Mn^{58} Isomers*

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A new 3.0±0.1-sec activity with a 6.1±0.3-MeV β endpoint energy was assigned to an isomer of Mn^{58}. The decay of the 65-sec Mn^{58} isomer was studied and a β-decay Q value of 6.1±0.2 MeV determined.

I. INTRODUCTION

THE only previously reported investigation of Mn^{58} was the initial discovery by Chittenden *et al.*,[1] who produced this nuclide through the $Fe^{58}(n,p)Mn^{58}$ reaction at 14.8 MeV neutron energy. They observed a 66±6 sec activity in the radiochemically separated Mn fraction from irradiated enriched $Fe_2{}^{58}O_3$. They reported observing γ rays of 0.36, 0.41, 0.52, 0.57, 0.82, 1.0, 1.25, 1.4, 1.6, 2.2, and 2.8 MeV. No β-ray energy measurements were performed.

II. EXPERIMENTAL

A 100-mg sample of enriched Fe^{58} metal was obtained from the Stable Isotope Division, Oak Ridge National Laboratory. The isotopic composition of this sample is given in Table I. The sample was sealed in a polyethylene capsule, irradiated with 14.8-MeV neutrons, and transported to the detection system by the use of a pneumatic transport system.

TABLE I. Isotopic composition of enriched Fe^{58} metal.

Isotopes	Abundance (%)
Fe^{54}	0.45±0.05
Fe^{56}	15.83±0.1
Fe^{57}	1.6±0.05
Fe^{58}	82.12±0.1

The detectors used for singles γ-ray spectra were a 3-in.×3-in. NaI(Tl) detector and a 4-cm²×0.5-cm deep Ge(Li) drifted spectrometer. The Ge detector was used in conjunction with a 4096-channel Nuclear Data 3300 analyzer. β spectra were obtained using a $1\frac{1}{2}$-in. diam×$\frac{15}{16}$-in. high cylindrical plastic detector. β-γ coincidences were measured using the plastic detector and a 3-in.×3-in. NaI(Tl) detector. γ-γ, sum peak, and sum peak coincidence spectra were obtained with two NaI(Tl) detectors.

Gross β and γ decay measurements were performed using either the plastic detector or the NaI(Tl) detector in conjunction with a 200-channel RIDL analyzer in the multiscale mode.

III. RESULTS

Figure 1 shows a typical gross β decay curve of irradiated enriched Fe^{58}. An integral bias of 3.0 MeV and greater was used in order to eliminate 3.5 min Cr^{55} produced through the $Fe^{58}(n,\alpha)Cr^{55}$ reaction. The decay curve clearly shows the existence of two components with half-lives of 3.0±0.1 and 65±1 sec. Gross γ decay of the 0.81±0.05 MeV γ-ray region (see Fig. 2) revealed only 65±1 sec Mn^{58} after 2.58 h Mn^{56} had been subtracted.

Figure 3 shows the γ-ray spectrum of irradiated enriched Fe^{58} obtained with the Ge detector. The contribution of 2.58-h Mn^{56} has been subtracted out. The decay of 1.54-min Mn^{57} has recently been studied.[2] Assignment of the 0.122-, 0.136-, 1.263-, and 1.613-MeV γ rays can be made to Mn^{57} produced through the $Fe^{57}(n,p)Mn^{57}$ and $Fe^{58}(n,np)Mn^{57}$ reactions. The energies and intensities of those γ rays associated with 65-sec Mn^{58} are summarized in Table II. Singles γ-ray spectra obtained with a NaI(Tl) detector did not reveal any higher energy γ ray than 1.67 MeV that could be assigned to 65 sec Mn^{58}. No γ ray was found to be associated with the 3.0-sec activity when successive 10-sec NaI(Tl) spectra were analyzed.

β spectra obtained 20 sec after bombardment from irradiated enriched Fe^{58} revealed a 3.9±0.2-MeV β endpoint energy, which decayed with a 65-sec half-life. Analyses of the β-spectra from 10-sec bombardments and 10-sec counting intervals were observed to have a 6.1±0.3-MeV β endpoint energy. The 6.1-MeV β ray decayed with an approximate 3-sec half-life. The logft values for the 3.9-MeV 65-sec and 6.1-MeV 3.0-sec β-ray activities were calculated to be 5.2 and 5.0, respectively.

γ-γ coincidence measurements were performed for those γ-rays of 65-sec Mn^{58}. The 0.467-MeV γ-ray was observed to have coincidences of 0.82 (doublet) and 1.67 MeV. The 1.332-MeV γ ray revealed only the 0.810-MeV γ ray in coincidence, whereas only the 0.467-MeV γ ray was observed in coincidence with the 1.675-MeV γ ray. No γ-γ coincidences were performed on the 0.810-MeV γ ray. β-γ coincidences on the 0.46±0.05,- 0.83±0.05-, and 1.33±0.05-MeV γ-ray regions

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[1] D. M. Chittenden, II, D. G. Gardner, and R. W. Fink, Phys. Rev. 122, 860 (1961).

[2] T. E. Ward, P. H. Pile, and P. K. Kuroda, Nucl. Phys. (to be published).

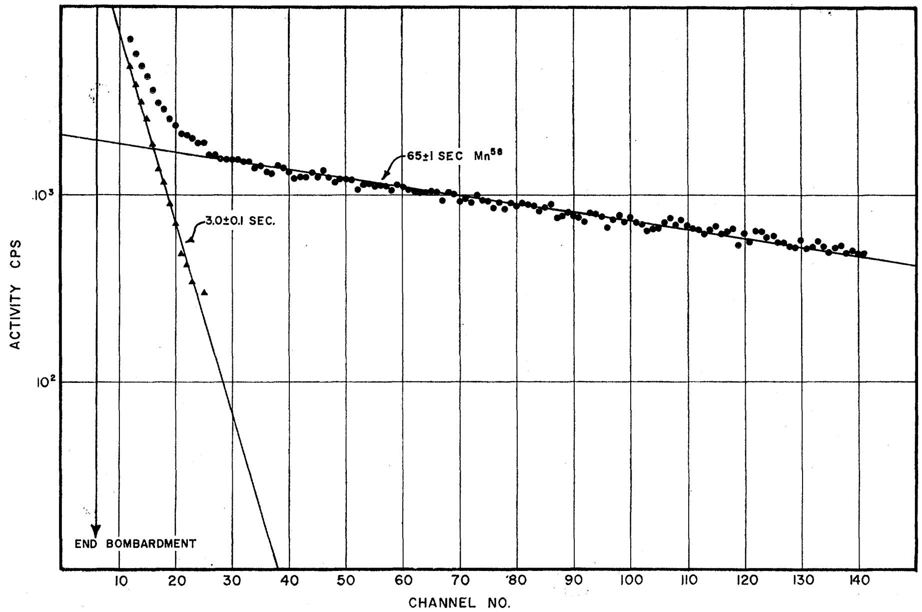

FIG. 1. Gross β-decay curve from irradiated enriched Fe^{58} metal. Obtained with a plastic β scintillator biased 3 MeV and greater in order to eliminate 3.5-min Cr^{55} produced through the $Fe^{58}(n, \alpha)Cr^{55}$ reaction.

were all measured to have 3.9±0.2-MeV β endpoint. energies. The coincidence measurements are summarized in Table III. Sum peak and sum peak coincidence measurements revealed peaks at 1.68±0.03 and 2.14±0.03 MeV associated with 65-sec Mn^{58}.

IV. DISCUSSION

The γ-rays of 0.36, 0.57, and 1.25 MeV reported by Chittenden *et al.*[1] to belong to the decay of Mn^{58} can be assigned to Mn^{57}.[2] We were unable to observe the

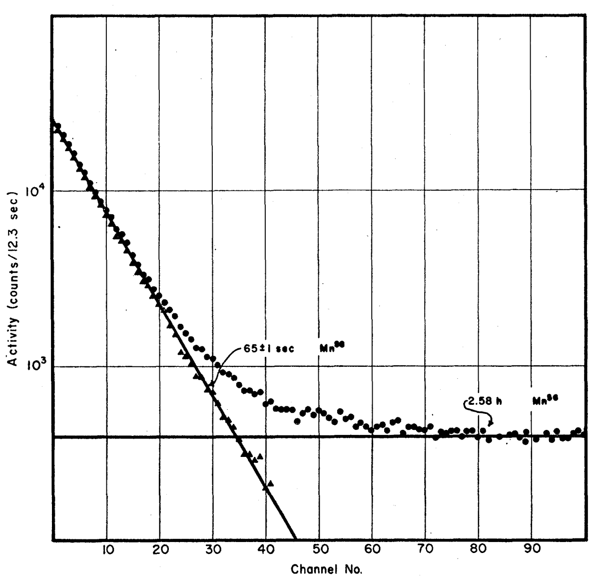

FIG. 2. Gross γ-decay curve from irradiated enriched Fe^{58} metal biased on the 0.81±0.05-MeV region.

0.41-, 0.52-, 1.0-, 1.4-, and 2.8-MeV γ rays reported by Chittenden *et al.*[1]

In Fig. 4 is shown a proposed decay scheme for the Mn^{58} isomers which was derived from Tables II and III. The 1.675-, 0.865-, and 0.810-MeV γ rays are known[3] in the *EC* of 71*d* Co^{58} and have been determined to depopulate the first and second 2^+ excited states at 0.810 and 1.675 MeV in Fe^{58}. The 0.467- and 1.332-MeV γ rays can be assigned to depopulate the 2.142-MeV level in Fe^{58}, whose spin and parity are 4^+.[4]

The single β-ray component of 3.9-MeV feeding the 4^+ level at 2.142 MeV was calculated to have a logft value of 5.2. The allowed character of the β ray indicates that the spin and parity of 65 sec Mn^{58} is either 4^+ or 5^+. The absence of any higher energy β rays populating the 2^+ levels at 0.810 and 1.675 MeV in Fe^{58} rules out any spin assignment less than 4. Yamada and Matumoto[5] have estimated the β-decay Q value of Mn^{58} to be approximately 6.2 MeV. The β-decay Q value of 6.1±0.2 MeV obtained for 65-sec Mn^{58} is in excellent agreement with the estimate.

As pointed out elsewhere,[6] Mn^{55} appears to exhibit some collective motion, since a pure shell-model configuration predicts a $\frac{7}{2}^-$ ground state spin and parity, and a $\frac{5}{2}^-$ has been measured.[7] The ground-state spin

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[6] G. Friedlander, J. W. Kennedy, and J. M. Miller, in *Nuclear and Radiochemistry* (Wiley-Interscience, Inc., New York, 1964), 2nd ed., p. 83.

[7] I. Lindgren, Table of Nuclear Spins and Moments, in *Alpha-, Beta-, and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Co., Amsterdam, 1964), Appendix 4.

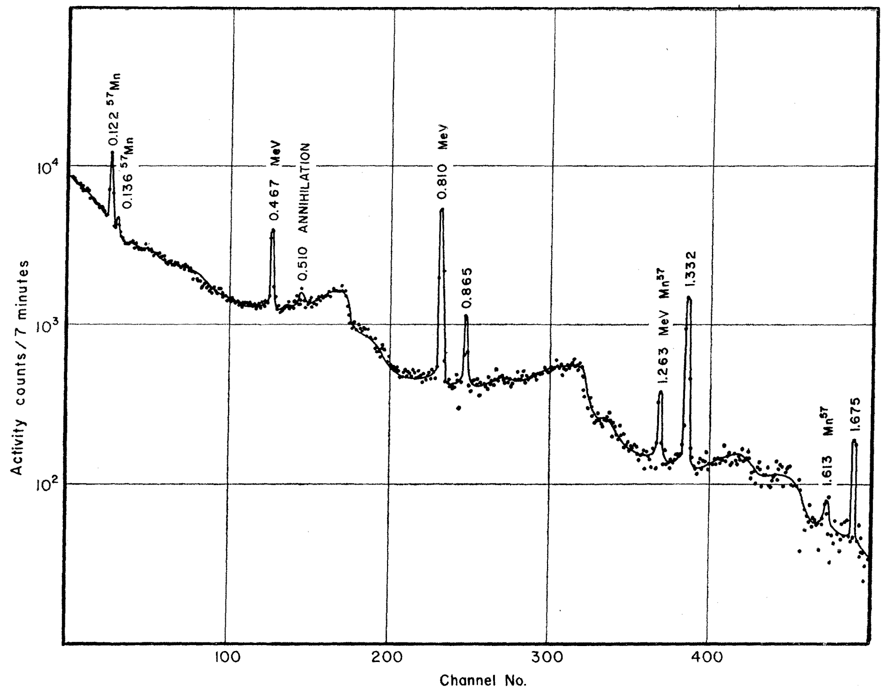

FIG. 3. Typical singles germanium spectrum of irradiated enriched Fe^{58} metal. The 0.122-, 0.136-, 1.263-, and 1.613-MeV γ rays are assigned to Mn^{57}.

TABLE II. Radiations from Mn^{58} isomers.

Isomer	Radiation	Energy (MeV)	Relative intensity	Remarks
65 sec	γ_1	0.467±0.001	25.8±0.8	
	γ_2	0.810±0.001	100.0	
	γ_3	0.865±0.001	17.3±0.7	
	γ_4	1.332±0.002	76.6±2.3	
	γ_5	1.675±0.002	11±4	
	β	3.9±0.2	100%	logft=5.2
3.0 sec	β	6.1±0.3	100%	logft=5.0

TABLE III. Coincidences from 65-sec Mn^{58}.

γ-ray region (MeV)	Coincident-radiation γ rays (MeV)					β ray
	0.467	0.810	0.865	1.332	1.675	
0.46±0.05	no	yes	yes	no	yes	3.9±0.2
0.83±0.05	(γ-ray coincidences not performed)					3.9±0.2
1.33±0.05	no	yes	no	no	no	3.9±0.2
1.67±0.10	yes	no	no	no	no	

and parity of Mn^{57} has been deduced as $\frac{5}{2}^-$ from its β decay,[2] and both Mn^{54} and Mn^{56} are known[7] to have a 3^+ spin and parity. From the curves of proton and neutron orbitals given by Mottelson and Nilsson[8] assuming a slight deformation ($\epsilon < +0.10$), the expected ground-state spin and parity for the 25th proton is $\frac{5}{2}^-$, since it falls into the $\frac{5}{2}^-[3, 1, 2]$ orbital.[9,10] This is in agreement with the observed or deduced spin and parity for Mn^{55} and Mn^{57}. For Mn^{54} and Mn^{56} the 29th and 31st neutrons, respectively, fall into the $\frac{1}{2}^-[3, 2, 1]$ and $\frac{1}{2}^-[3, 1, 0]$ orbitals and a spin and parity of 3^+ could be expected for the coupling of the odd proton and odd neutron. For Mn^{58} the $\frac{5}{2}^-[3, 1, 2]$ proton and the 33rd neutron, whose assignment is $\frac{3}{2}^-[3, 1, 2]$, could couple their spins parallel to produce $I\Pi = 4^+$, although the coupling rules of odd-odd nuclei as given by Gallagher and Moszkowski[11] predicts a ground state spin of 1.

The 3.0 ± 0.1-sec activity which was observed to have a 6.1 ± 0.3-MeV β endpoint energy can be assigned tentatively to an isomer of Mn^{58} on the basis of the following considerations: (a) the 6.1 ± 0.3-MeV β-decay Q value is in agreement with the estimate of 6.2 MeV for Mn^{58}; (b) no other fast-neutron reaction product from Fe is expected to have greater than 4-MeV β-decay energy available and also a search of Table of Isotopes[12] did not reveal any 3.0 ± 0.1-sec activity with a 6.1-MeV β ray that could be produced by fast neutron bombardment on any possible contaminant; and (c) the production cross-section ratio of 1.3 ± 0.5 for the 3.0-sec activity to the 65-sec Mn^{58} activity is about what one would expect for the $Fe^{58}(n, p)Mn^{58}$ isomer cross-section ratio.

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[8] B. R. Mottelson and S. G. Nilsson, Z. Physik **141**, 217 (1955).
[9] The symbolism used here is $\Omega\Pi[N, n_z, \Lambda]$; see Ref. 10.
[10] J. M. Hollander, Phys. Rev. **105**, 1518 (1957).
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[12] C. M. Lederer, J. M. Hollander, and I. Perlman, in *Table of Isotopes* (Wiley-Interscience, Inc., New York, 1967), 6th ed.

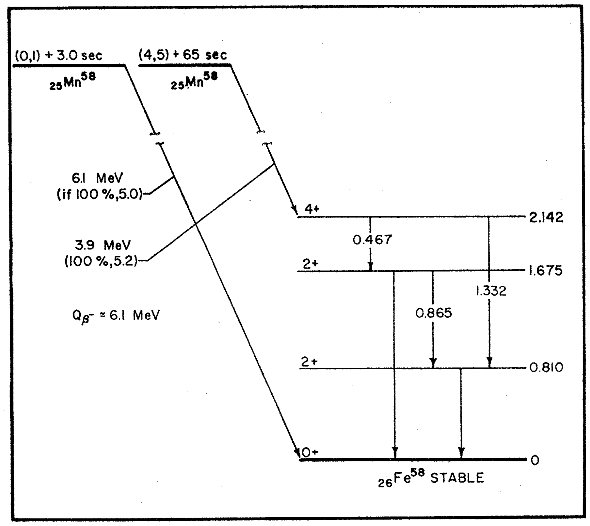

FIG. 4. Tentatively proposed decay scheme of the Mn^{58} isomers.

The logft value of 5.0 for the 6.1-MeV β ray of 3.0 sec Mn^{58} indicates a spin and parity change of 0 or 1, no. On this basis a tentative spin and parity of 0^+ or 1^+ can be assigned to the 3-sec Mn^{58} isomer. In terms of the collective model, the possible spin and parity assignment of 1^+ could occur, since the antiparallel coupling of the orbital angular momentum could account for the low spin.

No low-energy γ ray which may have been due to an isomeric transition was observed. It is difficult to determine which isomer is in the ground-state, because both β-decay Q values are approximately 6.1 MeV.

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