BETA-DECAY OF THE $T_z = -1/2$ MIRROR NUCLEUS ^{71}Kr

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ABSTRACT

A new isotope ^{71}Kr has been observed following mass separation of products from Nb irradiated by 600 MeV protons. The measured half-life of its high energy β^+ activity is 97 ± 9 msec. This is the heaviest $T_z = -1/2$ mirror nucleus so far observed. Using a decay energy calculated from Coulomb Energy systematics, information is obtained about the Gamow-Teller matrix element for the mirror β -transition.

E [RADIOACTIVITY ^{71}Kr (from $^{93}\text{Nb}(p,6p17n)$, chem. mass separation);
measured $t_{1/2}$. GT matrix element deduced. Plastic scintillators.]

Geneva - July 1980

Submitted to Nuclear Physics

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1. INTRODUCTION

The beta-decay of $T_z = -1/2$ mirror nuclei depends on both the Fermi and Gamow-Teller matrix elements. For the ground state decay the Fermi transition strength is constant for all such nuclei because of the conservation of isospin and conserved vector current. From a measurement of the total transition strength it is then possible to obtain the value of the GT matrix element which depends on nuclear wave functions¹⁾. The GT matrix elements for the superallowed decay branches of most known $T_z = -1/2$ nuclides have been determined in this way^{2,3,4)}. The β -decays of all but two of these nuclides below ^{59}Zn ($Z = 30$, $N = 29$) have previously been reported.

In this letter we report the observation of the β^+ -decay and the measurement of the half-life of ^{71}Kr ($Z = 36$, $N = 35$) which is the heaviest $T_z = -1/2$ mirror nucleus so far observed. If assumptions are made regarding the systematics of Coulomb energies an approximate value of the decay energy for this nuclide and hence an ft value can be deduced. This ft value has been used to deduce information on the GT matrix element.

2. EXPERIMENTAL PROCEDURE

The mirror nucleus ^{71}Kr was separated in the ISOLDE Facility from a 50 g/cm^2 target of Nb powder maintained at a temperature of 2200°C . The target was irradiated by a beam of $\sim 2 \text{ }\mu\text{A}$ of 600 MeV protons from the CERN synchro-cyclotron. The isotope separator ion source conditions were chosen to enhance the fast release of Kr isotopes⁵⁾. Atoms of mass 71 were collected on a thin aluminium foil placed directly in front of a beta-ray telescope. Because ^{71}Kr was produced through the rare reaction $^{93}\text{Nb} (p,6p17n) ^{71}\text{Kr}$ and has a short half-life the yield was very low ($\sim 100 \text{ atoms/min}$).

The β -ray telescope⁶⁾ consisted of two Ne 110 plastic scintillators, a 1 mm thick $\times 1 \text{ cm}^2$ area ΔE counter followed by a 5 cm thick $\times 8 \text{ cm}$ diameter E counter. The energy window on the ΔE counter was set to accept the minimum ionisation peak from high energy electrons. The detector telescope system was tested and calibrated using a source of ^{106}Rh ($E_{\beta^-(\text{max})} = 3.55 \text{ MeV}$).

Assignment of the β -activity to mass 71 was made by scanning over this mass region with the separator magnet. A strong maximum in the β -activity was observed at the setting corresponding to mass 72 and was assigned to the known isotope ^{72}Kr which has a half life of 17 s and $E_{\beta}(\text{max}) = 3.8 \text{ MeV}^{7)}$. A weaker maximum was found at mass 71. This maximum was most pronounced for high energy β -rays ($> 5 \text{ MeV}$) and was assigned to ^{71}Kr which has an estimated $E_{\beta}(\text{max}) = 9.19 \text{ MeV}$.

The tail of the distribution of mass 72 at the position of mass 71 gave a contamination of the order $\sim 10^{-3}$. Because of the much higher yield of long-lived ^{72}Kr this contaminant activity was important at β -energies of less than 3 MeV. At high β -energies there was a background due to the daughter of ^{72}Kr , 1.3 min ^{72}Br ($E_{\beta}(\text{max}) \sim 8 \text{ MeV}$)⁸⁾ which was reduced by the short collection time. The different backgrounds and the low yield of ^{71}Kr made it impracticable to attempt to measure the end-point energy of the beta-spectrum from ^{71}Kr .

The half-life of the ^{71}Kr beta-activity was determined using a multispectrum analysis technique. After each 0.2 s collection of the activity, the 512 channel beta-spectra were recorded in 16 sub-groups each of 50 ms with intervals of 4 ms between the subgroups. This cycle was repeated at 1.1 s intervals over a period of $\sim 15 \text{ h}$ corresponding to an integrated collection time of $\sim 2.8 \text{ h}$.

3. ANALYSIS OF DATA

In order to avoid the low energy background due to contaminant 17 s ^{72}Kr , a lower limit of $E_{\beta} > 5 \text{ MeV}$ was imposed in the data analysis. The long-lived background due to 1.3 min ^{72}Br ($E_{\beta}(\text{max}) \sim 8 \text{ MeV}$) was taken as constant over the time range of 0.86 s (16×0.054). Separate decay curves corresponding to different sections of the beta-spectrum above 5 MeV gave the same value for the half-life of ^{71}Kr within the statistical errors. The decay curve for $E_{\beta} > 5 \text{ MeV}$ is shown in fig. 1 and the 97 ms activity is assigned to the previously unreported mirror nuclide ^{71}Kr .

4. DISCUSSION

In order to determine the log ft value for the decay of ^{71}Kr the decay energy Q_{EC} must be known as well as the half-life. An approximate estimate of this energy can be obtained using the semi-empirical formula of Jänecke⁹⁾ for Coulomb energies. Another, probably more accurate, estimate can be made using calculated differences in Coulomb energies and the fact that the Q_{EC} value of ^{74}Rb can be derived with good precision. The half-life⁶⁾ of the $0^+ \rightarrow 0^+ \beta^+$ -transition in ^{74}Rb and the systematics of Fermi matrix elements¹⁰⁾ indicate $Q_{\text{EC}} = 10.40$ MeV for ^{74}Rb . The difference in Coulomb energy between ^{74}Rb and ^{71}Kr , again using Jänecke's formula, is 0.191 MeV. Using this value and the estimated Q_{EC} value for ^{74}Rb we predict $Q_{\text{EC}}(^{71}\text{Kr}) = 10.21$ MeV and $E_{\beta^+}(\text{max}) = 9.19$ MeV. We have used this value in our calculations. It is difficult to estimate the accuracy of this value because of the possibility of systematic errors in the calculation of Coulomb energies. Based on the accuracy of the formula in other regions we have adopted for the purpose of calculation an estimated error of ± 100 keV.

In calculating the ft value for the ground state transition we have assumed that feeding to higher levels can be neglected. The most intense beta-transition will occur between isospin doublets i.e. between the ground states. The strongest known β -transition feeding an excited state in a $T_Z = \frac{1}{2}$ nuclide is that of ^{49}Mn , which accounts for 6.4% of the decay strength.

The calculated $f(\beta^+)$ value¹¹⁾ for ^{71}Kr with $E_{\beta^+}(\text{max}) = 9.19 \pm 0.10$ MeV is

$$f(\beta^+) = (43170 \pm 2340)$$

Using the experimental half-life (97 ± 9) ms this gives

$$ft = (4190 \pm 450)$$

The G.T. matrix element $\langle \underline{\sigma} \cdot \underline{\tau} \rangle$ can be calculated from the formula given by Raman et al²⁾

$$(1 + \delta_R)t = \frac{K/G'V}{f_V \langle 1 \rangle^2 (1 - \delta_c) + f_A R^2 \langle \underline{\sigma} \cdot \underline{\tau} \rangle^2}$$

where δ_R and δ_c are the radioactive and charge dependent mixing corrections. We have taken $\delta_R = 2.5\%$ and $\delta_c = 0.5\%$. The small corrections ($\sim 1\%$) to the statistical rate

functions due to second order and higher order forbidden corrections are negligible compared to the accuracy of our half-life determination ($\pm 10\%$) and we have taken $f_V = f_A = f$. The values used for K and G'_V are those given in the review paper by Raman et al.⁴⁾.

From the measured half-life and estimated decay energy we obtain

$$\begin{aligned} R^2 \langle \underline{\sigma} \cdot \underline{\tau} \rangle^2 &= 0.45 \pm 0.17 \\ \text{and using } R &= 1.237 \pm 0.008 \\ \langle \underline{\sigma} \cdot \underline{\tau} \rangle &= 0.54 \pm 0.10 \end{aligned}$$

A simple shell model description of ^{71}Kr would be $(p_{3/2})^4 (f_{5/2})^3$ neutrons outside the closed $f_{7/2}$ shell at $Z = 28$. An estimate of the GT matrix element can be made on the assumption that the ground state wave function corresponds to the extreme single particle model with only the last $f_{5/2}$ proton contributing. For $j = 1 - 1/2$

$$\langle \underline{\sigma} \cdot \underline{\tau} \rangle_{s.p} = \left(\frac{J}{J+1} \right)^{1/2} = \left(\frac{5}{7} \right)^{1/2} = 0.845$$

In Table 1 we compare GT matrix elements with those of other mirror nuclei in the $f_{7/2}$ and higher shells. Where possible the extreme single particle estimate is given. ^{47}Cr and ^{51}Fe do not have spins corresponding to the extreme single particle value. The magnitude of the GT matrix element for ^{71}Kr deduced from the present half-life measurement is comparable with others for lighter mirror nuclei within the rather large uncertainties associated with the present measurement.

The experimental GT matrix elements for mirror transitions are lower than the simple shell model estimates. Renormalization of the axial coupling constant due to axial polarizability has been discussed by Delorme et al.¹³⁾. Recent papers by Oset and Rho¹⁴⁾ and Towner and Khanna¹⁵⁾ have shown that the GT matrix element is reduced when corrections are made for mesonic degrees of freedom. They obtained reasonable agreement for simple one-particle and one-hole configurations outside a closed shell nucleus. In the case of ^{71}Kr our comparison assumes an extreme single particle configuration although the ground state configuration is probably more complex. The other possible orbitals could affect the GT transition strength and this has been discussed by Hardy et al.³⁾ in the decay of ^{49}Mn .

The explanation of the reduction of the GT matrix elements is of considerable interest. The present results show that this effect persists to the heaviest $T_Z = -\frac{1}{2}$ mirror transition so far observed.

Table 1

Gamow-Teller Matrix Elements for Mirror Nuclei with $Z \geq 19$

Nuclide	I^π	Configuration	$\langle \sigma \cdot \tau \rangle_{\text{theo}}$ Single part.	$\langle \sigma \cdot \tau \rangle_{\text{exp}}$	Difference (%)	Ref.
$^{39}_{20}\text{Ca}_{19}$	$3/2^+$	$(d_{3/2})^{-1}$	$\sqrt{\frac{3}{5}} = 0.775$	0.531 ± 0.007	-31	16)
$^{41}_{21}\text{Sc}_{20}$	$7/2^-$	$f_{7/2}$	$\sqrt{\frac{9}{7}} = 1.134$	0.863 ± 0.007	-24	16)
$^{43}_{22}\text{Ti}_{21}$	$7/2^-$	$f_{7/2}$	$\sqrt{\frac{9}{7}} = 1.134$	0.719 ± 0.011	-37	4)
$^{47}_{24}\text{Cr}_{23}$	$3/2^- *$			0.551 ± 0.032		12)
$^{49}_{25}\text{Mn}_{24}$	$5/2^- *$			0.434 ± 0.052		3)
$^{51}_{26}\text{Fe}_{25}$	$5/2^- *$			0.721 ± 0.019		12)
$^{55}_{28}\text{Ni}_{27}$	$7/2^- *$	$(f_{7/2})^{-1}$	$\sqrt{\frac{9}{7}} = 1.134$	0.613 ± 0.017	-46	12)
$^{71}_{36}\text{Kr}_{35}$	$(5/2^-)$	$(f_{5/2})$	$\sqrt{\frac{5}{7}} = 0.845$	0.55 ± 0.12	-35	present work

* Spin based on mirror transitions to states with known spin

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FIGURE CAPTION

Fig. 1 : Decay curve of β -rays with energy greater than 5 MeV following a series of 200 ms collections. The 97 ± 9 ms activity is assigned to the decay of the mirror nucleus ^{71}Kr . The long-lived background is mainly due to contamination of 1.3 min ^{72}Br .