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]

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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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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

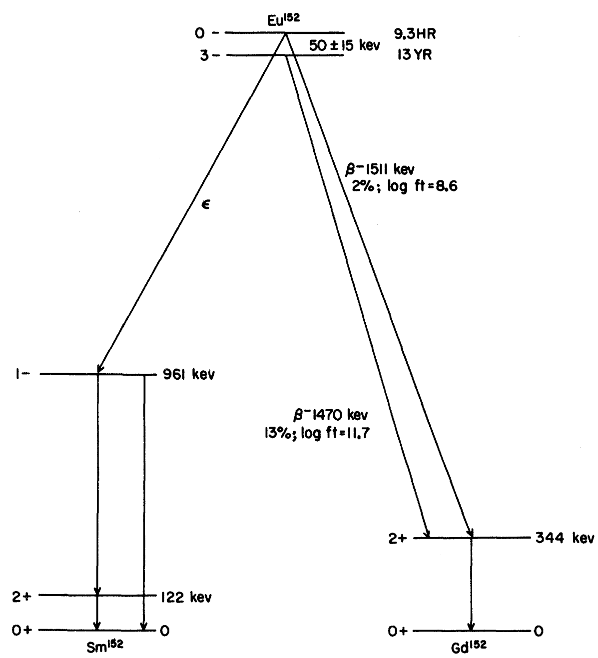

FIG. 1. Partial decay scheme for Eu^{152m} and Eu^{152}.

parts of the decay scheme) by Alburger et al.,[4] and by Grodzins and Sunyar.[5] A lower limit of 50 years was placed by both groups on the partial isomeric mean life, representing a retardation in terms of single-proton transitions in excess of 10^{13} for $E2$ radiation, thus favoring an $M3$ assignment, which would imply a 0^- assignment to Eu^{152m}. (2) The shapes of the negatron and positron transitions to the 2^+ first excited states of Gd^{152} and Sm^{152}, respectively, were examined.[4] Though the data obtained were not accurate enough to draw unambiguous conclusions, Alburger at al.[4] find that the assumption of an alpha shape for the positron group to the first excited state of Sm^{152} (expected if the spin of Eu^{152m} is 0^-) leads to better agreement with the energy expected for the inner positron groups. (3) Cohen et al.[6] have measured the magnetic moment of Eu^{152m}. They find that it is smaller than 4×10^{-3} nuclear magneton, thus establishing the strongest evidence for 0 spin. (4) We have investigated the Eu^{152m}(1.511-kev β^-) 2^+(344-kev γ) 0^+ beta-gamma correlation which should yield a strong, "uniquely" determined, correlation if the spin-parity of Eu^{152m} is 0^-. We find a strong correlation, thus fixing the parity of Eu^{152m} as odd, and thus corroborating the earlier argument[1] based on the allowed ft value of the K-capture transition to the 1^- level in Sm^{152}. The logft value[7] of the 1.511-Mev transition is 8.6, which is consistent with first forbidden "unique" systematics. The magnitude of the correlation we observe is compatible with a spin-parity of 0^- for Eu^{152m} but does not exclude the possibility of a 1^- assignment.

The beta-gamma correlation apparatus was conventional. The fast-slow coincidence circuit had a resolving time $\tau \simeq 10^{-8}$sec. Beta detectors of various diameters and of thicknesses equal to or greater than one cm, both plastic and anthracene, were used. The gamma detector was either an $1\frac{1}{2}$ in.$\times$1 in. or 3 in.$\times$3 in. NaI(Tl) scintillator. Transparent sources, containing approximately 3 micrograms of solid, were prepared by evaporating a drop of $EuCl_3$ solution on scotch tape. The sources were approximately 3 mm in diameter and between 20 and 70 microcuries in strength; the counting rate in the beta crystals was never greater than 10^4 per second.

The first experiments were done in air using an $1\frac{1}{2}$ in.$\times$1 in. NaI(Tl) gamma detector, 3 in. from the source, and a small anthracene scintillator, $0.5\times0.5\times1$ cm in thickness, whose front face was approximately 0.5 inch from the source. With this geometry the multiple scattering in the air path, as well as the scattering between crystals, was small. A strong correlation, $W(\theta)=1+[0.28\pm0.03]P_2(\cos\theta)$ (background coincidences have been subtracted), was observed between 344-kev gamma rays and beta rays of 1.1 to 1.5 Mev. Unfortunately it was very difficult with this geometry to measure or even estimate the effects of scattering, or to determine the geometry corrections. To circumvent this difficulty we compared the observed correlation with that obtained for the $Pr^{144}(\beta^-)\,2^+(\gamma)\,0^+$ β-γ correlation. The Pr^{144} source was placed in the same geometry as the Eu^{152m}. The Pr^{144} decay scheme and beta-gamma correlation have been investigated in some detail by Graham et al.[8] They present strong evidence for the transition being 0^-(2293-kev β^-) 2^+(691-kev γ) 0^+, though their beta-gamma correlation is considerably lower than the theory predicts. If we use the anisotropy observed using Pr^{144} as a standard, we find that the beta-gamma correlation of Eu^{152m}, for beta energies$>$1.1 Mev, is $W(\theta)=1+(0.50\pm0.06)P_2(\cos\theta)$. The theoretically predicted value for our experimental β-ray energy range is $W(\theta)=1+0.472P_2(\cos\theta)$ for the spin sequence $0^-(\beta^-)\,2^+(\gamma)\,0^+$.

Anisotropies were then measured using beta detectors of larger diameter placed farther from the source in order to facilitate the calculation of the geometry correction. With this geometry a strong $\cos\theta$ term manifested itself, even at beta energies $>$1 Mev, arising from scattering of the beta rays from the face of the gamma counter into the beta detector. To obviate this difficulty the source and beta detector were placed inside a cylindrical brass vacuum chamber, 6 in. in diam, 1/8-in. wall, lined with Lucite; the 3 in. $\times$3 in. gamma detector was outside of the vacuum chamber, $5\frac{1}{4}$ in. from the source. In this geometry, no electron scattering could take place which depended on the position of the gamma counter. A 1-in. diam, 1 cm thick, Pilot B crystal, 2 in. from the source, was used as the beta detector. The uncorrected correlation was measured to be $W(\theta)=1+[0.286\pm0.02]P_2(\cos\theta)$. Corrections were made for accidental and gamma-gamma coincidences, as well as for coincidences arising with Compton gamma rays under the 344-kev photopeak. The correlation was attenuated to 88% by the finite detector sizes. The corrected correlation was then found to be $W(\theta)=1+[0.36\pm0.03]P_2(\cos\theta)$. This correlation is about 25% smaller than the predicted correlation for a first forbidden "unique" β^- transition. Several effects can contribute to reduce the predicted anisotropy. The source was perhaps somewhat lumpy and there may have been some attenuation due to backscattering and multiple-scattering in the source. The mean life of the 344-kev state is $\simeq 10^{-10}$ sec.[9] This comparatively long lifetime could account for a considerable attenuation as a result of nuclear precession. The observed correlation, by itself, can be fitted by a spin-one assignment. In fact, assuming spin-parity 1^-, a range of ratios of nuclear matrix elements can yield the observed anisotropy. In the approximation[10] $V = \alpha Z/2\rho >> W_0$, the correlation can be expressed as a function of

$$Y = \frac{i\,V\,C_V\,\mathfrak{M}(\vec{r}) - C_V\,\mathfrak{M}(\vec{\alpha}) + VC_A\,\mathfrak{M}(\vec{\sigma}\times\vec{r})}{i\,C_A\,\mathfrak{M}(B_{ij})}$$

A range of Y from $+0.3$ to $+2.0$ yields agreement with experiment. (It is in general true that an angular correlation, or a shape measurement, cannot by itself decide between a first forbidden and first forbidden "unique" transition.)

All of the experiments[1,4,6] are compatible with a spin-parity of 0^- for Eu^{152m}. The work of Cohen et al.[6] is the strongest evidence for spin 0. The beta-gamma correlation presented in this Letter proves that the parity of Eu^{152m} is odd, and is compatible with spin zero for Eu^{152m}.

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INELASTIC DEUTERON SCATTERING FROM Cu^{63} AND Cu^{65}†

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A gross structure has been observed in the spectra obtained from inelastic scattering of protons,[1] deuterons,[2] and alpha particles[3,4] by nuclei. Similarly, gross structure has been observed in a number of (d,p) spectra.[5] A number of possible interpretations have been suggested for the appearance of gross structure in inelastic scattering.[6] In the investigation of the elastic scattering of deuterons by separated isotopes of nickel and copper,[7,8] it was found that the spectra of Cu^{63} and Cu^{65} show a group in the neighborhood of 1.3 Mev. The spectra of the two copper isotopes together with the spectrum obtained for Ni^{58}, are shown in Fig. 1. The resolution is such that the levels in the copper isotopes could not be well resolved. However, it is clear both from the location and the width of the peak that the peak is due to more than one of the five levels around 1.3 Mev in these isotopes. The angular distribution of the inelastically scattered deuterons of the 2^+ level at 1.45 Mev in Ni^{58} can be uniquely fitted by $F(\theta)\times[j_2(QR)]^2$, where $F = 1/(Q^2+\alpha^2)^2$, Q is the momentum transfer, and α is a constant. The angular distributions of the inelastic groups in the copper isotopes are shown in Fig. 2 together with the distribution obtained for Ni^{58} (solid line). The three sets of data were

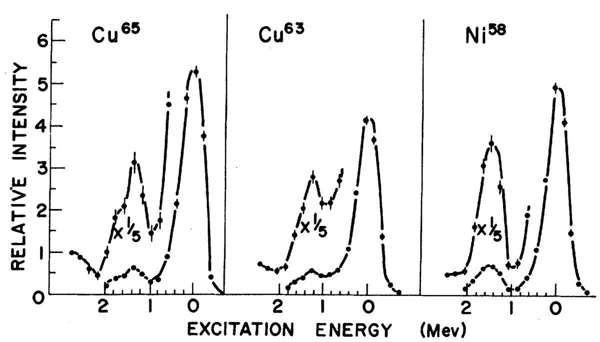

FIG. 1. Deuteron spectra of Ni^{58}, Cu^{63}, and Cu^{65} at 44° (lab system).