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DISCLAIMER

COSMIC RAY HALF LIFE OF ^{54}MN

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Abstract

A search for the β^+ decay of ^{54}Mn has established an upper limit of 4.4×10^{-8} for this branching ratio, and a lower limit of 13.3 for the log ft value for this second forbidden unique transition. Assuming that the β^- decay branch has the same log ft value, then its partial half life must be greater than 4×10^4 years. Experiments to directly measure the β^- decay rate of ^{54}Mn are now in progress.

Introduction In the laboratory, ^{54}Mn decays with a 312 day half-life via an allowed electron capture transition to the 835-keV level in ^{54}Cr. As a cosmic ray, ^{54}Mn is believed to be produced through spallation of primary iron nuclei on interstellar hydrogen and would be stripped of all its atomic electrons. While this would prevent its decay by electron capture, as can be seen in Figure 1, it is energetically possible for it to decay via second forbidden unique transitions to the ground states of ^{54}Cr and ^{54}Fe by positron or negatron emission, respectively (Browne and Firestone 1986). Because of the expected long β^+ and β^- lifetimes, ^{54}Mn has been proposed as a cosmic-ray chronometer (Cassé 1973, Wilson 1978). More recently, the presence of ^{54}Mn in the cosmic rays has been experimentally confirmed (Tarlé et al. 1979), with a half-life estimated to be $(1 - 2) \times 10^6$ years in order to explain the observed energy spectrum (Koch et al. 1981).

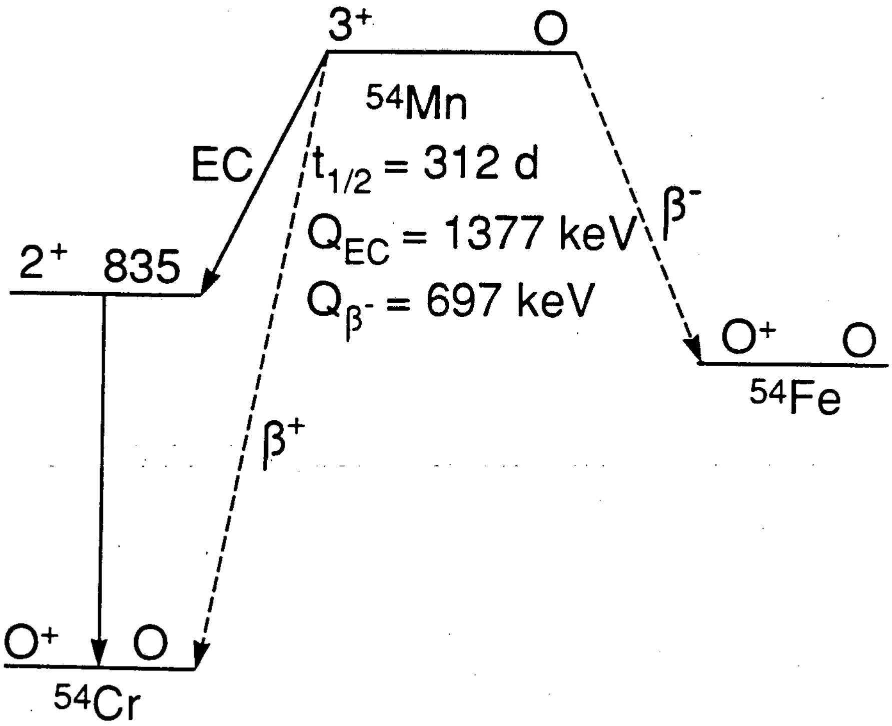

Figure 1. Decay scheme of ^{54}Mn.

Experiment Because there is more energy available for β^- decay, this is expected to be the dominant decay mode for fully ionized ^{54}Mn. However, it is extremely hard to experimentally isolate the expected $\leq 10^{-6}$ branch in the laboratory. The basic problem is how to find this tiny 697-keV endpoint β^- spectrum in the presence of the 835-keV gamma rays, which are emitted nearly 100% of the time, and of the 829-835 keV internal conversion electrons, which are emitted with a branching ratio of 2.5×10^{-4} (Browne and Firestone 1986). Thus, the initial studies of Sur et al. (1989) searched for the even smaller, but easier to detect, β^+ decay branch. A schematic view of the experimental apparatus is shown in Figure 2.

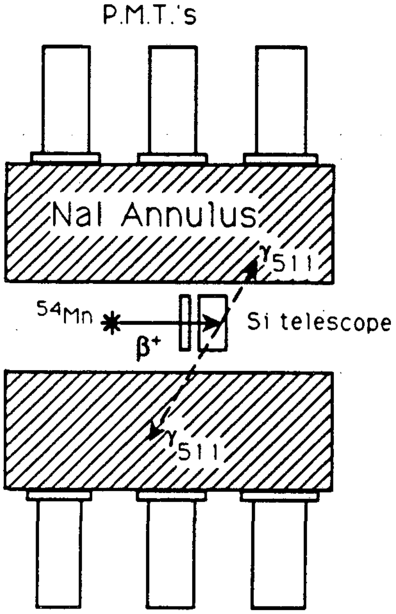

Figure 2. Schematic view of the apparatus for detecting positrons.

A chemically purified 7.3 μCi ^{54}Mn source was mounted in front of a two-element silicon surface-barrier detector telescope to detect the emitted positrons. The source and telescope were mounted at the center of an annular NaI detector that was optically divided into two halves. The back-to-back 511-keV γ rays from positrons annihilating in the back element of the telescope were detected in these two halves of the annular detector. A fourfold coincidence between the telescope elements and each half of the annular NaI detector was required in the electronic hardware trigger. For each such trigger, the energy signals from all four detectors, the summed energy in the telescope, timing signals between the back silicon detector and each of the other three detectors, and the timing signal between the two halves of the NaI annulus were recorded. The efficiency of the apparatus for detecting positrons by this method was measured by detecting positrons from a calibrated ^{65}Zn source mounted in the same geometry as the ^{54}Mn source. ^{65}Zn was chosen for this calibration because its β^+ decay endpoint energy of 325 keV is very close to the expected 355 keV β^+ decay endpoint energy of ^{54}Mn.

Results and Discussion The nine parameter event-by-event data was sorted with a variety of software gates. The candidate positron spectrum was extracted by projecting out the summed telescope energy spectrum in coincidence with 511-keV γ rays detected in both halves of the annular NaI detector within the prompt timing requirement for all detectors. Background spectra were extracted by projecting out the summed telescope energy spectrum in coincidence with combinations of gates set above and below 511 keV in both halves of the NaI annulus. Background events due to random coincidences were determined to be negligible by setting gates off the prompt peak in each of the timing spectra. During a total running time of 360.4 hours, no excess counts were observed in the back-to-back prompt 511-keV gated spectrum over those in the background gates. In the 511-511-keV gate of interest we observed 208±14.4 events in the first 355 keV of the summed telescope energy spectrum, while the average number of events in all the background gates was 213±5.6. Thus, the 1σ upper limit set on the number of ^{54}Mn positrons detected was 15.5. Using the experimentally determined efficiency of 0.10% for detecting positrons, we obtain an upper limit of 4.4×10^{-8} for the β^+ decay branching ratio of ^{54}Mn, which corresponds to a lower limit of 2.0×10^7 years for the partial half-life of this decay channel. This result clearly rules out the possibility that β^+ is the dominant decay mode for the ^{54}Mn nuclei found in cosmic rays.

Using the accepted value of 1377 keV for the mass difference between ^{54}Mn and ^{54}Cr (Browne and Firestone 1986), a lower limit of 13.3 was established for the log ft value of this transition. Using this log ft value for the β^- decay branch with 697 keV of available energy, a lower limit of 4×10^4 years was obtained for the partial half-life of this decay mode. This value is about 25 times shorter than the estimated half-life of ^{54}Mn in cosmic rays and thus consistent with β^- as the dominant channel for this decay.

Two different experiments to measure the β^- decay rate of ^{54}Mn are now in progress. The first is a direct β^- detection experiment similar to the β^+ search described above. The silicon detector telescope used in the β^+ search is replaced with a plastic scintillator-CsI phoswich detector positioned on one side of the ^{54}Mn source with a NaI detector on the opposite side of the source. Again, this entire assembly is placed inside the annular NaI detector. In this experiment, the β^- particles of interest stop in the thin plastic scintillator, while γ rays pass through and are detected in the CsI and/or NaI detectors. A single photomultiplier tube views both the plastic scintillator and the CsI detector. The timing characteristics of the output signals are used to distinguish events originating in the plastic from those originating in the CsI. Thus, a β^- decay produces a signal in the plastic scintillator and no signal in the CsI or in any of the NaI detectors. The second approach is an attempt to measure the rate of ingrowth of ^{54}Fe atoms produced as a result of the β^- decay of ^{54}Mn. This would be accomplished by allowing a ^{54}Mn sample to sit for some time, after which any iron present in the sample would be chemically extracted. A measurement of the ^{54}Fe content of this iron fraction via neutron activation analysis would then provide the desired ^{54}Mn β^- decay rate.

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