the junction has permitted the detection of neutrons by the $B^{10}(n, \alpha)Li^7$ reaction.

We are indebted to Mr. R. J. Toone for his assistance in the measurements reported.

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NUCLEAR MAGNETIC MOMENT AND SPIN OF EUROPIUM-152m*

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(Received March 13, 1959)

Goldhaber, Grodzins, and Sunyar[1] have made a determination of the helicity of the neutrino by studying the decay of the 9.3-hour isomeric state of Eu^{152}. Their conclusions rest, in part, upon a knowledge of the spin and parity of this state. At the time their experiment was performed, the possible assignments for this state were considered to be 0^-, 1^-, and 1^+. Higher spin values were ruled out by the fact that the partial lifetime for the decay of the isomeric state to the spin 3 ground state of Eu^{152} was found to be greater than 5000 hours. From a study of the β-γ correlation in the decay of Eu^{152m} to Gd^{152}, Grodzins and Sunyar[2] have been able to rule out definitely the 1^+ assignment.

We have performed an atomic beam flop-in experiment with radioactive detection on Eu^{152m} in order to distinguish between the 0 and 1 assignments. A Eu^{152m} beam was formed by evaporating neutron-irradiated Eu metal from a tantalum oven at about 650°C. Detection was effected with sulfur-coated metal buttons. A Eu^{152m} resonance obtained at a field value of 1.4 gauss is shown in Fig. 1. Resonance curves have also been obtained at 0.8 and 1.0 gauss. The resonance frequency has been found to vary linearly with the field and to correspond to a Landé g factor of nearly 2.0. Woodgate[3] has found that $g_J = 1.994$ for europium. These observations show either that the spin of Eu^{152m} is zero or that if the spin were different from zero, the hfs splitting of the atomic ground state must be very small compared with 4 Mc/sec. If the spin were 1 or 2 and if the splitting were large, the apparatus would detect the transition $\Delta F = 0$, $m_F(-F \leftarrow -F+1)$ and a resonance would have occurred at the points marked 1 or 2 in Fig. 1. If the spin were different from zero and

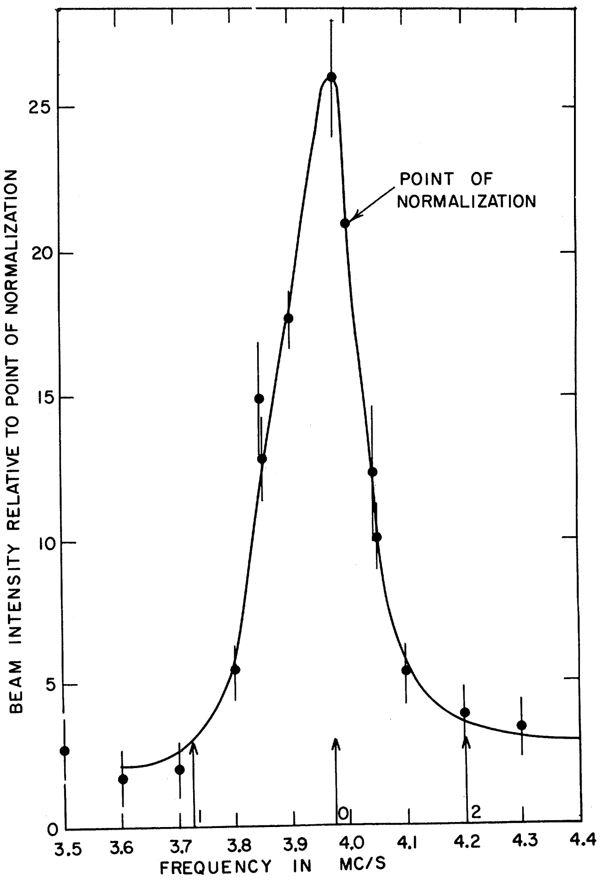

FIG. 1. Resonance curve obtained for Eu^{152m} at a field of 1.4 gauss. A counter background of about 9 cpm has been subtracted from all of the observations and the data have been corrected for decay. The beam intensity showed a steady decrease with time. Every fifth observation was taken at 4.0 Mc/sec and this information was used to normalize the points on the remainder of the curve.

if the hfs splitting were comparable to 4 Mc/sec (intermediate field case), the resonance frequency might accidentally occur at the spin-zero value at one field but it would not vary linearly with the field. If the spin were 1 and if the hfs splitting were very small (Back-Goudsmit region), the apparatus would indicate the transition $m_J(+1/2 \longleftarrow -1/2)$, $\Delta m_I = 0$, and we would observe three resonances centered about the spin-zero frequency with a spacing equal to the hfs interaction energy a of the Eu^{152m} atom.[4] If there were such a multiplicity of lines unresolved by our apparatus, we could obtain an upper limit for a by a consideration of the line width. Aside from possible unresolved hyperfine structure, the line width is determined by the inhomogeneities in the transition magnetic field and time spent in the oscillating field. The latter effect is calculated to be roughly 30 kc/sec for Eu and 50 kc/sec for a potassium beam used in calibrating the magnetic field. The effect of field inhomogeneities is expected to be four times greater for Eu than for K since the g factors are in the ratio of four to one. A study was made of the shape of the K resonance and it was found that the width of this resonance could be varied over a range of 60 to 120 kc/sec by changes in the magnetic history of the transition magnet. This shows that, at least in the case of K, the line shape is determined by field inhomogeneities. Before the data shown in Fig. 1 were obtained, the transition magnet was carefully manipulated to obtain the narrowest possible K^{39} resonance (60 kc/sec). If this 60-kc/sec width were due entirely to field inhomogeneity, then we would expect a 240-kc/sec width for the Eu^{152m} resonance. In fact, the 60-kc/sec width for K results from a combination of natural broadening and inhomogeneity broadening. Lacking detailed knowledge of the distribution of both the steady and oscillating magnetic fields in the transition region, we cannot make an exact estimate of the width to be expected for the Eu^{152m} resonance. The observed 170-kc/sec width is less than the extreme value estimated above and is entirely consistent with the assumption that there is no unresolved hyperfine structure. We can obtain an absolute upper bound on a by assuming that the observed 170-kc/sec width results entirely from the blending of three lines, each of which has a width of 30 kc/sec (the natural width for Eu in our apparatus). In this way we find that $a \leq 60$ kc/sec. By comparing this limit of a with the value, $a = -20.0$ Mc/sec, obtained by Woodgate[3] for Eu^{151}, for which $I = 5/2$ and $\mu = 3.4$ nm,[4] we can evaluate $\mu(\mathrm{Eu}^{152m}) \leq 4.0\times10^{-3}$ n It should be emphasized that this is an absolute upper bound and that there is nothing in our data that requires us to assume that the value is different from zero.

The nuclear moments of deformed odd-odd nuclei have recently been discussed by Gallagher and Moszkowski[5] and by Hooke[6] in the context of the Nilsson model.[7] In Table I we list the moments predicted for a possible 1^- state of Eu^{152m} on the basis of this model, for several different proton and neutron assignments and for three different values of the nuclear deformation parameter (δ). The range of deformation considered lies between the values appropriate to Eu^{151} and Eu^{153}. A comparison of these values with our limit shows that, if the Nilsson model

Table I. Nuclear magnetic moments predicted for a possible 1^- state of Eu^{152m} on the basis of the Nilsson model for several proton and neutron assignments and for three values of the nuclear deformation parameter (δ). The assignments are listed in order of decreasing likelihood for each value of δ.

$\delta = +0.15$		$\delta = +0.20$		$\delta = +0.25$	
Assignment	μ (nm)	Assignment	μ (nm)	Assignment	μ (nm)
e	+1.5	e	+1.4	a	+2.6
c	+1.0	h	+0.6	c	+1.2
b	-1.1	a	+2.5	h	+0.4
f	-0.5	c	+1.1	g	+2.1
d	-1.5	g	+1.9	b	-0.9
a	+2.4	b	-1.0		

Assignment	Proton state[a]	Neutron state[a]
a	5/2 - (532+)	3/2 + (651+)
b	3/2 + (411+)	5/2 - (523-)
c	5/2 + (413-)	3/2 - (521+)
d	3/2 - (541+)	5/2 + (642+)
e	3/2 - (541+)	1/2 + (660+)
f	1/2 - (550+)	3/2 + (651+)
g	3/2 + (411+)	1/2 - (530+)
h	5/2 + (413-)	3/2 - (532-)

[a] The nucleon states are characterized by Ω (the component of angular momentum along the nuclear axis), parity, and the asymptotic quantum numbers (N, n_z, Λ, Σ).

is valid, our result provides strong support for the supposition that the spin of Eu^{152m} is zero. The possibility that the spin is different from zero and that states exhibiting positive and negative moments are mixed so that the moment accidentally vanishes can, of course, never be completely ruled out.[8] In this connection it is important to note that the simple Nilsson model without mixing correctly predicts the spin, parity, and moments of the ground states of Eu^{151}, Eu^{152}, and Eu^{153}, and furthermore that a 0^- isomeric state of Eu^{152} can be formed with plausible proton and neutron assignments. Lastly, it is noteworthy that there is only one measured moment smaller than our limit, namely Tl^{198}, for which $\mu < 0.002$ nm.[9]

The authors would like to acknowledge their appreciation to Dr. M. Goldhaber for many helpful discussions, and to A. W. Kane and J. Ciperano for their painstaking technical assistance throughout the course of this work. One of the authors (RN) would like to acknowledge the hospitality extended to him while he was a guest of the Brookhaven National Laboratory. He would also like to thank Dr. J. D. Jackson and Dr. H. Lipkin for many helpful discussions of the Nilsson model. Finally, we would also like to thank R. L. Cohen for his very enthusiastic assistance in the early stages of this experiment.

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[*] Work performed at the Brookhaven National Laboratory under the auspices of the U. S. Atomic Energy Commission.

[†] One of the authors (RN) participated in this experiment as a guest of the Brookhaven National Laboratory.

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EVIDENCE CONCERNING THE SPIN AND PARITY OF Eu^{152m}[†]

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(Received March 13, 1959)

The importance of measuring the spin and parity of Eu^{152m} has greatly increased with the recent experiment by Goldhaber *et al.*,[1] which measured the helicity of the neutrinos emitted by this isotope when decaying by K-capture to a 1^- level in Sm^{152}. Arguments were presented in that paper for assuming the spin-parity to be 0^-, in which case the neutrino has negative helicity. The conclusion is the same, though the argument becomes more complicated, if the spin-parity is 1^-; no conclusion can be drawn from the data if the spin-parity has the unlikely value 1^+. Because of the importance of the neutrino helicity experiment (which has been confirmed by various nuclear recoil experiments[2]) an effort has been made to find more convincing evidence for the parity and, if possible, the spin of Eu^{152m} than the circumstancial evidence presented by Goldhaber *et al.*[1]

Various groups have pursued four distinct lines of research. (1) A more intensive search was made for the isomeric transition to the 3^-, 13-year Eu^{152} ground state[3] (see Fig. 1 for pertinent

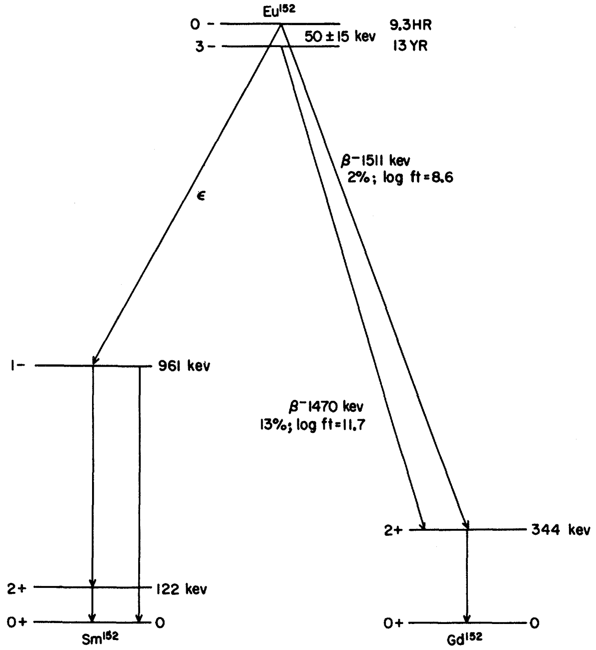

FIG. 1. Partial decay scheme for Eu^{152m} and Eu^{152}.