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Nuclear Physics A 758 (2005) 367c–370c
NUCLEAR PHYSICS A

Measurement of the cross section of $^{12}C(\alpha,\gamma)^{16}O$ using the recoil mass separator ERNA

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The reaction $^{12}C(\alpha,\gamma)^{16}O$ plays a key role in determining the C/O ratio in the stellar core at the end of helium burning, which in turn influences the further evolution and nucleosynthesis. The determination of the cross section at the relevant astrophysical energy $E_{cm} = 0.3$ MeV, which is of the order of 10^{-17} b, requires extrapolation of the S factor determined from data collected with high precision and accuracy at higher energy. A new experimental approach has been undertaken in order to study this reaction for the first time by the direct detection of the ^{16}O nuclides using the recoil mass separator ERNA.

1. Introduction

The reaction $^{12}C(\alpha,\gamma)^{16}O$ ($Q = 7.16$ MeV) takes place during stellar helium burning [1]. The cross section at the relevant Gamow-energy, $E_{cm} = 0.3$ MeV, together with the convection mechanism in the Helium stellar core, determines the abundances of Carbon and Oxygen at the end of Helium burning. This, in turn, influences the nucleosynthesis of elements up to the iron region for massive stars [2] and the composition of C/O White Dwarfs in the case of intermediate mass stars [3].

The existing data [4–10] provide an estimate of the astrophysical S factor, S_{300}, at the relevant energy, but the uncertainty is much too large to provide the precision required by stellar models, which is about 10%. The reason is a weak constraint imposed by the existing data on the 2 sub-threshold resonances, which mostly determine S_{300}. This, in turn, depends on the large uncertainties, both statistical and systematic, affecting the data, arising from the difficulties in extracting the different amplitudes, which need to be extrapolated individually, due to their different energy dependences.

Most of the previous efforts have focused on the observation of the capture γ-rays.

0375-9474/$ – see front matter
doi:10.1016/j.nuclphysa.2005.05.067

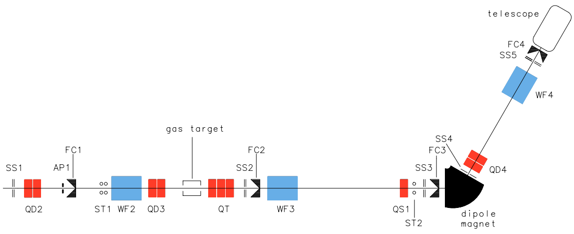

Figure 1. Schematic diagram of the recoil separator ERNA, for details see text.

Due to the low cross section and various backgrounds depending on the exact nature of the experiments, γ-ray data with useful, but still inadequate, precision were limited to center-of-mass energies $0.9 \leq E_{cm} \leq 3.2$ MeV.

To improve the situation, a new experimental approach has been undertaken at the 4 MV Dynamitron tandem accelerator in Bochum, called ERNA = European Recoil separator for Nuclear Astrophysics [11,12]. In this approach, the reaction is initiated in inverse kinematics, ^{4}He(^{12}C,γ)^{16}O, i.e. a ^{12}C ion beam is guided into a windowless ^{4}He gas target and the ^{16}O recoils are counted in a ΔE-E telescope placed in the beam line at the end of the separator. This provides the necessary suppression of the intense ^{12}C projectiles which emerge from the target together with the ^{16}O recoils. ERNA is designed to study the reaction over the energy range $E_{cm} = 1$ to 5.0 MeV. The detection of the ^{16}O recoils allows, for the first time, a measurement of the total cross section of ^{12}C(α, γ)^{16}O. At the same time a coincident measurement of the γ-rays allows identification of the different amplitudes involved in the radiative capture, and the coincidence condition with the recoils provides a suppression by several orders of magnitude of the background in the collected γ-spectra.

2. Experimental equipment and setup

The ERNA setup (Fig. 1) has been described previously [11–13]. Briefly, the ion beam emerging from the tandem is focused by a quadrupole doublet, filtered by a 52° analysing magnet, and guided into the 75° beam line of ERNA by a switching magnet. A quadrupole doublet (QD2) after the switching magnet is used to focus the beam on the gas target. For the purpose of beam purification, there is one Wien filter (WF1) before the analysing magnet and one (WF2) between QD2 and the gas target. The doublesided windowless gas target includes a post-target stripping system. After the gas target, the separator consists sequentially of the following elements: a quadrupole triplet (QT), a Wien filter (WF3), a quadrupole singlet (QS1), a 60° dipole magnet, a quadrupole doublet (QD4), a Wien filter (WF4), and the ΔE-E telescope. Finally, several steerers (ST), Faraday cups (FC), slit systems (SS), and apertures (AP) are installed along the beam line for setting-up and