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Improved experimental determination of the branching ratio for β-delayed α decay of ^{16}N

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Abstract. We report on the preliminary results of an experimental study of the β decay of ^{16}N, aiming to determine the branching ratio of the $\beta\alpha$ channel with a precision of $\leq 5\%$.

1 Introduction

During hydrostatic helium burning carbon is converted to oxygen via the reaction ^{12}C$(\alpha,\gamma)^{16}$O. The temperature at which this takes place is $T \sim 10^8$ K, implying that reactions preferentially occur close to a center-of-mass energy of $E_{\rm cm} \sim 0.3$ MeV. At such low energies the cross section is too small to be measured directly in laboratory experiments and must be determined by extrapolating the data obtained at higher energies ($E_{\rm cm} \gtrsim 1.0$ MeV). Typically, R-matrix theory [1] is used to parametrize the, a priori unknown, energy dependence of the cross section in terms of the properties of the levels in ^{16}O that are involved in the reaction. Since the same levels can be observed in other reactions many of the relevant parameters can be accurately determined or at least constrained by indirect techniques. Following this approach the cross section at 0.3 MeV has been determined with an estimated precision of $\sim 20\%$ while a precision of at least $\sim 10\%$ is desired [2]. Among the indirect techniques used the β-delayed α decay of ^{16}N, shown in Fig. 1, has proven useful to determine how strongly the 7.12 MeV level in ^{16}O couples to the $\alpha + {}^{12}$C channel, and hence constrain the level's significant contribution ($\sim 54\%$) to the capture cross section at 0.3 MeV. This requires precise measurements of the branching ratio to the 7.12 MeV level, the branching ratio for α emission, and the shape of the α spectrum. Here, we bring the preliminary results of a new experimental study of the β decay of ^{16}N recently performed at the ISOLDE facility [3] with the aim of obtaining precise values for the branching ratios.

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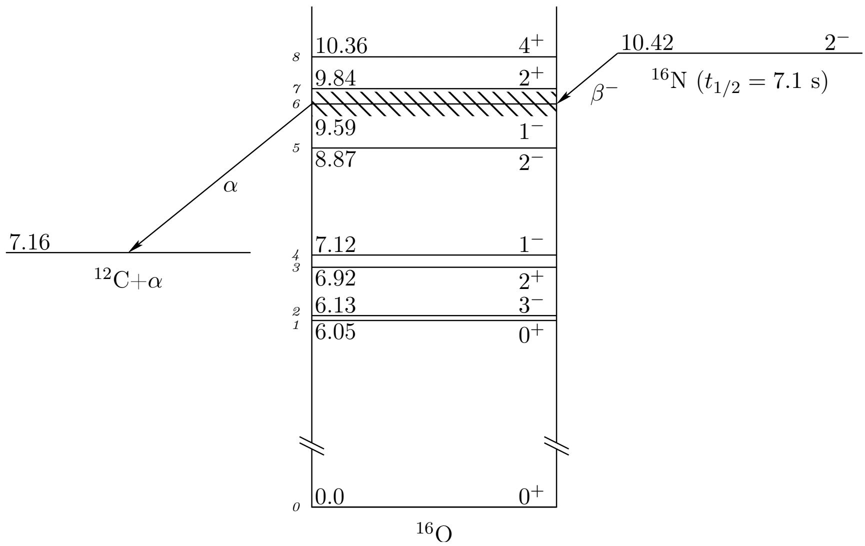

Figure 1. ^{16}N decay scheme [4]. Energies are in MeV relative to the ^{16}O ground state. The levels in the ^{16}O are indexed 0–8. The main decay branches go to the ground state (28%) and the the 6.13 MeV level (66%) with smaller branches going to the levels at 7.12 MeV (4.8%) and 8.87 MeV (1.1%) while even smaller branches ($< 10^{-3}$) go to the other levels including an α branch of $\sim 10^{-5}$ indicated by the two arrows.

2 Existing knowledge about the β decay of ^{16}N

We proceed by giving a brief review of the existing empirical knowledge about the β decay of ^{16}N [4]. The main decay branches go to the ground state (28%) and the the 3^- level at 6.13 MeV (66%) with smaller branches going to the 1^- level at 7.12 MeV (4.8%) and the 2^- level at 8.87 MeV (1.1%) while even smaller branches ($< 10^{-3}$) go to the other levels, including a β-delayed α-decay branch of $\sim 10^{-5}$ to the ground state of ^{12}C. It is remarkable that much of the existing data on the β decay of ^{16}N stems from γ-ray studies performed in the 1950s and 1960s using NaI detectors with poor energy resolution. For example, the branching ratio to the 7.12 MeV level is known with a precision of $\sim$ 8% based on three independent measurements of the intensity ratio of the 6.13 and 7.12 MeV γ-rays performed in the 1950s [5–7]. With modern HPGe detectors it should be possible to obtain significantly improved values, not only for the branching ratio to the 7.12 MeV level, but also for the branching ratios to some of the other levels.[1] On the other hand, the ratio of the two main branches, which account for 94% of the total intensity, has been determined very precisely ($\sim$ 1%) by careful measurements of the shape of the β spectrum.

The α-decay branching ratio was first determined to have a value of $1.20(5) \times 10^{-5}$ by Kaufmann *et al.* [9]. More recently, Zhao *et al.* have obtained the value $1.3(3) \times 10^{-5}$ [10], while Refsgaard *et al.* find $1.49(5) \times 10^{-5}$ with a possible systematic uncertainty of -0.10×10^{-5} [11]. There is evidently a significant discrepancy between the values of Kaufmann *et al.* and Refsgaard *et al.*, while the value of Zhao *et al.* has sufficiently large error bars to be consistent with either of the two other values. A new measurement of α-decay branching ratio is needed to resolve the discrepancy.

[1] Tang *et al.* [8] have recently reported a new value for the braching ratio to the 7.12 MeV level with an uncertainty of 4%, but the details of the measurement have not yet been made available.

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3 New experiment and preliminary results

In order to close some of the gaps in our knowledge about the β decay of ^{16}N, we have studied the decay at ISOLDE [3]. In this study, performed in May 2016, a 30 keV beam of ^{14}N^{16}N^{+} molecular ions was delivered to the ISOLDE Decay Station (IDS) [12] at an average rate of $\sim 2 \times 10^4$ s^{-1} for a total of 32 hours. The ions were stopped in a thin (30 μg/cm^2) carbon foil surrounded by five double-sided silicon strip detectors (DSSD) and four high-purity germanium (HPGe) clovers, allowing for the simultaneous detection of charged particles and γ rays, while auxiliary detectors were used to check that the beam was being fully transmitted to the center of the setup and fully stopped in the foil. Three of the DSSDs were sufficiently thin (40–60 μm) to allow the α spectrum to be clearly separated from the β background, as shown in Fig. 2. The other two DSSDs were much thicker (300 μm and 1 mm)

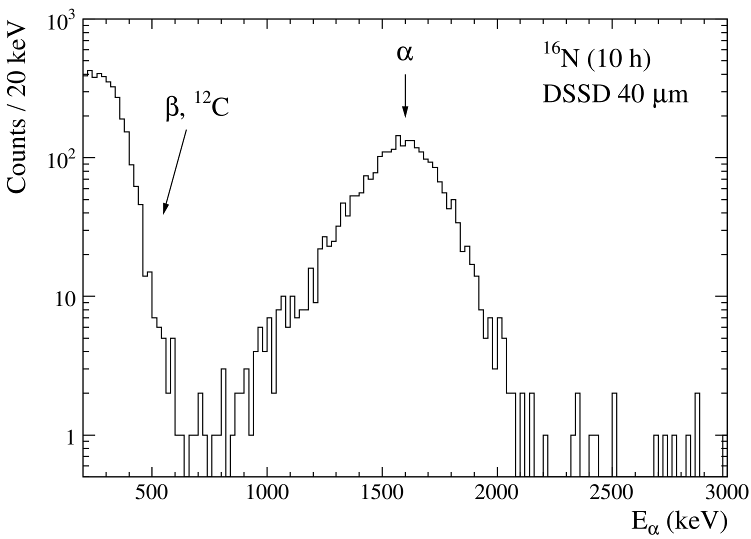

Figure 2. Energy spectrum measured in the 40-μm thick DSSD. The α particles emitted in the decay of ^{16}N have energies between 0.8 MeV and 2.2 MeV and are seen to be well separated from the β particles and the ^{12}C recoils. The data shown here represents 1/3 of the total acquired data. The remaining data have yet to be analyzed.

and served primarily to detect the β particles. The γ-ray spectrum measured in the HPGe clovers (Fig. 3) contains several γ-rays from the decay of ^{16}N with no evidence of other radioactive isotopes. In order to convert the observed γ-ray yields to intensity ratios it is necessary to correct for the energy dependent detection efficiency of the HPGe array. An absolutely calibrated ^{152}Eu source was used to determine the detection efficiency at low energies ($E_\gamma < 1.5$ MeV), while $\beta\gamma$ and $\gamma\gamma$ coincidences will be used to extend the calibration up to 7 MeV.

4 Summary and outlook

The β decay of ^{16}N has been studied in an experiment at the ISOLDE Decay Station in which both charged particles and γ rays were detected. It is expected that the data will constrain the branching ratio for β-delayed α emission and the branching ratio to the 7.12 MeV level with a precision of 5% or better. The data analysis is nearing completion and the results will soon be published, including an assessment of the impact on the inferred cross section of the ^{12}C$(\alpha, \gamma)^{16}$O reaction at $E_{\rm cm} = 0.3$ MeV.

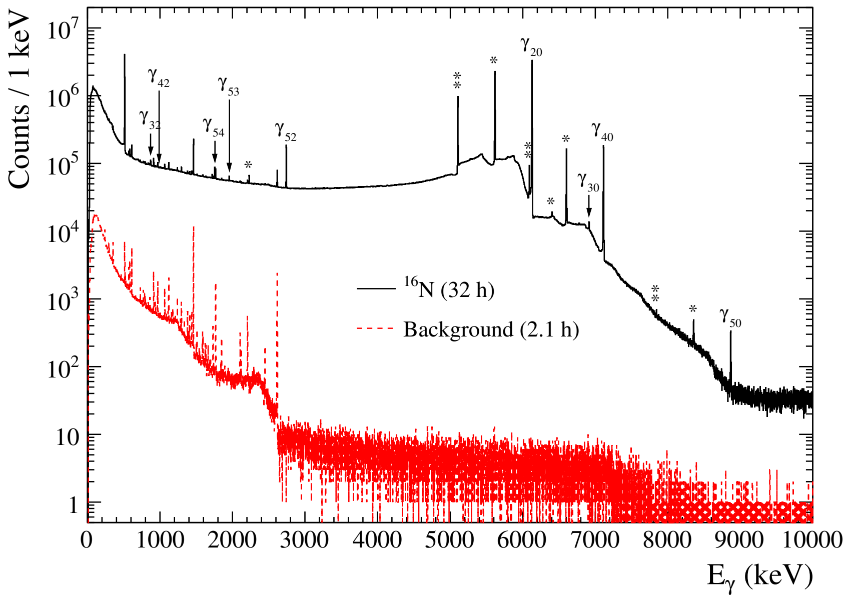

Figure 3. Add-back γ-ray spectrum obtained in the present experiment. ^{16}N: solid (black) line. Background: dashed (red) line. Photopeaks due to transitions $i \rightarrow j$ in ^{16}O are indicated by the symbol γ_{ij} while first- and second-escape peaks are indicated by a single asterisk ($*$) and a double asterisk ($**$), respectively.

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