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The $^{41}Ca(n,\alpha)^{38}Ar$ cross section up to 100 keV neutron energy

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The $^{41}Ca(n,\alpha)^{38}Ar$ reaction cross section has been studied with resonance neutrons at the GELINA neutron facility of the Institute for Reference Materials and Measurements in Geel (Belgium) from a few eV up to 100 keV. A Frisch-gridded ionization chamber with methane as detector gas was installed at a 30 meter long flight path. About 20 resonances have been identified. From the cross section data obtained, the Maxwellian averaged cross section (MACS) as a function of stellar temperature has been calculated by numerical integration.

11th Symposium on Nuclei in the Cosmos - NIC XI
Heidelberg, Germany
July 19–23 2010

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1.Introduction

^{41}Ca is one of the few nuclides for which the (n,α) reaction in the neutron resonance region strongly dominates over the (n,γ) reaction. As a consequence, the Maxwellian averaged cross section (MACS) at stellar temperatures of importance for s-process nucleosynthesis in stars will be larger for the ^{41}Ca(n,α) reaction than for ^{41}Ca(n,γ). This will cause a branching in the nucleosynthesis path. To verify theoretical MACS values (e.g. calculated by Goriely et al. [1] and Rauscher et al. [2]), a high resolution measurement of the ^{41}Ca(n,α) reaction cross section as a function of the neutron energy has been performed.

2.Experimental setup

The ^{41}Ca(n,α)^{38}Ar reaction was studied at the GELINA neutron time-of-flight facility of the IRMM in Geel, Belgium, using a Frisch gridded ionization chamber with methane as detector gas.

For neutron induced charged particle reactions on ^{41}Ca, both (n,p) and (n,α) reactions are possible, as shown in the level scheme (Figure 1). The presence of (n,α_0), (n,α_1), (n,γα) and (n,p) transitions has been clearly demonstrated with thermal neutrons by Wagemans et al. [3]. However, the settings of the ionization chamber were adjusted to detect only the α-particles.

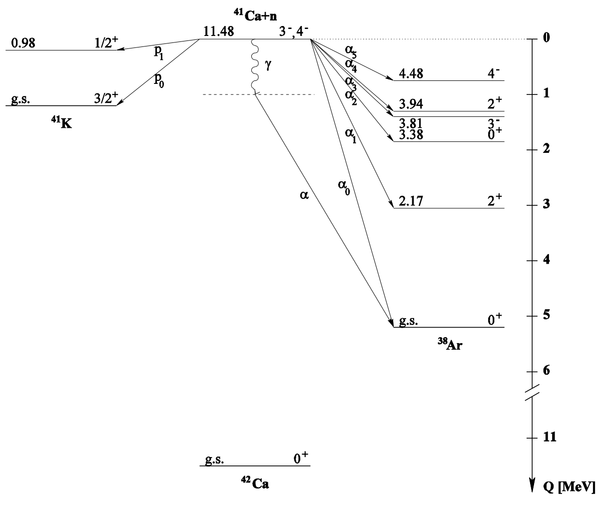

Figure 1: Level scheme for the possible interactions of neutrons with ^{41}Ca. The energies are in MeV.

The ^{41}Ca sample used for the measurements was prepared at the IRMM by suspension spraying of $CaCo_3$ in methanol on an aluminium foil. This resulted in a $^{41}CaCo_3$ sample with 63.38% enrichment [4] containing (4.08 ± 0.40) × 10^{18} ^{41}Ca atoms on a 6 × 5 cm^2 effective area. The number of ^{41}Ca atoms was obtained after a careful new measurement of the 3.6 keV KX-rays emitted by ^{41}Ca after electron conversion, using a dedicated detector [5]. The uncertainty is

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mainly due to the uncertainty on the ^{41}Ca half-life, for which a value of (1.02 ± 0.07) × 10^5 year is adopted [6]. For the neutron flux determination a ^{10}B layer containing (8.51 ± 0.43) ×10^{19} atoms was used.

3.Measurements

Two different measurement campaigns were performed to define the (n,α) reaction cross section, one at an 8.5 m long flight path and a second one at 30 m to improve the energy resolution and to extend the energy range. The results from the 8.5 m measurement have been reported previously by De Smet et al. [7].

For all the measurements, the accelerator was operated at a repetition frequency of 800 Hz and the electron bursts had a width of 1 ns. To remove neutrons from previous bursts, a boron overlap filter was permanently used. The time dependent background was determined in a separate measurement by putting black resonance filters (Au, Co, Mn, W and Al) in the neutron beam.

The total observed counting rate $Y_{Ca}(E_n)$ for the ^{41}Ca(n,α) reaction as a function of the neutron energy is:

$$Y_{Ca}(E_n) = \varepsilon_{Ca} N_{Ca} \sigma_{Ca}(E_n) \varphi(E_n) + Y_{Ca}^{BG}(E_n),$$

where ε_{Ca} is the detector efficiency and N_{Ca} the number of atoms in the ^{41}Ca sample used. $\sigma_{Ca}(E_n)$ is the differential neutron induced cross section to be determined and $\varphi(E_n)$ represents the neutron flux. The time dependent background Y_{Ca}^{BG} has been determined as a function of the time-of-flight t by fitting a function $Y_{Ca}^{BG}(t) = at^b + c$ through the counting rates in the black resonance regions; it has been subtracted from the counting rate $Y_{Ca}(t)$ after normalisation to the same integrated neutron flux. An identical relation for the flux counting rate, in our case the ^{10}B(n,α)-counting rate, is adopted and dividing them gives:

$$\sigma_{Ca}(E_n) = \frac{\varepsilon_B}{\varepsilon_{Ca}} \frac{Y_{Ca}(E_n) - Y_{Ca}^{BG}(E_n)}{Y_B(E_n) - Y_B^{BG}(E_n)} \frac{N_B}{N_{Ca}} \sigma_B(E_n).$$

Since the ^{41}Ca(n,α) reaction and the ^{10}B(n,α) reaction have been measured in the same experimental conditions, $\frac{\varepsilon_B}{\varepsilon_{Ca}} = 1$ (detection geometry equals 2π). The known ^{10}B(n,α) reference cross section $\sigma_B(E_n)$ is taken from the ENDF/B-VII database.

4.Results and discussion

The results are shown in Figure 2, which gives detailed views on the ^{41}Ca(n,α) resonances between 3 and 100 keV. This figure clearly demonstrates that the energy resolution of the

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present measurement at a 30 m long flight path (red line) is much better than the previous results obtained at 8.5 m (blue line).

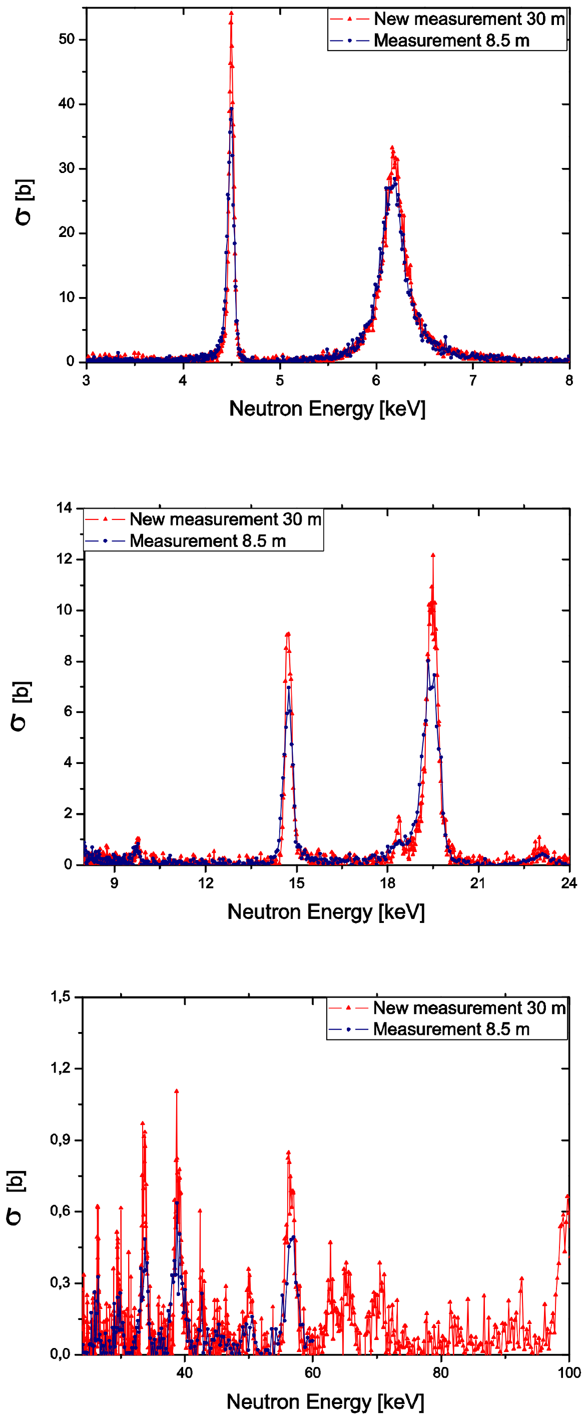

Figure 2: ^{41}Ca(n,α) cross section between 3 and 100 keV neutron energy. The red line shows the results of the present measurement at a 30 m long flight path, the blue curves are the data of De Smet et al. [7] obtained at 8.5 m.

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Figure 3 shows the ^{41}Ca(n,α) MACS values, which are obtained by numerical integration of the present cross section data (red line). The corresponding values of De Smet et al. [7] are represented by the blue line. The present results and those of De Smet et al. [7] are in perfect agreement up to about 20 keV; above this value, the present results are somewhat higher. This is in accordance with expectations, since in the present calculations the data extend to 100 keV neutron energy, compared to 45 keV in the case of [7]. Since a resonance at an energy E_{res} has its maximum contribution at kT = 0.5 E_{res}, the MACS values above 22 keV reported by De Smet et al. [7] are lower limits.

In the energy region covered by the present measurement, two stellar temperatures are of particular interest to the s-process calculations: 8 and 25 keV. From Figure 3 it is clear that the MACS value at 8 keV obtained in this work is larger than both theoretical values. At 25 keV however, the MOST value [1] perfectly agrees with our experimental result.

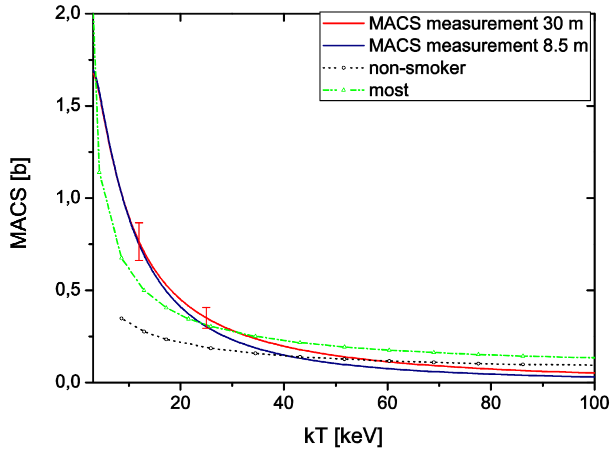

Figure 3: The ^{41}Ca(n,α)^{38}Ar MACS values obtained by numerical integration of the obtained cross section data. A comparison is made with theoretical values.

Acknowledgments

Part of this work was performed in the framework of the Interuniversity Attraction Poles project financed by the Belgian Science Policy Office of the Belgian State.

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