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THE MOST ACCURATE DETERMINATION OF THE ^{8}B HALF-LIFE*

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Beta decay is a primary source of information of the structure of a nucleus. An accurate measurement of the half-life of a nucleus is essential for the proper determination of the reduced Gammow–Teller transition probability B(GT). In this work, we present an experiment using a compact set-up of Si-telescope detectors to measure the half-life of the ^{8}B nucleus. Three independent measurements have been analysed, obtaining the values 771.9(17) ms, 773.9(18) ms, and 770.9(27) ms. The value of the half-life obtained as the weighted averaged with the previous published measures is 771.17(94) ms which is a factor 3.2 of improvement in the uncertainty of the half-life.

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1. Introduction

The ^{8}B nucleus is of strong interest for astrophysics as it is the main source of solar neutrinos with energies above 2 MeV. However, there is much

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to be understood both about its decay and the nuclear structure of the daughter ^{8}Be. For example, we are interested in the β^{+}-feeding of the 2^{+} doublet at 16.626(3) MeV and 16.922(3) MeV states in ^{8}Be (see Fig. 1) which are strongly isospin mixed [1] as the two states should have dominant configuration as $^{7}\mathrm{Li} + p$ and $^{7}\mathrm{Be} + n$, respectively.

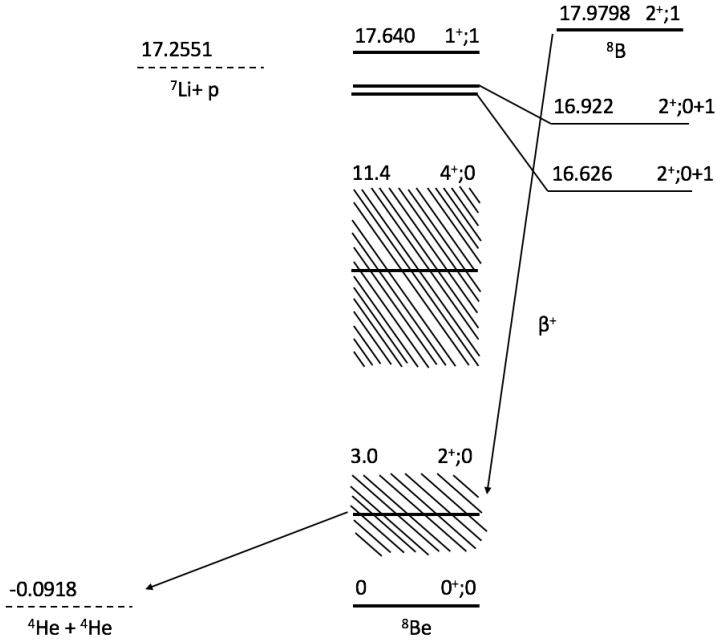

Fig. 1. Level scheme of ^{8}B decay into ^{8}Be. On the 2^{+} doublet at 16 MeV, the $0+1$ in the isospin component indicates the isospin mixing of the two states.

The two states of interest are close to the endpoint of the β^{+}-decay phase space, which is determined by a Q_{β} of 16.958 MeV. The 16.626 MeV state is only 332 keV below the Q_{β} and the 16.922 MeV state is 34 keV below the Q_{β}. It is necessary to also include the electron capture (EC) phase space to resolve the decay ratio. Including both decay-modes and assuming fully isospin mixed states, the decay ratio is [2]

$$\frac{R_{\beta+\mathrm{EC}}(16.922)}{R_{\beta+\mathrm{EC}}(16.626)} = \frac{f_{\mathrm{EC}}(16.922) + f_{\beta}(16.922)}{f_{\mathrm{EC}}(16.626) + f_{\beta}(16.626)} = 2.4 \times 10^{-2}\,. \qquad (1)$$

The 16.922 MeV state has only been seen once before in a decay experiment that was performed at IGISOL [2] by our collaboration, where only 5 counts were observed in the corresponding relevant energy region.

A measurement of the half-life provides one of the observable needed for the determination of the nuclear structure, including the B(GT) of the states populated in the β^{+}/EC-decay. In order to determine the isospin mixing of the doublet, an R-matrix analysis will provide the description of the resonances of the ^{8}B decay in terms of the B(GT). To perform this analysis, a high-precision measurement of the half-life is mandatory. The previous literature value, prior to this work, for the half-life of ^{8}B was 770(3) ms as found in Ref. [3]. However, these measurements date back to the 70s and one would expect that with present-day techniques, an improvement in the precision can be obtained. We have performed an experiment using a compact detection system to improve both the statistics and the time-measurement to determine this half-life.

2. Experimental set-up

The set-up used was a "diamond" configuration of four Si-telescopes (see Fig. 2). The telescopes were composed of a thin ΔE–Double-sided Silicon Stripped Detector (DSSD) with 16 strips each side backed by a thicker Si-detector. The detectors were fixed into a 3D-printed plastic structure to avoid any movement during the experiment and facilitate the reproducibility of the geometrical conditions of the experiment during the use of external al-

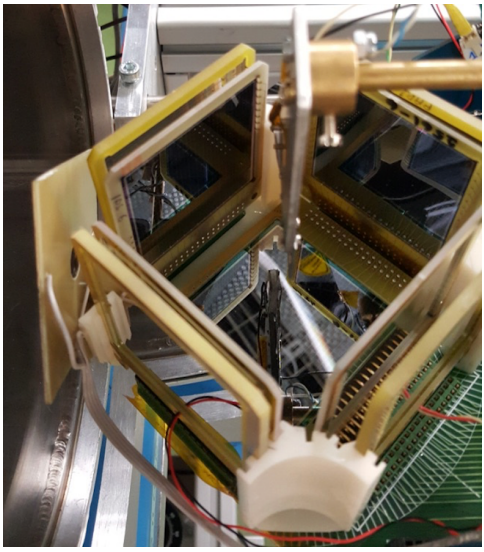

Fig. 2. Configuration of the ΔE–E telescopes around the collection point in the vacuum chamber installed at IDS@ISOLDE. The C-foil is hanging from the upper arm shown on the right-hand side. In the picture, the ^{8}B beam comes from the left.

pha sources for calibration. The 3D-plastic support was fixed onto a printed circuit board, where the detectors were directly connected. An additional DSSD was placed on the bottom. Its thickness was of 1000 μm and used mainly as a β detector. Figure 2 shows a photo of the set-up with the detectors surrounding the carbon-catcher foil (C-foil of 31 μg/cm^2), where the ^{8}B beam was implanted perpendicular to the foil.

Two different front detector thicknesses were used in the telescopes; the thicker ΔE–DSSD of 60 μm assured the full detection of the highest energy α emitted in the break up of the ^{8}Be. The thinner ΔE–DSSD of 40 μm were placed to search for the delayed proton emission as in this case a low β^+-response background is mandatory. For the E-detectors of the telescope, the thicknesses were 1000 μm and 1500 μm, respectively. The efficiency of the set-up was calculated using a Geant4 simulation and for a 3 MeV decay is approximately 38% of 4π. Figure 3 shows a scheme of the detectors with the distances labelled as in the experiment. The distances are in cm and the dark grey/red arrow is the incoming beam.

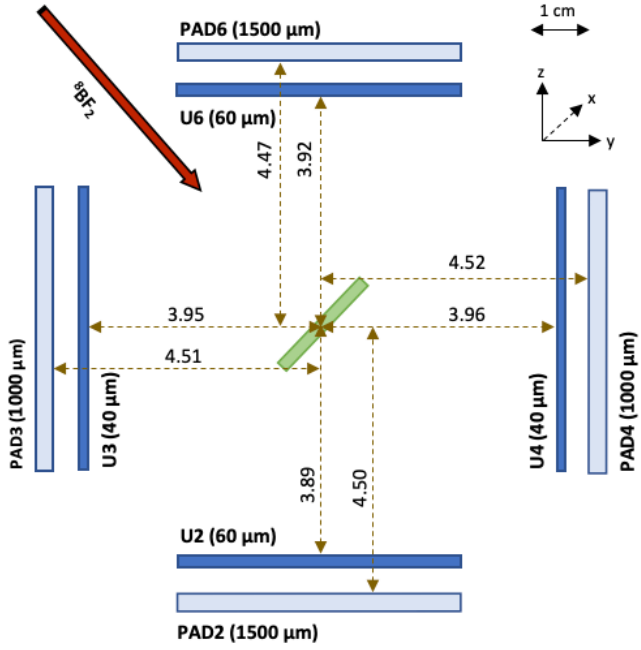

Fig. 3. (Colour on-line) Scheme of the set-up where the distances and thickness of the detectors are shown for IS633 experiment. The dark grey/red thick arrow is the incoming $^8BF_2$ beam. All the distances are in cm and defined by the plastic structure where the set-up was assembled.

3. Methodology and results

Recently, a ^{8}B beam has become available at ISOLDE in the form of $^8BF_2$ with a yield of 25.000 counts/s measured in our chamber. This high rate was mandatory to have sufficient statistics to resolve the isospin mixing but it produced a considerable dead time of up to 40% in our acquisition system. In order to decrease the dead time and maximise the statistics in the region of interest, the electronic thresholds were increased up to 2.5 MeV in order not to trigger on the main decay of the ^{8}B nucleus to the 3.03 MeV state of ^{8}Be.

The decay of ^{8}B is correlated in time with the proton pulses arriving at the ISOLDE target unit. The PS-Booster was running with 36 proton pulses per cycle of 43.2 s, being the interval between pulses 1.2 s. For the experiment, seven equidistant pulses of the 36 were selected so the time between each pulse is higher than 7 times the half-life. With the proton request condition, the reduced proton current on target (1.6 μA) and the electronic thresholds set to 2.5 MeV, the dead time of our system calculated with the accepted triggers was 4.48(8)%.

In order to obtain an accurate result and improve the uncertainty, the data is corrected for dead time. Since the dead time will decrease with the activity of the nucleus, the correction has been done bin per bin to correct the count loss due to this effect. The correction applied follows Eq. (2), where λ is the published decay constant derived from the ^{8}B half-life and τ is the time after the implantation. DT_0 is the maximum dead time of our system, happening at the beginning of each implantation, namely 4.48% under the constrains explained above. Equation (3) is the correction applied to the amount of α–α coincidences considered for the half-life measurement in each bin

$$\mathrm{DT} = \mathrm{DT}_0\, \mathrm{e}^{-\lambda\tau}\,, \tag{2}$$

$$N_{\mathrm{corrected}} = N_{\mathrm{meas}}(1 + \mathrm{DT})\,. \tag{3}$$

From our experiment, three uncorrelated measures of the half-life can be obtained as due to the configuration and the characteristics of the ^{8}B decay, the two αs are emitted at 180°.

From the 4 DSSD, two α–α-coincidence spectra can be analysed. The coincidence conditions are geometrical and energetic. The geometrical conditions are that both αs have to be detected in opposite detectors at 180(4)° and emitted from the implantation point that was defined as an extended circle of 5 mm radii in the center of the C-foil. The implantation point has in consideration the uncertainty on the break up direction of the α due to the recoil effect as well as the dimension of our pixels of 3×3 mm^2. The cut in energy is more restrictive, since the difference between the energies

of the two αs must be lower than 200 keV (which is a good assumption for single α energies above 3 MeV) and, in order to avoid possible effects of the high thresholds or punched through of the most energetic α on the 40 μm detectors, the energy range of the coincidence is fixed from 7 MeV to 14 MeV. This range ensures that no β will be considered as the maximum energy that a β will deposit on the DSSD is less than 200 keV.

Moreover, from the bottom detector of 1000 μm, both α and β particles are detected and gating above the β-contribution, an independent single-α spectrum is obtained. The energy range considered in this case is above 4 MeV.

The time spectra were produced with the coincidence conditions and energy restrictions explained above. Figure 4 shows the time spectrum corrected by dead-time of the α–α coincidence spectrum of the 60 μm DSSD (in grey/blue) and the fit to an exponential decay function to extract the half-life (in black/red). The relative residuals of the fitted region are presented. The extra counts above 6 s correspond to some cycles where instead of seven, eight pulses have been delivered. These events are not considered in the analysis.

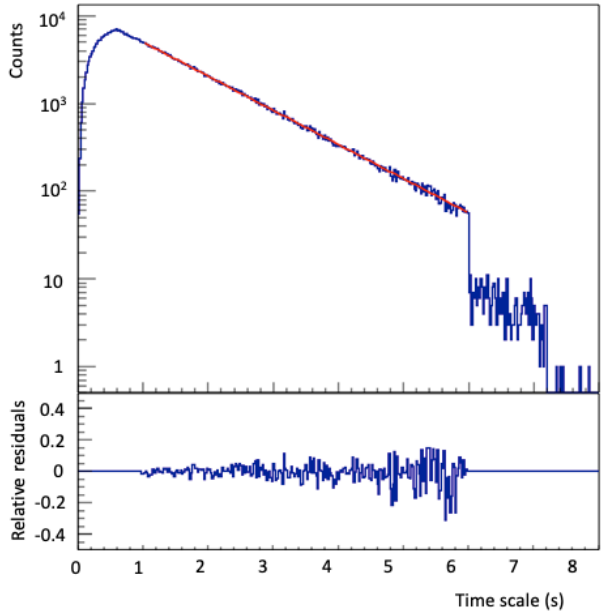

Fig. 4. (Colour on-line) Upper panel: Time spectrum of the α–α coincidence in the 60 μm detectors using the upper energy range from 7 MeV to 14 MeV (grey/blue histogram) and an exponential decay fit to the data (black/red line). Lower panel: Relative residuals to the experimental data in the fitted region. The binning of both histograms is 20 μs.

Even though our DT_0 was 4.48% right at the implantation time, we have started our fit to obtain the half-life 0.6 s after the implantation, when the dead time is only 1%; 3 seconds later, it drops to 0.1%.

For the three measurements, the results obtained with the fit are:

— From α–α coincidence in the 60 μm DSSD: $T_{1/2}$ = 771.9(17) ms (χ^2/d.o.f. = 1.10),

— From α–α coincidence in the 40 μm DSSD: $T_{1/2}$ = 773.9(18) ms (χ^2/d.o.f. = 1.19),

— From α in the 1000 μm DSSD: $T_{1/2}$ = 770.9(27) ms (χ^2/d.o.f. = 1.15).

The weighted average of the three values is 772.2(10) ms and the weighted averaged with the prior value from [3] is 771.17(94) ms, reducing the uncertainty of the half-life by a factor 3.2.

4. Summary

An experiment to measure the feeding to the high excited states of the ^{8}Be nucleus populated by β^+/EC-decay from ^{8}B was performed in 2017 at ISOLDE. As a part of the main purpose of the experiment, a measurement of the half-life of the ^{8}B nucleus was done in order to improve the last published value (770(3) ms). Three uncorrelated measurements are presented and analysed in this paper. Each time spectrum is obtained under certain conditions: two of them are from the α–α coincidence at 180° in opposite detectors in an energy range between 7 and 14 MeV. The third time spectrum is from the αs measured in the bottom DSSD gating above the β-contribution. Each time spectrum has been corrected by the acquisition dead time bin per bin using an exponential form for the dead time.

The result of the half-life obtained from our experiment weighted average with the adopted value in the literature is 771.17(94) ms, reducing the uncertainty by a factor of 3.2.

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