^{52}Fe(6.8 MeV) β-Decaying Isomeric State*

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An isomeric state in ^{52}Fe has been located at $E_x = 6.83 \pm 0.25$ MeV with the reaction ^{40}Ca(^{14}N, pn)^{52}Fe. The state decays by positron emission to the (11$^+$) 3.837-MeV state of ^{52}Mn with $T_{1/2} = 56 \pm 8$ sec. The probable spin and parity of the isomer is 12$^+$.

It is well known that residual interactions acting within the ground-state shell-model configuration can produce long-lived "spin-gap" isomers at high excitation with unusual decay properties. For example, the $J^\pi = \frac{19}{2}^-$ isomers at $E_x \cong 3.1$ MeV in the mirror nuclei ^{53}Fe and ^{53}Co decay by $E4$, $M5$, and $E6$ γ-ray transitions[1] ($T_{1/2} = 2.5$ min) and by combined proton-β^+ emission[2] ($T_{1/2} = 242$ msec), respectively. Up to now, however, the only reported example of this phenomenon in an even-even nucleus is the 45-sec α-decaying state at 2.93 MeV in ^{212}Po.[3,4]

This Letter reports the observation of an isomeric state analogous to that in ^{212}Po at 6.83 ± 0.25 MeV excitation in the $N = Z$ nucleus ^{52}Fe. The state decays by β^+ emission ($T_{1/2} = 56 \pm 8$ sec) and evidently has $J^\pi = 12^+$, the maximum spin attainable in the $(f_{7/2})^{-4}$ configuration. The ^{52}Fe isomer, as well as the absence of isomerism[5] in the conjugate nucleus ^{44}Ti, can be accounted for by shell-model calculations based on the $(f_{7/2})^{\mp 2}$ spectra of ^{54}Co and ^{42}Sc, respectively.

The ^{52m}Fe activity was first observed in the course of delayed-β-γ coincidence experiments designed to study proton-rich nuclei in the $f_{7/2}$ shell. A natural calcium target ~2 mg/cm^2 thick evaporated onto a gold backing was bombarded with 46-MeV ^{14}N ions from the Stony Brook FN Van de Graaff accelerator. A slotted rotating wheel periodically interrupted the incident beam and provided a signal to enable the electronics and initiate a linear ramp voltage. Electrons passing through a thin Mylar window were detected in a collimated NE102 scintillator, and γ rays were observed with a 50-cm^3 Ge(Li) detector. For each beam-off event the β- and γ-energy signals, the β-γ time-to-amplitude signal, and the magnitude of the ramp voltage were converted to digital words and stored sequentially on magnetic tape for later analysis.

Figure 1 shows a typical delayed-γ-ray coincidence spectrum. In addition to lines from known[6] β activities, γ rays at 622, 870, 929, 1416, and 2038 keV are apparent. Recently, a γ-ray cascade through high-spin states in ^{52}Mn has been observed in studies of the reactions ^{51}V(^{3}He, $2n$)^{52}Mn and ^{24}Mg(^{32}S, $3pn$)^{52}Mn by Signorini and Stefanini.[7] The five transitions in their ^{52}Mn level scheme (Fig. 2) appear to be identical to those seen in Fig. 1, suggesting that the activity observed results from the β^+ decay of a high-spin isomeric level formed in the reaction ^{40}Ca(^{14}N, pn)^{52}Fe. The results of our experiments to date can be summarized as follows.

The five γ rays associated with the new activity have intensities in the delayed-γ-ray singles spectra consistent with the ^{52}Mn cascade,[7] and they decay with a common half-life of 56 ± 8 sec. The ^{42m}Sc peaks provide an internal check on the method; these data give $T_{1/2} = 61 \pm 7$ sec in agreement with previous work.[6]

The β spectra corresponding to the five ^{52}Mn transitions (and corrected for the underlying Compton continuum and chance coincidences) are consistent with a common end point, and therefore these spectra were summed in the final Kurie-plot analysis. With a scintillator calibration obtained from radioactive sources and the β^+ decay of ^{27}Si [$E_{\beta^+}(\max) = 3.788$ MeV[6]], the measured β^+ end point is 4.35 ± 0.25 MeV. This places the isomeric level at 6.83 ± 0.25 MeV in ^{52}Fe.

The β^+ branch to the 3.837-MeV ^{52}Mn state apparently accounts for > 80% of the decay width. In particular, there was no positive evidence in the delayed-γ-ray singles spectra for a ^{52}Fe $2^+ \rightarrow$ ground-state transition ($E_\gamma \cong 0.85$ MeV) with the isomer half-life.

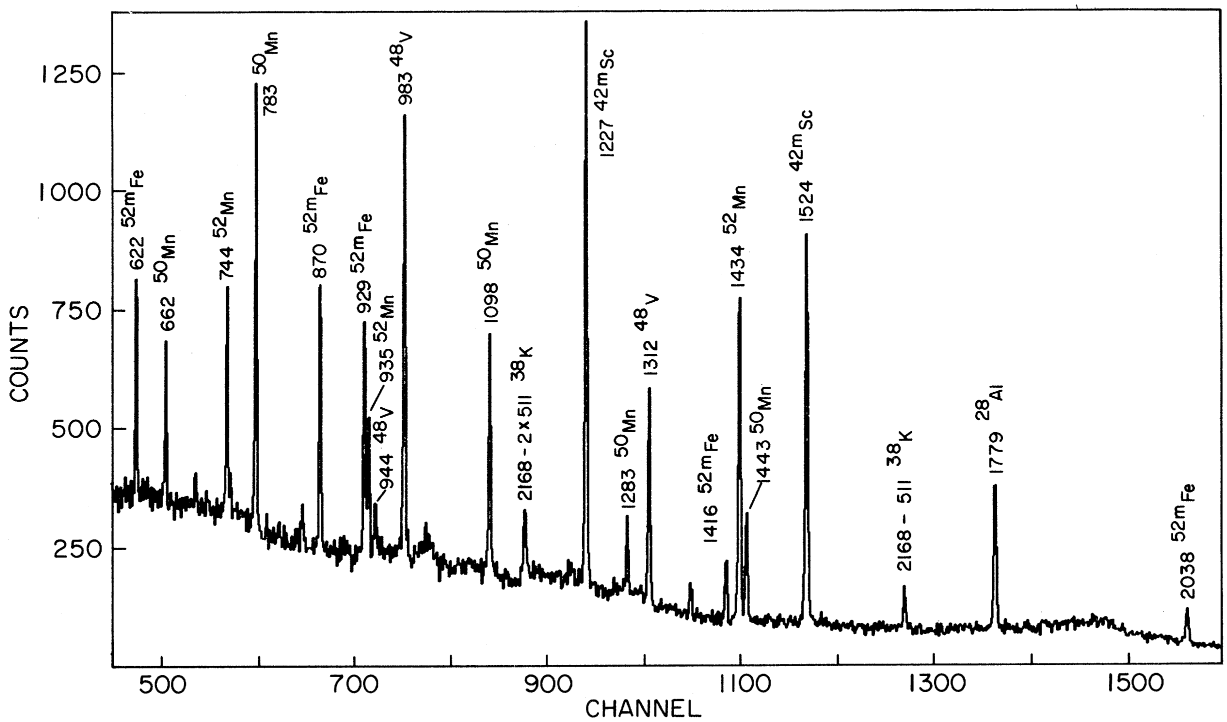

FIG. 1. Typical spectrum of delayed γ rays in coincidence with β particles from the ^{40}Ca + ^{14}N reaction at $E_{14\mathrm{N}}$ = 46 MeV. The prominent peaks are labeled by the activity parent and the γ-ray energy in keV.

Finally, there is further evidence (independent of the work of Ref. 7) which corroborates our assignment of the (56 ± 8)-sec activity to ^{52}Fe. A preliminary yield curve for the isomer production peaked at $E_{14\mathrm{N}} \cong 45$ MeV, a value consistent with p, n emission from the compound nucleus ^{54}Co. It is interesting to note in this context that in recent *in-beam* studies of γ rays from the ^{39}K + ^{16}O and ^{40}Ca + ^{14}N reactions there was no evidence for the expected ^{52}Fe $2^+ \rightarrow$ ground-state transition.[8] "Trapping" of the yrast γ-ray cascade by a high-spin isomer could explain these negative results. We were also able to produce the ^{52m}Fe activity with the reaction ^{50}Cr(α, $2n$)^{52}Fe at α-particle energies near the maximum obtainable from our accelerator. The β-γ coincidence yield (much smaller than in the ^{40}Ca + ^{14}N reaction) increased by a factor of ~4 in going from E_α = 27 MeV to 28 MeV, consistent with the ^{52}Fe(6.8 MeV) threshold of 24.3 MeV.

The measured logft value of 4.93 ± 0.15 together with the observed β-spectrum shape establishes that the ^{52m}Fe $\rightarrow$ ^{52}Mn decay is of the allowed type, and it therefore follows from the tentative ^{52}Mn 11^+ assignment[7] that ^{52m}Fe has $J^\pi = 10^+$, 11^+, or 12^+. The 10^+ possibility seems rather unlikely

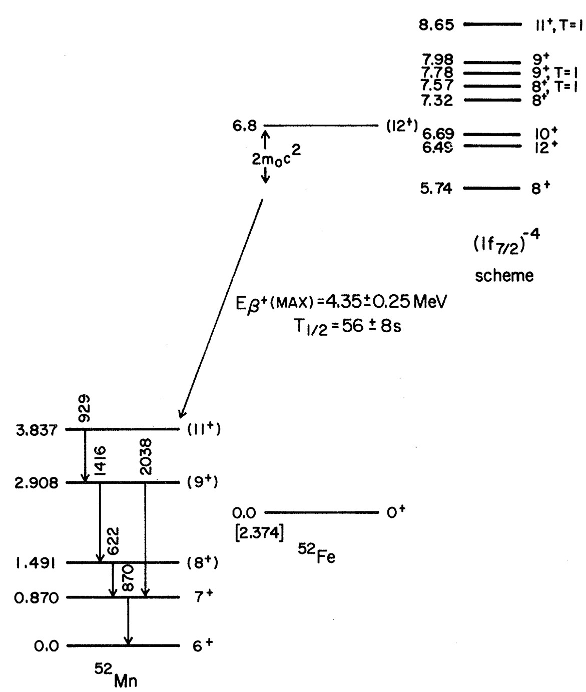

FIG. 2. Decay scheme for ^{52m}Fe. γ rays corresponding to the indicated transitions in ^{52}Mn (Ref. 7) are observed in coincidence with β particles from the isomer. A portion of the calculated ($J \geq 8$) ^{52}Fe $(f_{7/2})^{-4}$ spectrum is shown at the right-hand side.

in view of the fact that β decay to the (9^+) ^{52}Mn state would then be allowed, but is not observed. Similarly, in an $(f_{7/2})^n$ scheme the only ^{52}Fe 11^+ state would be the $T=1$ analog of the 3.837-MeV state in ^{52}Mn, and this ^{52}Fe 11^+ state is thus predicted to lie ~2.5 MeV above 6.8 MeV. The implication of the above arguments that ^{52m}Fe has $J^\pi=12^+$ depends critically, of course, on the work of Ref. 7. On the other hand, it seems clear from the shell-model calculations (see below) that the only possible β-isomeric state has $J^\pi=12^+$. With adoption of this assignment, it follows from Weisskopf estimates and the absence of γ-ray isomerism that the lowest ^{52}Fe 8^+ and 10^+ states lie no lower than ~700 and ~2 keV below the isomeric level, respectively. This is rather different from the situation in the conjugate nucleus ^{44}Ti, where the 8^+, 10^+, and 12^+ states have recently been located at 6.51, 7.67, and 8.04 MeV, respectively.[5]

In our $(f_{7/2})^{\pm 4}$ shell-model calculations the ^{42}Sc spectrum was taken from Sherr *et al.*,[9] while the ^{54}Co spectrum of $J=0$ to 7 states was assumed to be 0, 0.94, 1.446, 1.824, 2.645, 2.086, 2.900, and 0.197 MeV, respectively.[10] Results for the ^{44}Ti 8^+, 10^+, and 12^+ states are $E_x=6.08$, 7.37, and 7.69 MeV, respectively. Apart from an overall downward shift of ~350 keV, these values are in very good agreement with experiment.[5] A portion of the ^{52}Fe spectrum is shown at the right-hand side in Fig. 2; the calculated excitation of the 12^+ state is 6.49 MeV. It should be pointed out that the positions[10] of the 3^+, 4^+, 5^+, and 6^+ states in ^{54}Co are not yet certain. If the energies of the 4^+ and 6^+ $T=1$ states are taken instead from ^{54}Fe, then the calculated ^{52}Fe 10^+ state lies 16 keV below the 12^+ state. As this example illustrates, the isomeric character of the ^{52}Fe 12^+ state is quite sensitive to the details of the residual interaction. [This differs from the situation in the $(f_{7/2})^{-3}$ nuclei,[11] but is analogous to the results of Auerbach and Talmi for ^{211,212}Po.[4]] According to the present $(f_{7/2})^{-4}$ calculations, there should be an observable $12^+ \to 8^+$ $E4$ γ-ray branch from the ^{52}Fe isomer. A further search for this interesting decay mode is in progress.

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