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^{49}Fe: A NEW $T_Z = -\frac{3}{2}$ DELAYED-PROTON EMITTER*

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Iron-49 with a half-life of 75 ± 10 msec was produced by the reaction ^{40}Ca(^{12}C, $3n$)^{49}Fe using 65-MeV carbon ions; beta-delayed protons with an energy of 1.96 ± 0.05 MeV probably originating from the lowest $T = \frac{3}{2}$ state in ^{49}Mn were observed.

Although the series of $A = 4n+1$, $T_Z = \frac{1}{2}(N-Z) = -\frac{3}{2}$ beta-delayed proton emitters is known[1] from ^{9}C through ^{41}Ti, no technique for forming higher A nuclei of this type has been demonstrated and, in fact, almost no nuclei with $Z > N$ above the titanium isotopes can be considered as reliably established. We wish herein to report the observation of ^{49}Fe following carbon-ion bombardment of ^{40}Ca.

A pulsed beam of 65-MeV ^{12}C ions (4$^+$) from the Harwell variable-energy cyclotron was used to irradiate targets of ^{24}Mg, ^{28}Si, and ^{40}Ca. Beam intensities incident on the target averaged 0.5 μA. Reactions on these targets produced both the known delayed-proton emitters ^{33}Ar and ^{37}Ca as well as the new nuclide ^{49}Fe; the first two nuclides were studied to investigate the systematics of (^{12}C, $3n$) reactions on $T_Z = 0$ targets.

As indicated later, relatively low-energy protons (≈1.9 or 2.6 MeV) were expected in the decay of ^{49}Fe. In order to detect these protons reliably in a high β background, a semiconductor telescope consisting of two surface-barrier detectors—a 23-μ ΔE detector followed by an E detector depleted to 250 μ—was used. The targets were placed at an angle of 25° to the beam, and the telescope was mounted approximately perpendicular to the targets, subtending a solid angle of 0.13 sr.

Beam pulsing was achieved by modulating the voltage on the cyclotron dees. Signals from a repetitive ramp generator triggered the beam "on" for a chosen interval appropriate to the half-life being studied as well as triggering a shutter which dropped in between the target and the ΔE counter for a period overlapping the "beam-on" interval. Summed coincidence pulses between the ΔE and E detectors, further discriminated by requiring that their product ($\Delta E \times E \cong MZ^2$) be appropriate for a proton, were stored in a two-parameter analyzer as a function of time. Protons between 1.3 and 5.7 MeV could be linearly detected with this system. An ^{241}Am α source and a calibrated pulser established the energy scale. Normally 512 energy channels by 8 time channels, the latter covering 2 to 5 half-lives, were recorded.

A proton spectrum from ^{33}Ar produced via the (^{12}C, $3n$) reaction on a 2.8-mg/cm^2 natural Mg target is shown in Fig. 1(a). The overall energy

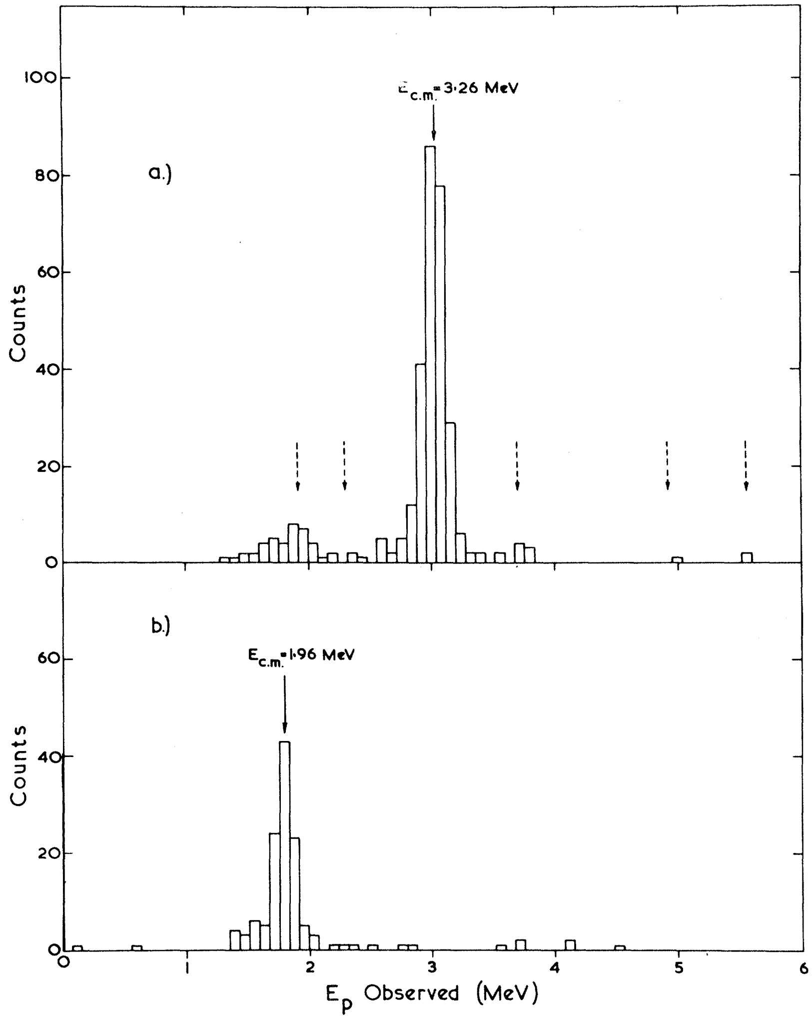

FIG. 1. (a) Proton spectrum following the decay of ^{33}Ar produced in 65-MeV ^{12}C bombardment of ^{24}Mg. The measured center-of-mass energy of the major peak is shown, and the dashed arrows indicate the expected positions of known minor peaks. (b) Proton spectrum following the decay of ^{49}Fe produced in 65-MeV ^{12}C bombardment of ^{40}Ca.

spectrum and the half-life of the dominant group agree well with the known[2,3] decay properties of ^{33}Ar. The cross section for production of this ^{33}Ar proton activity is of the order of 0.5 μb. Although the ^{24}Mg(^{12}C, $\alpha 3n$)^{29}S channel is open by 6 MeV in the c.m. at this bombarding energy, the Coulomb barrier for emission of the α particle effectively raises this threshold and no peaks attributable to the known[4] delayed-proton spectrum of ^{29}S were observed. Similar data consistent with these general results were also observed for the reaction ^{28}Si(^{12}C, $3n$)^{37}Ca but with poorer statistics.

Figure 1(b) presents a proton spectrum from ^{49}Fe produced from a 2.2-mg/cm^2 Ca target. A single peak corresponding to a c.m. energy of 1.96 ± 0.05 MeV, after correction for energy loss in the target, dominates the proton decay (though, as noted earlier, proton groups below 1.3 MeV could not have been observed). The half-life of this group was determined to be 75 ± 10 msec, and its production cross section is also of the order of 0.5 μb. Similar results were obtained at a bombarding energy of 60 MeV.

A crude excitation function places a threshold for production of this activity below 52 MeV. This is consistent with a threshold of 44.5 MeV based on a mass excess of −24.7 MeV for ^{49}Fe estimated from Coulomb displacement energy data.[5] (All unknown masses of $T_Z = -\frac{1}{2}, -1$ nuclei to be referred to were taken from the predictions of Ref. 5, while the $T_Z = -\frac{3}{2}$ masses were esti-

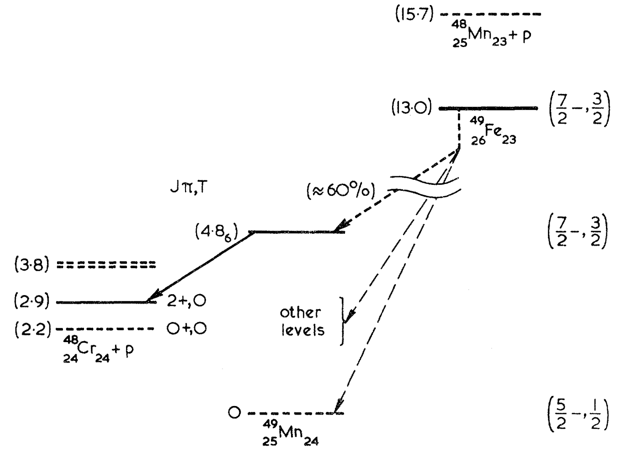

FIG. 2. A preliminary decay scheme for ^{49}Fe. Levels and decays that have not been directly observed are shown as dashed lines. Energies are given in MeV. Estimated energies and assumed J^{π}, T values are shown in parentheses. The β^+ branching ratio to the analog state is discussed in the text.

mated using the known mass of the analog $T_Z = +\frac{3}{2}$ nuclide and successive Coulomb displacement energies.) These results indicate that the reaction ^{40}Ca(^{12}C, $\alpha 3n$)^{45}Cr, threshold ~54.5 MeV, is not the origin of the observed activity. Furthermore, the above coupled with the known general systematics of the very weakly proton- and/or alpha-decaying nuclei of the $A = 4n$, $T_Z = -1$ series make it highly unlikely that these protons could arise from ^{48}Mn produced via the (^{12}C,$p3n$) reaction, for which the effective threshold (including Coulomb barrier) is also ~54.5 MeV.

A preliminary decay scheme for ^{49}Fe is presented in Fig. 2. The mass[6] of ^{48}Cr and preliminary values for its first few excited states[6,7] are known. If we assume that (isospin-forbidden) proton decay occurs to the first excited state of ^{48}Cr, rather than to its ground state, much better agreement is obtained between the calculated excitation energy for the lowest $T=\frac{3}{2}$ state in ^{49}Mn (~4.68 MeV rather than ~4.16 MeV) and its known analog in ^{49}Cr(4.76 ± 0.02 MeV).[8] Given this interpretation, less than 5% of the observed proton decays from this ^{49}Mn state populate the ^{48}Cr ground state.[9] Assuming for illustration a logft of 3.3 for the superallowed β^+ transition $^{49}\mathrm{Fe} \rightarrow {}^{49}\mathrm{Mn}^*$ ($T=\frac{3}{2}$) (as calculated for similar nuclei in the 2s, 1d shell[10]), the observed delayed protons could account for approximately 60% of the total decays.

If these cross section data are typical of ($T_Z = 0$ heavy-ion, $3n$) reactions on $T_Z = 0$ targets, then, for example, the use of ^{16}O and ^{20}Ne beams in this type of reaction on targets through ^{40}Ca should permit observation of other members of this $T_Z = -\frac{3}{2}$ series, such as ^{45}Cr, ^{53}Ni, and ^{57}Zn. Furthermore, delayed-proton data coupled with mass measurements from possible multineutron transfer reactions[11] such as ^{54}Fe(^{3}He, ^{8}He)^{49}Fe should permit completion of isospin quartets in regions of high Coulomb energy, thus permitting a more rigorous test of the isobaric-multiplet mass equation.[11]

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