestad and L. Westgaard, Proc. 3rd Internat. Conf. on Nuclei Far From Stability, Cargèse, 1976, CERN 76-13 (1976), p. 262.

[5] H.L. Ravn, S. Sundell, L. Westgaard and E. Roeckl, J. Inorg. Nuclear Chem. 37 (1975) 383.

[6] H.L. Ravn, S. Sundell and L. Westgaard, Phys. Letters 39B (1972) 337; Nuclear Instrum. Methods 123 (1975) 131.

[7] H.L. Ravn, L.C. Carraz, J. Denimal, E. Kugler, M. Skarestad, S. Sundell and L. Westgaard, Proc. Internat. Conf. on Electromagnetic Isotope Separators and Related Ion Accelerators, Kiryat Anavim (Israel), 1976; and to be published in Nuclear Instrum. Methods.

[8] H.L. Ravn, Proc. 3rd Internat. Conf. on Nuclei Far From Stability, Cargèse, 1976, CERN 76-13, pp. 22.

[9] G. Rudstam, Z. Naturforsch. 21a (1966) 7.

[10] E. Beck, Nuclear Instrum. Methods 76 (1969) 77.

[11] J.B. Cumming, *in* Applications of Computers to Nuclear and Radiochemistry (ed. by G.D. O'Kelley) (Gatlinburg, Tenn., USA, 1962) NAS-NS 3107.

[12] D.H. Wilkinson, Nuclear Instrum. Methods 134 (1976) 149.

[13] K. Takahashi, M. Yamada and T. Kondoh, Atomic Data and Nuclear Data Tables 12 (1973) 101.

[14] P. Hornshøj, L. Højsholt-Poulsen and N. Rud, Proc. 3rd Internat. Conf. on Nuclei Far From Stability, 1976, CERN 76-13 (1976) p. 120.

[15] J. Jänecke *in* Isospin in Nuclear Physics (ed. D.H. Wilkinson) (North-Holland Publ. Co., Amsterdam, 1969), Chapter 8.

[16] D.H. Wilkinson and B.E.F. Macefield, Nuclear Phys. A158 (1970) 110.

[17] I.S. Towner and J.C. Hardy, Nuclear Phys. A205 (1973) 33.

[18] N. Zeldes and S. Liran, Phys. Letters 62B (1976) 12.

[19] J.C. Hardy, personal communication (1976).

Figure captions

Fig. 1 : Observed yields (in atoms/sec) of rubidium isotopes and (inset) loss factors due to radioactive decay in the target and ion source. The black circles are the experimental yields at the collector corresponding to a 1 μA beam of 600 MeV protons impinging on a 50 g/cm^2 target of niobium powder (grain diameter 20 μ) at a temperature of 2200°C. The curve shows, in an arbitrary normalization, the spallation cross-sections calculated from Rudstam's semi-empirical formula [9]. For short half-lives, the yields are expected to reflect decay losses. The release yield as a function of half-life is shown in the inset, which is based on the discussion in ref. 7, and from which it can be seen that the target system used in the present work provides a 100 times higher yield of 65 msec ^{74}Rb than the molten-metal target (Y-La alloy at 1400°C) used in previous work [6].
When the release-yield correction is applied, the ^{74}Rb point (open circle) comes within a factor 4 of the Rudstam formula, while the corrected upper limit for ^{73}Rb remains a factor of 100 below. (It is assumed for this argument that ^{73}Rb decays by beta decay, which would give a half-life roughly equal to that of ^{74}Rb. The half-life for proton emission is likely to be very much shorter.)

Fig. 2 : Decay of beta-rays of energy greater than 5 MeV detected in a multiscaling mode following a 200 msec collection. The time per channel is 8.0 msec with 0.01 msec waiting time between channels. The cycle period (collection and counting) was 1255 msec and the data were recorded for a total of 31000 cycles, or about 11 hours.
The experimental arrangement is shown schematically in the inset. During the counting periods, the ^{74}Rb ion beam was intercepted by an electrostatic beam gate placed far upstream in the beam line. During the collections, the beam was directed electrostatically to an aluminized mylar foil placed in front of a counter telescope consisting

of a 1 mm thick ΔE counter of 1 cm^2 followed by an 8 cm dia. × 5 cm thick NE110 plastic scintillator. The over-all efficiency of the telescope including solid angle was 20%, determined for 3.5 MeV betas.

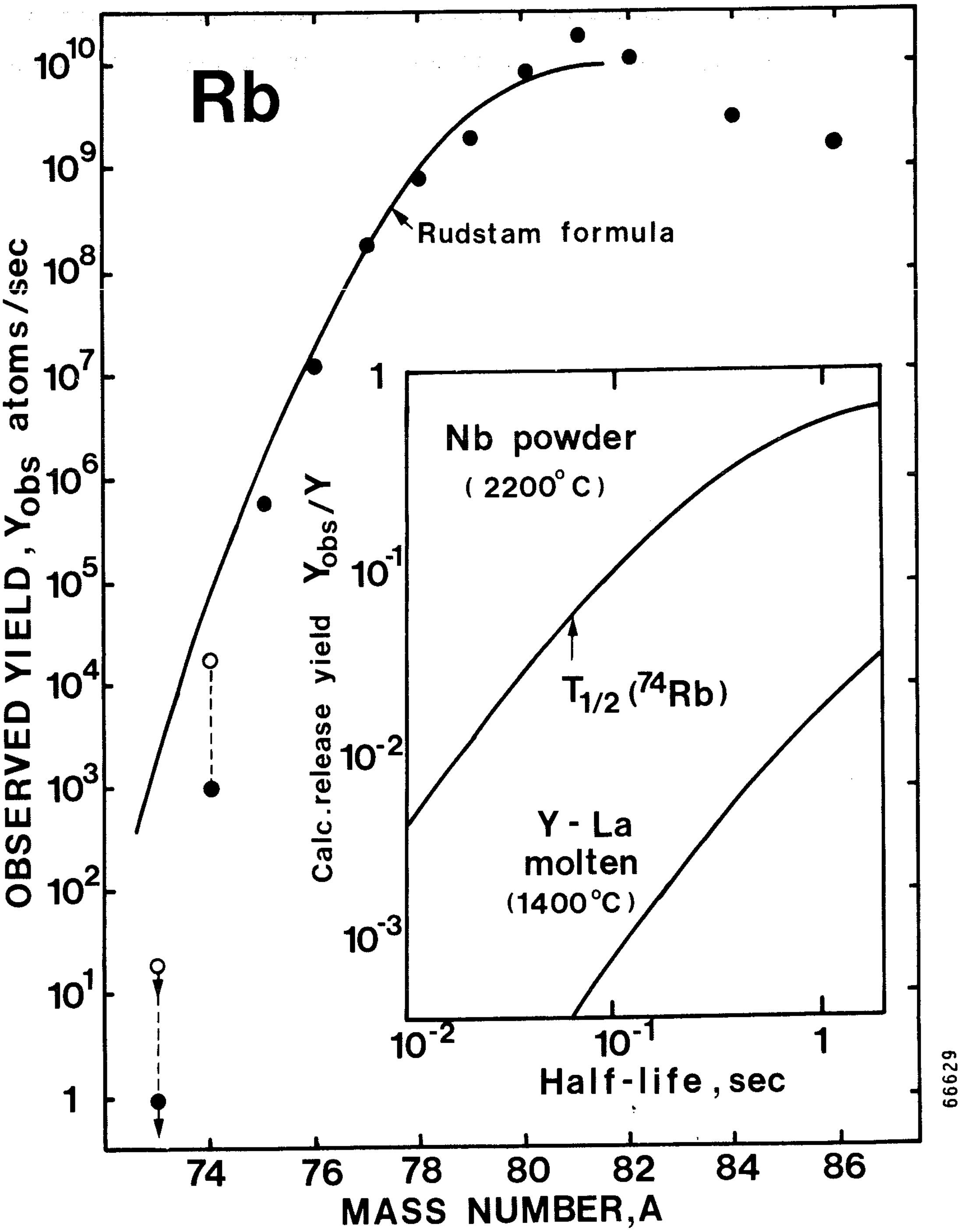
Rb
Rudstam formula
OBSERVED YIELD, Y_obs atoms/sec
MASS NUMBER, A
Nb powder
(2200°C)
Y - La
molten
(1400°C)
T_1/2 (74Rb)
Calc. release yield Y_obs/Y
Half-life, sec
66629

Fig. 1

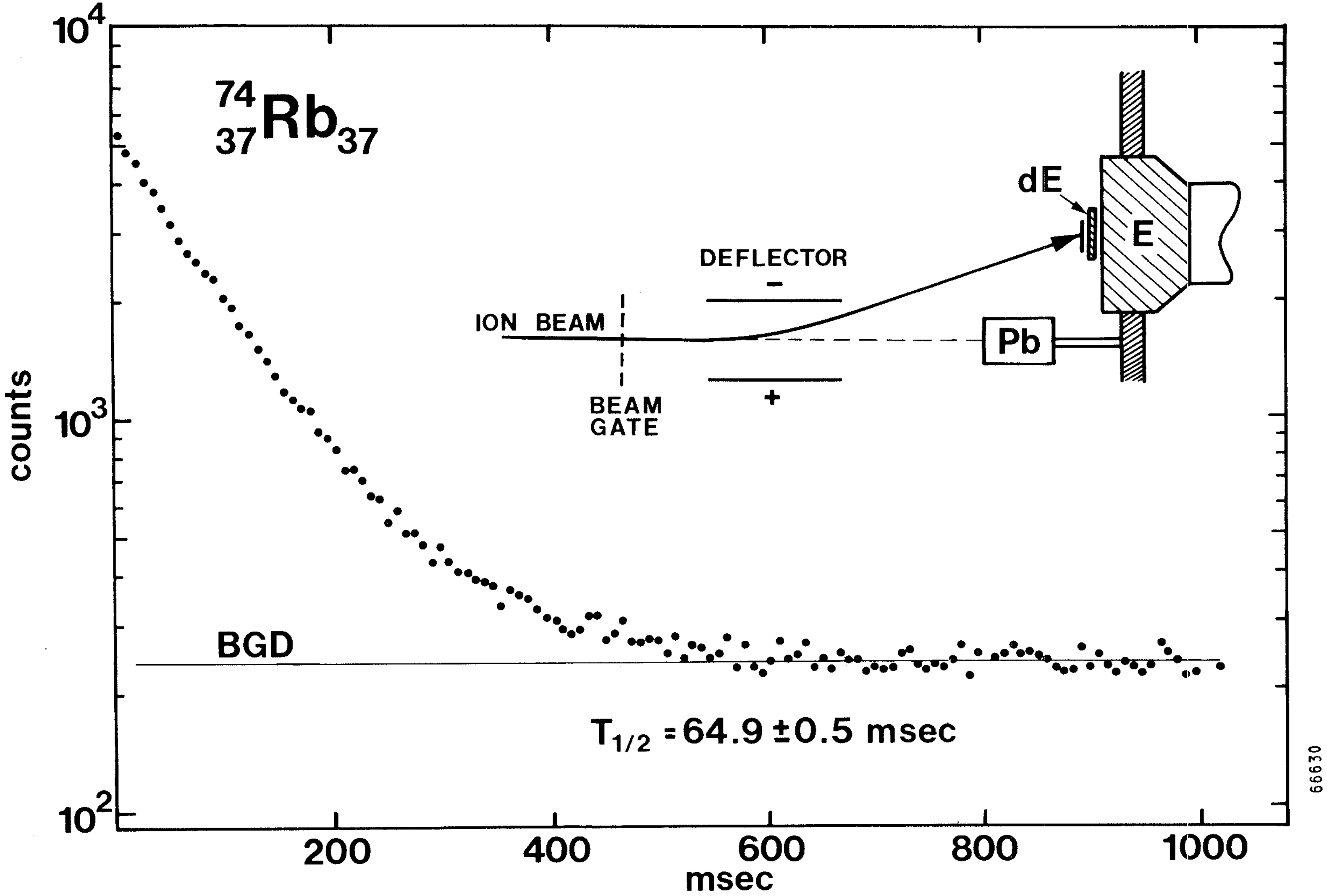
10^4
10^3
10^2
counts
74 37 Rb 37
dE
E
DEFLECTOR
−
+
ION BEAM
BEAM GATE
Pb
BGD
T1/2 = 64.9 ±0.5 msec
200
400
600
800
1000
msec
66630

Fig. 2