$E6$ and $M5$ Transitions Observed in Fe^{53m} Decay

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Photons corresponding to 3040.6-keV $E6$ and 1712.6-keV $M5$ transitions have been observed from the decay of 2.6-min Fe^{53m}. They have intensities of 2×10^{-4} and 7×10^{-3}, respectively, compared with the 701.1-keV $E4$ isomeric transition that is primarily responsible for depopulating Fe^{53m}. These correspond to retardations of 650 and 43 over simple single-particle estimates.

Opportunities for observing γ-ray transitions of very high multipolarity are extremely rare. The existence of $M5$, $E6$, and higher multipolarities has never been substantiated by experimental fact except for their presence as small admixtures occasionally being invoked to explain small discrepancies in experiments such as angular correlations. However, the recent discovery[1] of a high-energy, high-spin, three-quasiparticle isomer in the nuclide ${}_{26}Fe_{27}^{53}$ has now provided an opportunity for the direct observation of such transitions and the calculation of their transition probabilities with reasonable precision. In this Letter we report our observation of photons corresponding to 3040.6-keV $E6$ and 1712.6-keV $M5$ isomeric transitions from this nucleus.

The isomer Fe^{53m} has a half-life of 2.6 min and an excitation energy of 3040.6 keV.[1-3] It has been interpreted, primarily through isomer preparation ratios[1] and the reduced transition probability of the isomeric transition, apparently of $E4$ multipolarity, as having a spin and parity of $(19/2)^-$. This corresponds to the highest spin state that can result from the three-quasiparticle configuration, $[(\pi f_{7/2})^{-2}]_{6+}(\nu f_{7/2})^{-1}$. Our findings are quite consistent with these assignments, and we present the decay scheme, including our newly found transitions, in Fig. 1.

We prepared sources of Fe^{53m} by the reaction $Mn^{55}(p, 3n)Fe^{53m+g}$, using a 40-MeV proton beam from the Michigan State University sector-focused cyclotron. Bombardment time, beam energy, and all other parameters were adjusted to optimize the production of the metastable state. Typically, 0.5-g targets of powdered Mn metal (99.94% pure) were bombarded with a 2-μA beam for 1 min. To expedite handling of the short-lived Fe^{53m}, a pneumatic rabbit system was used to transport the target from the beam to the counting area with a transit time of ≈ 2 sec. Detachable aluminum packets were used to fix the Mn powder to the rabbit. Transfer of the powder to a plastic counting vial was accomplished merely by punching a hole in the packet and draining the radioactive powder into the vial. The total elapsed time between the end of a bom-

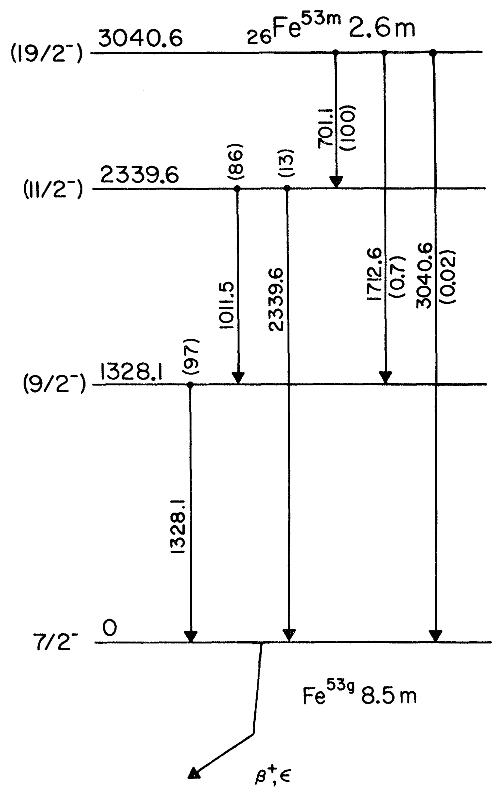

FIG. 1. Decay scheme of Fe^{53m}, including the new $E6$ (3040.6 keV) and $M5$ (1712.6 keV) transitions observed in this work.

bardment and the beginning of counting was typically ≈10 sec.

γ rays were detected with a 3.6%-efficient [for the Co^{60} 1332.48-keV γ, measured relative to a 3×3-in.^{2} NaI(Tl) detector at 25 cm], true-coaxial Ge(Li) detector having a resolution of 2.0 keV full width at half-maximum for the Co^{60} 1332.48-keV γ. The remainder of the system consisted of an amplifier having high-rate baseline restoration and a 50-MHz analog-to-digital converter interfaced to a Sigma-7 computer. Graded lead absorbers having a combined thickness of ≈3 cm were used between the source and the detector to attenuate the lower-energy γ rays. Even so, counting rates as high as possible without appreciable deterioration of resolution were maintained throughout the experiments, with an average count rate of about 6700 counts/sec. This combination of isomer optimization, detector efficiency and resolution, and high-count-rate electronics was deemed absolutely necessary in order to obtain the number of events necessary for direct observation of the weak $E6$ and $M5$ transitions.

Various spectra were taken at different times and with different geometries and produced consistent results. In Fig. 2 we show the spectrum resulting from a 24-h accumulation of data and front-end detector geometry. During this time a continuous cycle of bombarding and counting was maintained such that a fresh source was counted every 2 min. Definite peaks exist in this spectrum at the energies of 1712.6 and 3040.6 keV, where the $M5$ and $E6$ transitions are expected to occur. After careful energy and intensity analysis,[4] these peaks were found to correspond to transitions having intensities of 7×10^{-3} and 2×10^{-4} as compared with the 701.1-keV transition. Recent experiments using a large 10.5%-efficient Ge(Li) detector have shown that these peaks decay with the 2.6-min half-life of Fe^{53m} and are the only peaks in the spectrum (other than the four well-known, intense Fe^{53m} peaks) that decay with this half-life.

Having shown that these peaks are present, one is obligated to demonstrate that they are indeed true peaks and not merely the resultant sum peaks of two or more known constituents. Such sum peaks are known to occur in large-volume detectors under high-count-rate conditions. These can originate from two different physical conditions. First, if the source is suf-

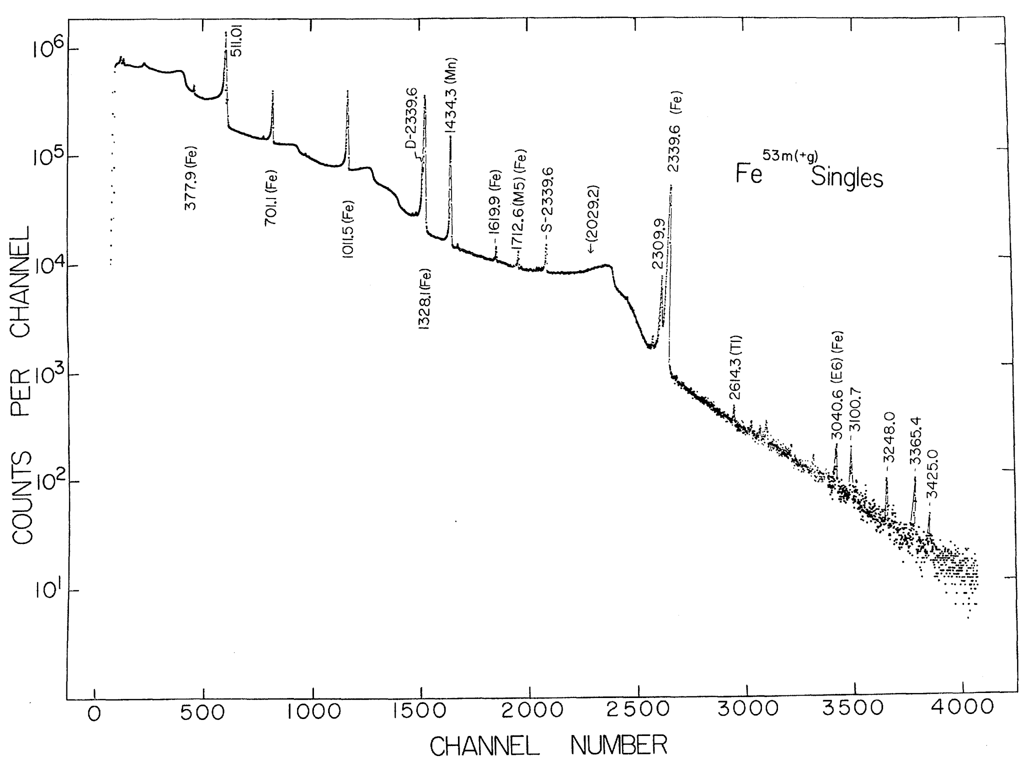

FIG. 2. γ-ray spectrum of $Fe^{53m(+g)}$ taken with a 3.6% Ge(Li) detector. This spectrum represents a 24-h accumulation of data. The $E6$ and $M5$ peaks are so labeled, and the arrow (at 2029.2 keV) shows where a sum peak between the 701.1- and 1328.1-keV transitions would appear.

ficiently close to the detector so that the detector presents a large solid angle, summing of events in the same γ-ray cascade can occur. Second, if the source is strong, accidental summing of events from the same or different γ-ray cascades can occur. With our Fe^{53m} experiments one needs to wory about both effects in turn.

This summing problem was examined both in light of the data themselves and also from additional experiments designed to elucidate the summing phenomenon. Considering the Fe^{53m} data alone, we can formulate several interesting arguments. Examination of the established decay scheme (Fig. 1) reveals that the two most intense transitions, at 701.1 and 1328.1 keV, are in a cascade connected by the 1011.5-keV transition, the third most intense. If indeed cascade-type summing were to occur to an appreciable extent during an experiment such as that recorded in Fig. 2, one would conclude that these two most intense transitions should give rise to a sum peak at 2029.2 keV. Examination of the spectrum, however, shows no evidence for a γ-ray peak at this energy. This absence was reproducible from experiment to experiment with widely varying count rates and source-detector distances. One can estimate for this spectrum, for example, that the contributions of summing to the $M5$ and $E6$ peaks would be considerably less than 0.1% and 10%, respectively, and come almost entirely from chance coincidences. Also, although the 511.01-keV $\gamma^{\pm}$ peak was the most intense peak in the spectrum, no evidence was found for $\gamma^{\pm}$ summing to give a 1022-keV peak or of their summing with any of the stronger γ rays in the spectrum. This indicates that chance type summing was not a significant factor in these experiments except for a small possible contribution to the weak $E6$ peak. A third consideration is the peak width. In general, sum peaks or peaks containing significant summing components tend to be wider than their true counterparts. However, here one finds the peaks corresponding to the $M5$ and $E6$ transitions to be of normal width, providing further evidence for the fact that they are true peaks. Finally, the $E6$ and $M5$ decay with the same half-life as the $E4$ isomeric transition, and one would expect to measure a different half-life if there were a substantial contribution from chance-coincidence summing.

To check the internal data, a series of experiments was performed in which Co^{60} spectra were taken with various source-detector geometries at a constant count rate. The degree of summing to form a 2505.71-keV sum peak was observed as a function of geometry. Then using the same count rates and geometries, an analogous set of Fe^{53m} spectra was taken. The resulting intensity variations of the $M5$ and $E6$ peaks as a function of geometry were compared with the variations of the Co^{60} spectra. This method corroborated the fact that the 1712.6- and 3040.6-keV peaks are not sum peaks but do indeed reflect true transitions in the Fe^{53} nucleus.

In Table I we summarize the results for the γ rays from Fe^{53m}, including a comparison of the $E4$, $M5$, and $E6$ half-lives with simple single-particle estimates.[5] The $E6$ appears to be retarded by a factor of 650 and the $M5$ and $E4$ by factors of 43 and 41, respectively, over the single-particle estimate. The retardation of the $E6$,

Table I. Fe^{53m} γ rays.

E_γ (keV)	Multipolarity	Photon intensity	Partial (photon) $t_{1/2}$ (sec) Expt[a]	Calc[b]	Retardation expt/calc
701.0 ± 0.1	$E4$	$\equiv 100$	1.57×10^3	3.8×10^1	41
1011.5 ± 0.1	$M1$	86 ± 9	...	...	...
1328.1 ± 0.1	$M1$	97 ± 10	...	...	...
1712.6 ± 0.3	$M5$	0.7 ± 0.1	2.2×10^5	5.2×10^3	43
2339.6 ± 0.1	$E2$	13 ± 2	...	...	...
3040.6 ± 0.5	$E6$	0.02 ± 0.005	7.8×10^6	1.2×10^4	650

[a]The 701.1-keV transition was corrected for conversion using a value of $\alpha_K = 0.003$, which we obtained by a linear extrapolation from the tables of R. S. Hager and E. C. Seltzer, Nucl. Data, Sec. A 4, 1 (1968). The conversion coefficients for the other transitions were small enough to be negligible.

[b]Ref. 5.

although large, should not be too surprising since it involves a recoupling in taking a state with seniority 3 to one primarily of seniority 1 ($\approx 60\%$).[6] The very similar retardations for the $M5$ and $E4$ very likely arise because these involve transitions between seniority-3 states. A more extensive treatment of the transition rates is given in a paper to be published elsewhere.[7]

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Core-Polarization Effects in Charge-Exchange Reactions; Application to ^{58}Ni(^{3}He, t)

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The formal relationship between tensor-force distorted-wave Born approximation theory and β decay is stated. Data on the reaction ^{58}Ni(^{3}He,t) are given and compared with the cross section calculated with model wave functions adjusted to account for the known retardation in the ^{58}Cu positron decay. The calculated (^{3}He,t) cross section is also retarded but to an extent sensitively dependent on the tensor strength and the configurations present.

Since it has been well established that core polarization strongly affects the absolute cross section in nuclear inelastic scattering, there has been hope expressed in a number of papers that collective effects are not important in charge exchange. We wish to point out, however, that there is already much information available on this question. This information comes from β decay. Collective effects can be expected in charge exchange if they are known to be present in β decay just as collective enhancement can be anticipated in (p, p') scattering if it is present in γ decay. The collective retardation of Gamow-Teller (GT) decay has been discussed[1] by several authors.

In this Letter we point out the formal relationship between β decay and charge exchange within the framework of the conventional distorted-wave Born approximation (DWBA) theory including the tensor interaction. As an example we choose the reaction ^{58}Ni(^{3}He, t) to the 1^+ ground state of ^{58}Cu because the positron decay for the inverse transition is retarded compared to the results of simple two-particle wave functions. Core polarization is taken into account by considering $(f_{5/2})(f_{7/2})^{-1}$ particle-hole pairs induced in the core by the two valence nucleons. The strength of the particle-hole component is adjusted to fit the experimental β decay, and the resulting wave functions are used to calculate the (^{3}He, t) cross section.