NEW ISOTOPES OF INTEREST TO ASTROPHYSICS*

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Abstract

The β decays of the new isotopes ^{53}Ti and ^{59}Mn have been studied. These neutron-rich isotopes have half-lives of 32.7 ± 0.9 s and 4.75 ± 0.14 s, respectively. They were produced via the ^{48}Ca(^{7}Li, pn)^{53}Ti and ^{48}Ca(^{13}C, pn)^{59}Mn reactions using beams from the Argonne National Laboratory FN Tandem Van de Graaff accelerator. Measurement of γ singles, γ-γ coincidences, and β-γ coincidences were facilitated by a pneumatic target-transfer system ("rabbit").

Decay schemes will be presented, and the measured masses will be compared with various predictions. The relevance to astrophysics will be discussed. In addition, a new 8-target multiple rabbit system will be described.

1. Introduction

The nuclear properties of neutron-rich isotopes in the $50 < A < 70$ region are of interest from a number of astrophysical points of view. The nucleosynthesis of the rare neutron-rich isotopes like ^{48}Ca and ^{64}Ni is thought to take place during explosive carbon burning in a supernova explosion. Calculations of such events require information such as neutron separation energies for neutron-rich nuclides in this mass region.

The formation of a neutron star from a supernova remnant is a process which involves the neutronization of the dense hot core of an exploding giant star. This occurs via electron captures, since the Fermi energy of the degenerate electrons in such a dense medium can approach 10 MeV. Inside the remnant the proton number density is very small, but in the surface region there may exist neutron-rich nuclides resulting from electron captures on abundant species such as ^{56}Fe. The masses and β-decay rates for neutron-rich isotopes in the $50 < A < 70$ region are the relevant nuclear data needed for calculations involving nuclei which might be present in neutron star crusts. Such information is also useful in checking the predictions of the various mass formulae in this region.

We have been studying the β decays of the $T_Z = 9/2$ nuclei heavier than ^{48}Ca by means of heavy-ion-induced fusion-evaporation reactions. So far these studies have resulted in the discovery of three new isotopes: ^{53}Ti, ^{59}Mn, and ^{60}Mn. The first two will be reported on in detail; work is still in progress on the study of ^{60}Mn decay.

Heavy-ion beams from the Argonne National Laboratory FN Tandem are used in conjunction with a fast pneumatic target transfer system ("rabbit") to perform these studies. Both Ge(Li) and intrinsic Ge detectors are used to observe β-delayed γ rays, while β spectra are measured using a NE102 plastic scintillator.

2. Decay of ^{53}Ti

The new nuclide ^{53}Ti has been produced via the ^{48}Ca(^{7}Li, pn)^{53}Ti reaction, using 14—20-MeV ^{7}Li beams. The rabbit system was used to obtain γ singles, γ-γ coincidence, and β-γ coincidence spectra. A preliminary report of this work appeared in Ref. 1). 16 γ rays are attributed to the decay of ^{53}Ti, and their energies and relative intensities are listed in Table I. ^{53}Ti has a decay half life of 32.7 ± 0.9 s.

Table I. γ rays observed in the decay of ^{53}Ti.

E_γ(keV)	I_γ(rel.)
100.8 ± 0.1	47.3 ± 3.6
127.6 ± 0.1	106.8 ± 15.6
228.4 ± 0.1	100
1422.0 ± 1.3	11.9 ± 3.0
1321.7 ± 1.9	11.9 ± 4.1
1776.4 ± 1.6	9.5 ± 1.6
1728.5 ± 1.2	13.0 ± 1.7
1675.4 ± 0.8	60.3 ± 4.8
1956.2 ± 2.1	8.7 ± 1.2
1904.0 ± 0.9	32.5 ± 2.8
1854.8 ± 1.2	7.4 ± 1.2
2456.0 ± 1.8	15.3 ± 2.0
2355.0 ± 1.7	7.7 ± 1.3
2701.4 ± 1.8	9.3 ± 1.5
2600.4 ± 2.1	15.4 ± 2.0
2828.4 ± 2.7	5.1 ± 1.2

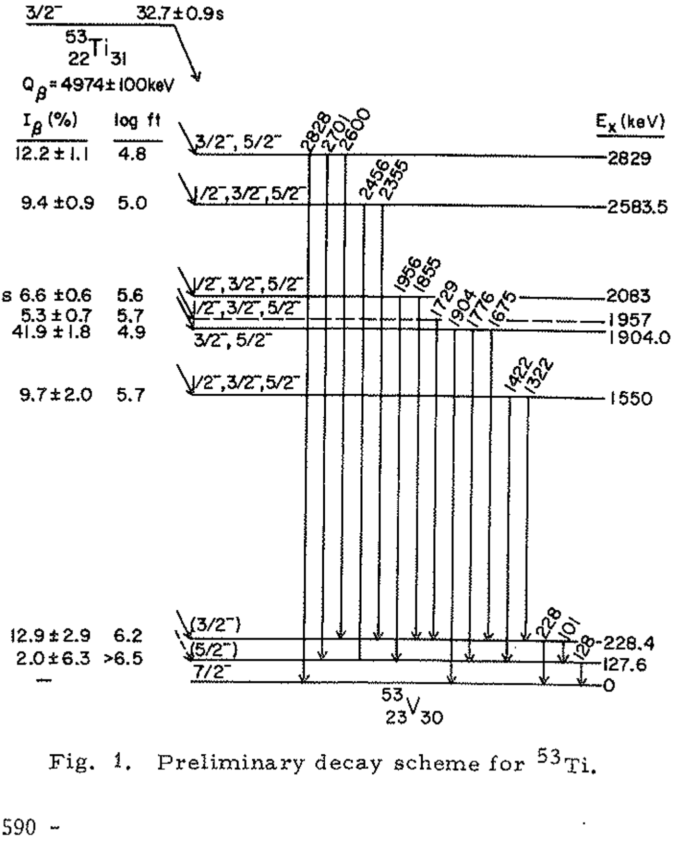

Fig. 1. Preliminary decay scheme for ^{53}Ti.

A preliminary decay scheme has been constructed for ^{53}Ti, and is shown in Fig. 1. The resulting excitation energies and γ decays of levels in the daughter nucleus ^{53}V compare favorably with those obtained by Pronko et al. [2] from the ^{51}V(t, pγ)^{53}V reaction and by Hinds et al. [3] from the ^{51}V(t, p)^{53}V reaction.

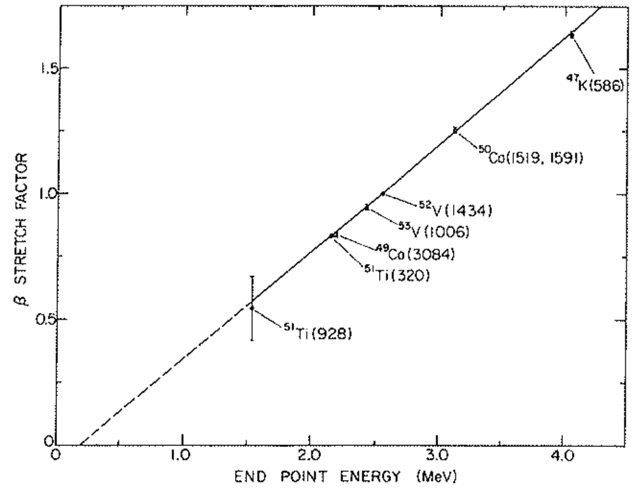

Fig. 2. β spectrum stretch factor for various β groups vs endpoint energy. The spectral shape used was that of ^{52}V. See text for details.

The total decay energy for ^{53}Ti was obtained by means of β-γ coincidence measurements. From the decay of strongly-produced ^{52}V, a β spectral shape was extracted. This "standard" spectrum was stretched or compressed to fit single β groups from other isotopes produced in the same experiment. Figure 2 shows the stretch factors obtained by this procedure as a function of the corresponding known endpoint energies. The correlation is well described by a straight line. Endpoint energies of 3 β groups from ^{53}Ti decay were extracted in the middle of the calibration curve, ranging from 2.38 to 3.09 MeV. The fitted spectrum for the latter case is shown in Fig. 3. The result is a total decay energy for ^{53}Ti of 4.97 ± 0.10 MeV and a mass excess of -46.89 ± 0.10 MeV.

From the shell model, the ground state of ^{53}Ti is expected to have a spin and parity of $3/2^-$. On the additional assumption that only allowed β decays will be observed to states in ^{53}V, these states must have $J^\pi = 1/2^-, 3/2^-, 5/2^-$. Pronko et al. [2] have suggested that the 127- and 228-keV states most likely have spin and parity $J^\pi = 5/2^-$ and $3/2^-$, respectively.

3. Decay of ^{59}Mn

The β decay of the new isotope ^{59}Mn has been observed using the rabbit system. A preliminary account has appeared in Ref. 4). The nuclide was produced via the ^{48}Ca(^{13}C, pn)^{59}Mn reaction with a 26-MeV ^{13}C beam. ^{59}Mn decays with a half life of 4.75 ± 0.14 s, and emits γ rays with energies of 287.1, 473.2, 571.4, and 726.6 keV (all ±0.4 keV). Identification of ^{59}Mn was aided by the observation of prompt γ rays from excited states of ^{59}Fe in a separate ^{58}Fe(d, pγ)^{59}Fe* experiment.

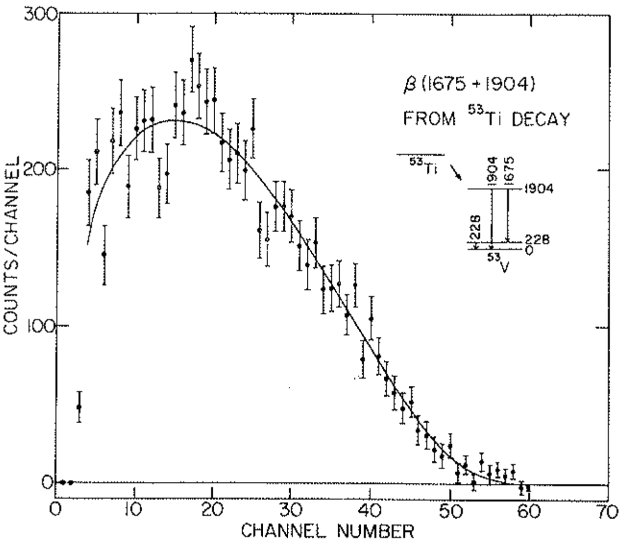

Fig. 3. β spectrum in coincidence with 1904- and 1675-keV γ rays in ^{53}Ti decay. Solid line represents a fit corresponding to a β endpoint energy of 3.09 ± 0.08 MeV.

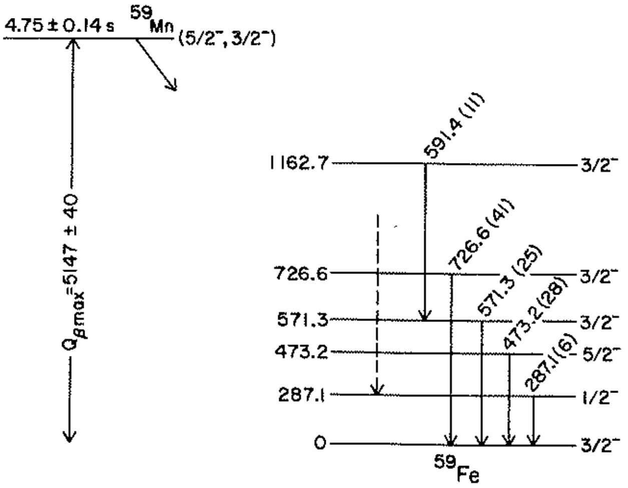

Fig. 4. Tentative decay scheme for ^{59}Mn.

A tentative decay scheme for ^{59}Mn is shown in Fig. 4. The spins and parities of the ^{59}Fe states are taken from the work of McLean et al., [5] who used the combination of ^{57}Fe(t, p)^{59}Fe and ^{58}Fe(d, p)^{59}Fe to deduce J^π values. Our preliminary β-γ measurements show that the 287.1-keV state is not fed directly by β decay. This remains to be investigated further by a careful γ-γ coincidence study. The 591.4 and 571.3-keV γ rays have been observed in coincidence.

Kashy et al. [6] have measured the mass excess of ^{59}Mn via the ^{64}Ni(^{3}He, ^{8}B)^{59}Mn reaction, and have obtained a value of -55.49 ± 0.04 MeV. They were unable to resolve what appears to be a low-lying excited state from the ground state.

^{59}Mn is expected to have a ground-state spin and parity of $5/2^-$, in analogy with ^{55}Mn and ^{57}Mn. Allowed β decay will then take place to states having $J^\pi = 3/2^-$, $5/2^-$, and $7/2^-$. Thus it is important to verify whether the $1/2^-$ state is populated directly.

4. Mass Predictions

Table II gives a summary of mass excess predictions for ^{53}Ti and ^{59}Mn, as well as the experimental values. For further discussion, see Ref. 7).

Table II. Comparison of Predicted and Experimental Mass Excesses (in MeV)

	Predictions				
Nuclide	D[a]	Transverse[a]	ZGS[b]	SH[c]	Expt.
^{53}Ti	-46.50	-46.59	-46.83	-46.4	-46.89 ± 0.10[d]
^{59}Mn	-55.35	-56.01	-55.70	-55.6	-55.49 ± 0.04[e]

[a] See Ref. 7) for further details.

[b] N. Zeldes, A. Grill, and A. Simievic, K. Dan. Vid. Selsk. Mat.-Fys. Skr 3, No. 5 (1967).

[c] P. A. Seeger and W. M. Howard, Los Alamos Report No. LA-5750, 1974 (unpublished).

[d] Present work.

[e] Reference 6).

5. Multiple-Rabbit Facility

A new multiple-target rabbit system has been constructed at the Argonne FN Tandem facility. This device holds up to 8 targets in a circular carrousel, allowing sequential bombardment of the targets. The sequential feature allows time between bombardments for the decay of long-lived background isotopes, thus enhancing the detection of the desired short-lived components. Figure 5 shows a front view of the multiple-rabbit chamber.

Precision alignment of the individual targets is achieved by rotating the carrousel by means of a Geneva drive mechanism. The shaft of this drive enters the vacuum chamber via a Ferro-fluidic coupling. Provision has also been made for loading fragile targets through a vacuum interlock.

Using the multiple rabbit to repeat the ^{53}Ti decay study resulted in doubling the number of γ rays which could be attributed to this isotope. The increased sensitivity for weaker transitions also enabled the relative intensities to be determined with higher precision.

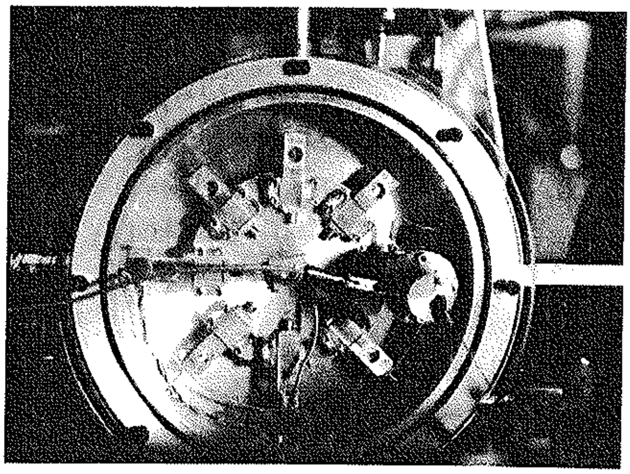

Fig. 5. Front view of multiple rabbit chamber. Horizontal transfer tube at right leads to shielded counting area. Beam direction is out of the plane of the photograph. Rabbit "hutches" and transfer tube are made of waveguide. Overall diameter of chamber is 29 cm.

References

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