A DIRECT DETERMINATION OF THE NUCLEAR GROUND-STATE SPIN OF ^{156}Eu

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Abstract: The nuclear ground-state spin of the doubly-odd nucleus ^{156}Eu has been measured directly using ABMR techniques to be $I = 0$, thus distinguishing between the contradicting results obtained in beta-decay and nuclear orientation measurements.

The nucleus ^{156}Eu has for many years been considered as one of the few well-established cases of doubly-odd nuclei with ground-state spin and parity $I^\pi = 0^+$. The strongly hindered beta transitions to the 0^+ ground state and to the 0^+ excited states at 1050 and 1168 keV in the daughter nucleus ^{156}Gd , interpreted as iso-spin-forbidden pure Fermi transitions [1-3], have given strong support for the validity of the isospin selection rule also in heavy nuclei. However, the basis for this interpretation has been cast into doubts by the recent nuclear orientation measurements on the nucleus ^{156}Eu [4] giving a spin $I = 1$ assignment to the ground state (the parity probably being positive) and a nuclear magnetic moment $|\mu| = 1.07 \pm 0.37$. Because of the fundamental character of this problem, we found it highly desirable to attempt a direct measurement of the ground-state spin of ^{156}Eu . The present experiment was performed using off-line atomic-beam magnetic resonance (ABMR) techniques [5] at the ISOLDE facility, CERN.

The radioactive sources were produced by double neutron-capture reactions in 17 mg samarium metal enriched to 97.7% in ^{154}Sm . Following a 19 days irradiation at a flux of 1.4×10^{14} n/cm²s in the reactor at the Risø National Laboratory, Denmark, and a cooling period of 20 days, the source strength amounted to 150 mCi of ^{156}Eu (15.2 d) and 8.7 mCi of ^{155}Eu (4.96 y). A few percent of this activity was transferred to a closed-oven system and introduced into the atomic-beam apparatus. The atomic beam was formed by heating the oven to about 900° C by electron bombardment.

The experiments were made in the $4f76s^2$ $8S_{7/2}$ electronic ground state of europium having a splitting factor of $g_J = 1.99340(7)$ [6].

Three different settings of the external magnetic field were used: $\mu_B B/h = 0.439$, 1.788 and 3.016 MHz corresponding to 0.314, 1.277 and 2.154 G. The transition frequency within a given hyperfine level F is, in the weak-field region, to a good approximation given by:

$$\nu = \frac{\mu_B B}{h} g_J \frac{F(F+1) - I(I+1) + J(J+1)}{2F(F+1)} \quad (1)$$

In the field of $\mu_B B/h = 0.439$ MHz, a careful frequency scan was made ranging from 0.600 to 1.200 MHz. This range covers the spin $I = 0$ and $I = 1$ transition frequencies which, according to Eq. (1), should appear at 0.875 MHz, and 0.681, 0.820 and 1.125 MHz, the latter three frequencies being due to the $F = 9/2$, $7/2$ and $5/2$ hyperfine levels, respectively. Only one resonance curve was observed (cf. Fig. 1), appearing at the $I = 0$

Fig. 1 Resonance curve corresponding to spin $I = 0$, recorded at an external magnetic field of 0.314 G.

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transition frequency. This result rules out a nuclear spin $I = 1$ and a magnetic moment $|\mu| \approx 1$ n.m. as measured in Ref. [4]. However, the resonance curve observed at the $I = 0$ frequency could arise from an unresolved multiplet due to a non-zero spin provided the hyperfine structure being extremely small. In this case we obtain an upper limit of the magnetic moment $|\mu| < 3 \times 10^{-4}$ n.m., using a procedure similar to that of Ref. [7]. The presence of such a small magnetic moment in the doubly-odd nucleus ^{156}Eu is indeed highly improbable, and we may assign with confidence a nuclear spin $I = 0$ to the ground state.

The spin $I = 0$ resonance was reproduced at the two stronger fields, $\mu_B/h = 1.788$ and 3.016 MHz, and shown to vary linearly with the field. The half-life of the resonances, measured to be 15 d, ascertains the association with ^{156}Eu . Searches for resonance signals due to a possible isomeric state in ^{156}Eu were also made at these fields. However no signals corresponding to the spin values $I = 1 - 8$ were observed (cf. Fig. 2).

Fig. 2 Count rate of collectors exposed for 4 min each to the atomic-beam at transition frequencies corresponding to spin $I = 0$ (the high points) and spin $I = 8 - 1$ as indicated in the figure. The non-zero frequencies are those of the largest F-values, except for $I = 1$ where all F-levels, $9/2$, $7/2$ and $5/2$, were taken into account. The beam intensity showed a steady decrease with time as evidenced by the reduced count rate of the spin $I = 0$ signals. The room background count rate of the 1 mm plastic scintillator, detecting the β^- particles, amounted to 11 cpm. This background is given by the horizontal line. A careful alignment of the apparatus has reduced the apparatus background to negligible amounts as shown by the non-resonant signals.

In the present experiment, the ground-state spin of the doubly-odd nucleus ^{156}Eu has been determined to be $I = 0$. Non-zero spin values give unrealistically small magnetic moments. This result is in contradiction to the data of the nuclear orientation experiment reported in Ref. [4]. The origin of the anisotropies observed in the latter experiment is at present not understood.

The interpretation of the $I = 0$ ground state of ^{156}Eu as the configuration $0^+ \{ \pi [413 5/2] \nu [642 5/2] \}$ decaying to the 0^+ states in ^{156}Gd through an admixture of the high-lying $T = 15$ isobaric analog state in ^{156}Gd , being the analog of the ^{156}Eu ground state, presented in Refs. [1-3,8] thus remains valid.

It is interesting in this context to point at the direct measurement of spin $I = 0$ of the doubly-odd nucleus ^{170}Lu [9], confirming the configuration assignment $0^+ \{ \pi [404 7/2] \nu [633 7/2] \}$ and the decay to the 0^+ ground state in ^{170}Yb as another example of isospin-forbidden Fermi transitions [10]. Furthermore, the spin $I = 0$ ground state of ^{78}Rb [7], built up of the odd proton and odd neutron both occupying orbitals associated with the shell model state $g_{9/2}$, has been proposed to exhibit decay characteristics of this kind [11].

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