Branching ratio in the electron-capture decay of ^{7}Be

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(Received 25 March 1983)

The branching ratio for the electron-capture decay of ^{7}Be to the 478 keV state in ^{7}Li has been measured. ^{7}Be nuclei recoiling near zero degrees from the ^{1}H(^{7}Li,^{7}Be)n reaction were counted by and implanted into a Si detector placed in the focal plane of an Enge split-pole spectrograph. After determining the total number of implanted ^{7}Be nuclei from the pulse height spectrum, the absolute number of 478 keV γ rays was measured with a Ge(Li) detector. The resulting branching ratio of 10.61 ± 0.23 % agrees well with previous measurements.

[RADIOACTIVITY ^{7}Be; measured I_γ, deduced branching ratio to 478-keV first-excited state of ^{7}Li.]

I. INTRODUCTION

The electron-capture decay of ^{7}Be ($t_{1/2}=53.3$ d) populates both the ground and first excited states of ^{7}Li. Knowledge of the branching ratio to the 477.6 keV first excited state is important, because it is through the observation of the resulting 477.6 keV γ ray that the decay of ^{7}Be is most readily detected. A large number of nuclear cross-section measurements involving ^{7}Be production rely heavily on an accurate value for the decay branching ratio. In particular, several astrophysically related experiments have recently used ^{7}Be counting to obtain absolute cross sections. These are the studies of the ^{3}He(α,γ)^{7}Be (Refs. 1 and 2) and ^{7}Be(p,γ)^{8}B (Ref. 3) reactions, both important in the solar neutrino problem.

The currently accepted value for the ^{7}Be decay branching ratio is 10.37 ± 0.12 %.[4] This value is based on measurements published since about 1962, reporting branching ratios in the neighborhood of 10.4% with a satisfying trend to both internal consistency and generally increasing precision. It should be pointed out that nearly all of the measurements in this data set used rather indirect methods for inferring the number of ^{7}Be nuclei in the sample. The methods include absolute neutron counting following the ^{7}Li(p,n)^{7}Be reaction, or detection of the low-energy Auger electrons emitted following the ^{7}Be decay.

Recently, a measurement of the ^{7}Be decay branching ratio was performed by Rolfs *et al.*[5] They implanted ^{7}Be nuclei into Si surface barrier detectors using the ^{10}B(p,α)^{7}Be reaction, and the ^{7}Be dose was obtained directly from the pulse height spectra in the detectors. The 477.6 keV γ-ray yield was then measured using a Ge(Li) detector. Their resulting ^{7}Be decay branching ratio of 15.4 ± 0.8 % is in strong disagreement with previous work. In view of the large effect that a 50% change in the branching ratio would have on the results of the ^{3}He(α,γ)^{7}Be and ^{7}Be(p,γ)^{8}B experiments, we decided to independently measure the branching ratio using a similar method of implantation into a Si detector followed by absolute γ counting with a Ge(Li) detector.

II. EXPERIMENTAL METHOD

A. ^{7}Be implantation

In order to reduce the background in the Si detector due to scattered beam and other reaction products, an Enge split-pole spectrograph was used in the present experiment to separate the ^{7}Be nuclei from contaminant products with differing charge-to-mass ratios.

The ^{1}H(^{7}Li,^{7}Be)n reaction at 15.5 MeV was used to produce ^{7}Be recoils with an energy of 13 MeV at a laboratory angle of 1.6°. At this bombarding energy all of the ^{7}Be ejectiles are contained within a forward cone with a half angle of 3°. A beam of $\sim$45 nA of ^{7}Li^{3+} obtained from the Argonne National Laboratory FN Tandem accelerator bombarded a target consisting of 50 μg/cm^2 of LiH evaporated onto a 20 μg/cm^2 carbon foil. The spectrograph aperture was opened to subtend a solid angle of 2 msr, which meant that ^{7}Be emission angles between 0.17° and 3.03° were accepted.

Preliminary runs taken with a position sensitive gas ionization chamber in the focal plane indicated that the position ($B\rho$) and energy of the ^{7}Be nuclei were well separated from those due to scattered beam particles. Figure 1 shows a total energy versus position plot from this detector. The ^{7}Be ions occupy a region well separated in total energy from the low-energy scattered beam particles. These energy-degraded ^{7}Li ions originate from slit edge scattering, since they possess only a fraction of the beam energy, and they are present even when the target is removed. Under these spectrograph field conditions the

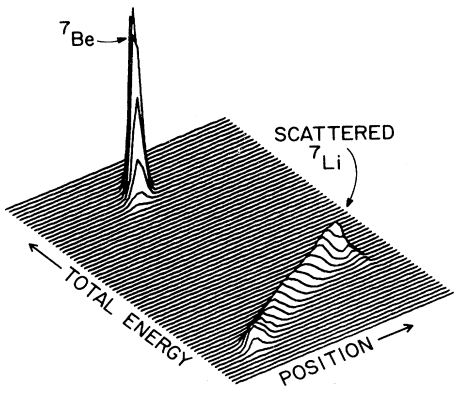

FIG. 1. Total energy versus position measured in focal plane gas ionization chamber, with the Enge split-pole spectrograph at 1.6°. The main reaction product is ^{7}Be from the ^{1}H(^{7}Li,^{7}Be)n reaction.

direct ^{7}Li beam did not strike the detector.

To collect the ^{7}Be nuclei, a 100 mm^2 300 μm Si detector was mounted in the focal plane of the spectrograph, at the position indicated by the results of the measurements with the gas detector. The detector was placed so that particles entered perpendicular to its front surface. At 13 MeV the ^{7}Be particles have a range of approximately 25 μm in Si. A 9.53 mm diam Ta collimator, 0.3 mm thick, was placed in front of the detector. A separate mask of 0.8 mm thick Al was located 20 mm from the Ta collimator, having a 19.1 mm aperture.

To monitor dead time in the data acquisition system, a pulser signal was injected into the detector preamplifier. The pulser was externally triggered at a rate proportional to the beam current by signals from another Si detector placed in the spectrograph target chamber as a monitor. No beam current integration was possible with the spectrograph at 1.6°, since the Faraday cup would have intercepted ^{7}Be particles had it been inserted behind the target.

Figure 2 shows an energy spectrum in the Si detector from a typical run of 40 min duration. About 2.8×10^6 counts are contained in the ^{7}Be peak, with the background near the peak constituting less than 0.1% of its yield. The data rate during the experiment was in the vicinity of 1400 counts/sec, of which 1200 counts/sec were due to ^{7}Be. Dead time in the data acquisition system was typically 10%. The total bombardment lasted 27 h, and produced nearly 9×10^7 ^{7}Be particles in the detector.

B. Gamma-ray counting

Following the ^{7}Be implantation, the Si detector containing the implanted ^{7}Be particles was accurately positioned on the axis of a 10% relative efficiency Ge(Li) detector, at a source distance of approximately 0.3 cm. A low background count rate was obtained by placing the entire Ge(Li) detector inside a steel enclosure whose walls were 15 cm thick. A Ge(Li) energy spectrum was accumulated over a period of 114 h, with intermediate readouts every 6 h. The Si detector was then placed at a source distance of about 2.3 cm, and a second spectrum was accumulated for 162 h. Figure 3 shows the relevant portion of the second spectrum.

Following these measurements, a mixed radionuclide γ-ray standard source[6] was used to determine the 477.6 keV full-energy peak efficiency of the Ge(Li) detector at each of the two counting locations. Studies were also made of the detector efficiency variation with axial and radial displacements of the standard source, in order to take into account the distribution of the ^{7}Be particles across the Si detector area and to determine the effects of small uncertainties in positioning. All measurements with the Ge(Li) detector utilized an injected pulser signal for dead time correction. Only γ rays at 279 (^{203}Hg), 392 (^{113}Sn), 514 (^{85}Sr), and 662 keV (^{137}Cs) were used to obtain the Ge(Li) detector efficiency curve. None of these transitions involve a coincidence, and so no summing corrections were needed. The resulting efficiencies were fit to curves of the form AE_γ^{-B}, in order to obtain the Ge(Li) efficiency at 477.6 keV. The maximum dead time correction for the efficiency runs was 14%.

III. RESULTS

To determine the number of ^{7}Be particles implanted in the Si detector, each of about 40 runs was analyzed to obtain the dead time corrected yield in the ^{7}Be peak. After making a small correction for decay during production, the total number of implanted ^{7}Be particles present at the beginning of the first γ-counting run was 8.904×10^7. For the second run, this number was appropriately corrected for decay. A part of the detector mount about the same size as the Si detector but shielded from the direct ^{7}Be flux in the spectrograph was assayed for 477.6 keV γ rays; less than 0.1% of the implanted number was observed, indicating negligible contamination by a conceivably volatile ^{7}Be component in the spectrograph.

The yield of 477.6 keV γ rays in the full-energy peaks from the two runs was 19 750±154 and 8493±107, respec-

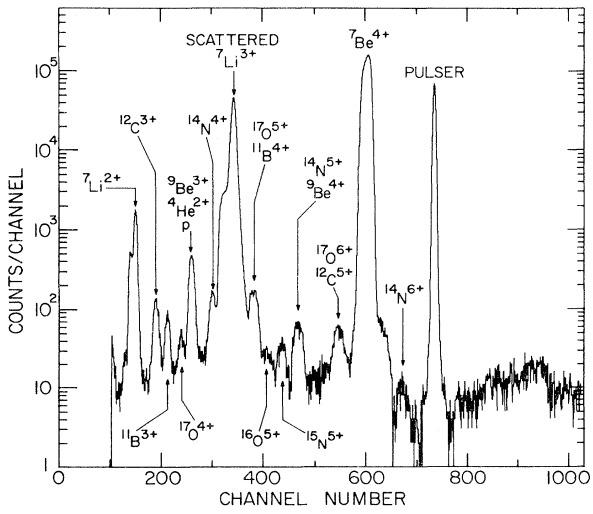

FIG. 2. Energy spectrum in the Si detector mounted in the focal plane of the Enge split-pole spectrograph. The double peak marked "^{7}Li^{3+}" is due to slit-edge scattered beam particles. Other identified peaks are due to ^{7}Li-induced reactions on ^{7}Li and ^{12}C.

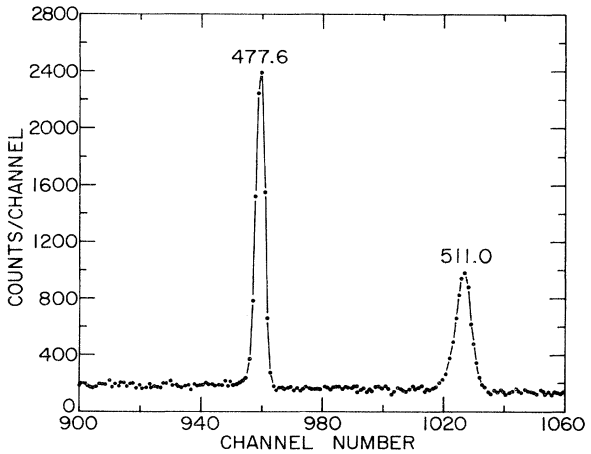

FIG. 3. Portion of the 162-h Ge(Li) energy spectrum taken at a source distance of 2.3 cm.

TABLE I. Error analysis and results.

Source distance	0.3 cm	2.3 cm
Uncertainties not common to both measurements		
(a) Ge(Li) efficiency at 477.6 keV (includes geometrical effects and fitting uncertainties)	2.2%	1.6%
(b) γ-counting statistics	0.8%	1.3%
(c) Ge(Li) efficiency dead time correction	1.4%	0.4%
	2.7%	2.1%
Branching ratio	10.80±0.29 %	10.51±0.22 %
Weighted mean	10.61±0.18 %	
Uncertainties common to both measurements		
(a) Standard source strengths	1.0%	
(b) Areal distribution of ^{7}Be in detector	0.2%	
(c) ^{7}Be implantation dead time correction	1.0%	
	1.4%	
Final result	10.61±0.23 %	

tively. A branching ratio (BR) was obtained from each run, using the formula

$$\mathrm{BR}=\frac{Y_\gamma}{\epsilon_\gamma N_0[1-\exp(-\lambda T)]},$$

where Y_γ is the γ-ray yield, ϵ_γ is the full-energy peak efficiency, N_0 is the number of ^{7}Be nuclei present in the Si detector at the beginning of each run, λ is the ^{7}Be decay constant, and T is the length of the γ-counting period. The efficiencies ϵ_γ were 0.0343 and 0.0115, respectively, for the two source positions.

In combining the two γ-counting runs to obtain an average branching ratio, both common systematic errors and errors differing for the two measurements must be considered. First, a weighted mean of the two branching ratios was calculated, using as weights the sum in quadrature of the uncertainties of the latter type. The error in this mean value was then combined in quadrature with the remaining 1.4% systematic uncertainty to obtain the final uncertainty. Table I shows the error analysis, which leads to a final branching ratio of 10.61±0.23 %.

The result of the present experiment agrees well with the currently accepted value[4] for the ^{7}Be decay branching ratio, and is in strong disagreement with the value of 15.4±0.8 % obtained by Rolfs *et al.*[5]

ACKNOWLEDGMENTS

The authors wish to thank D. F. Geesaman for a careful reading of the manuscript, and G. E. Thomas for the target fabrication. This work was supported by the U.S. Department of Energy under Contract W-109-Eng-38.

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