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Cosmic Ray Half Life of ^{56}Ni

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Abstract

A search for the β^+ decay of ^{56}Ni has established an upper limit on the branching ratio of 7.2×10^{-7} for the most likely such transition. This provides a lower limit of 2.3×10^4 years for the cosmic ray half life of ^{56}Ni.

Introduction A major product of charged-particle induced nucleosynthesis in stars is the doubly magic nucleus ^{56}Ni. In the laboratory, ^{56}Ni decays via an allowed electron capture transition to the 1720-keV level in ^{56}Co. Soon after the supernova that produces the ^{56}Ni takes place, temperatures are low enough that neutral atoms can exist. Thus, ^{56}Ni would decay with its laboratory half life of 6.1 days. However, supernovae may be sites of cosmic ray production and acceleration. If ^{56}Ni produced in such explosions were accelerated to high energies, it 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 by forbidden positron transitions to the three lowest energy levels of ^{56}Co (Browne and Firestone 1986). Thus, the cosmic ray lifetime of ^{56}Ni would be determined by its β^+ decay half life . Future observations of ^{56}Ni in the cosmic rays could be used to determine the time interval between nucleosynthesis and cosmic-ray acceleration if this half life were known (Cassé 1973).

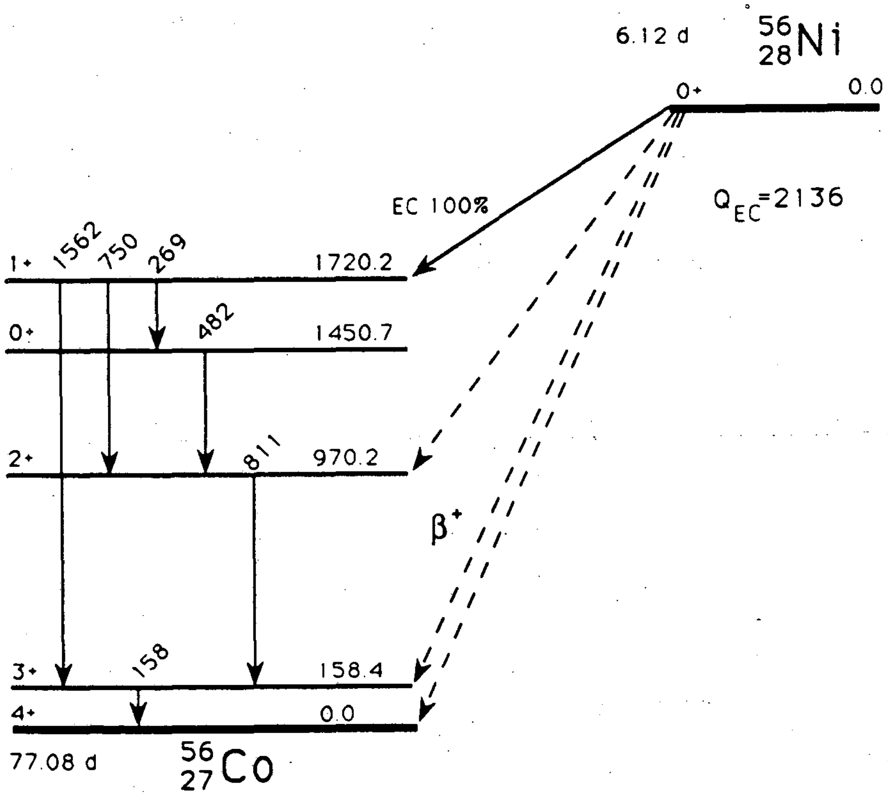

Figure 1. Decay scheme of ^{56}Ni.

Experiment Because of the excitation energies, spins, and parities of the possible final states in ^{56}Co, it has been suggested that the most likely β^+ decay transition of ^{56}Ni would be to the $J^\pi = 3^+$, 158-keV first excited state of ^{56}Co (Cassé 1973, Wilson 1978). We have searched for this β^+ decay branch of ^{56}Ni in the laboratory by attempting to measure the energy spectrum of the emitted positrons in coincidence with the deexcitation gamma rays from the resulting ^{56}Co nucleus and the back-to-back 511-keV γ rays from the annihilation of the positron. A schematic view of the experimental apparatus is shown in Figure 2.

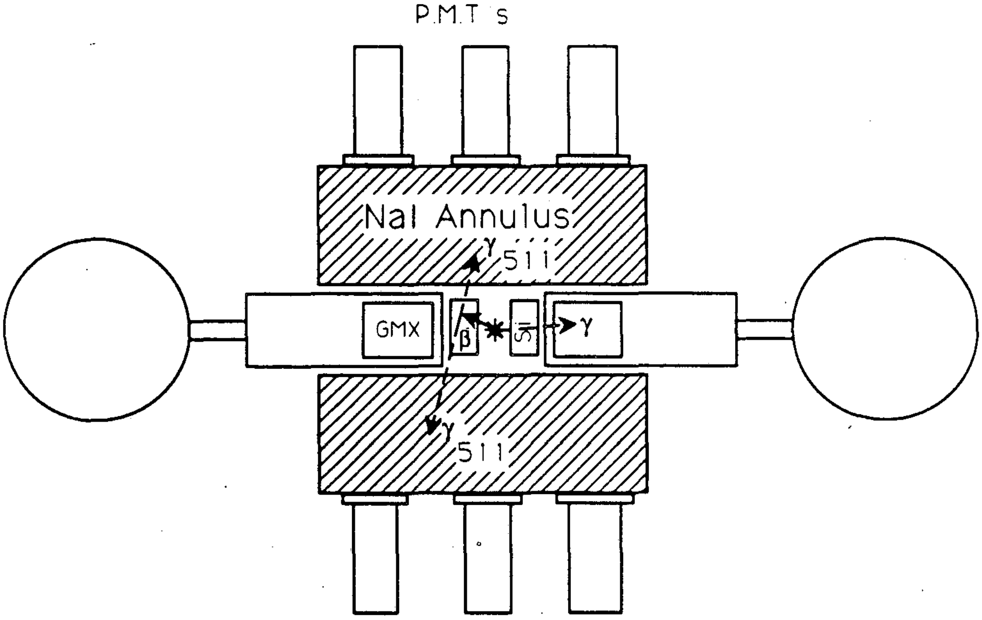

Figure 2. Schematic view of the apparatus used to search for the β^+ decay of ^{56}Ni.

We produced ^{56}Ni by bombarding a stack of several metallic iron foils with a beam of 50-MeV ^{3}He ions from LBL's 88-Inch Cyclotron. After allowing the targets to cool for approximately 10 days, the nickel activity was chemically separated form the targets. The resulting 1.2 μCi ^{56}Ni source was sandwiched between two thin polyethylene foils for counting. The source was positioned between two silicon surface barrier detectors that were placed between two germanium γ-ray detectors as shown in Fig. 2. The ^{56}Ni source and all of these detectctors were located inside an annular NaI detector that is optically divided into two halves. The signature of the β^+ decay to the 158-keV level in ^{56}Co would be an event in one of the silicon detectors in coincidence with a 158-keV γ ray in one of the germanium detectors and with a 511-keV γ ray in each half of the NaI annulus. A fourfold coincidence between either one of the silicon detectors and either one of the germanium detectors and both halves of the annular NaI detector was required in the electronic hardware trigger. For each such trigger, the energy signals in all six detectors were recorded. The efficiency of the apparatus for detecting positrons by this method was determined by observing positrons from the decay of ^{57}Ni, produced along with the ^{56}Ni in our source, and by using a calibrated ^{22}Na source mounted in the same geometry as the ^{56}Ni source.

Results and Discussion The six parameter event-by-event data was sorted with a variety of software gates. The candidate positron spectrum was extracted by projecting out the energy spectrum of each of the silicon detectors in coincidence with a 158-keV γ ray in one of the germanium detectors and with a 511-keV γ ray in each half of the annular NaI detector.

Background spectra were extracted by placing gates on the germanium detector spectra above and below the 158-keV peak.

The normal electron capture decay of ^{56}Ni produces 1720 keV of electromagnetic energy. Our gating condition demanded that a total of 158+511+511 = 1180 keV appear in our germanium and NaI detectors. Thus, the silicon detector spectra are contaminated with Compton-scattered γ rays and internal conversion electrons up to 1720-1180 = 540 keV. Due to the relatively poor energy resolution of the annular NaI detector, this restricted our use of the silicon detector spectra to the region above 635 keV. During a total running time of 6 days, the number of events satisfying the above criteria was 18±14.5. Thus, the 1σ upper limit set on the number of ^{56}Ni positrons observed between 635 and 955 keV was 32.5. Using the experimentally determined efficiency of 4.8×10^{-3} for detecting positrons in this way, we establish an upper limit on the branching ratio of 7.2×10^{-7} for this decay. This provides a lower limit of 2.3×10^{4} years on the cosmic ray half life of ^{56}Ni.

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