$^{14}N(n,p)^{14}C$ cross section near thermal energy

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The $^{14}N(n,p)^{14}C$ cross section was measured, relative to $^{6}Li(n,\alpha)^{3}H$, from thermal energy to approximately 5 eV. The measured cross section has a shape indistinguishable from $1/v$. The astrophysical implications of this result are discussed.

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In the s process of nucleosynthesis ^{14}N may act as a strong neutron "poison" during the operation of the chain of reactions involving the $^{13}C(\alpha,n)^{16}O$ neutron source, possibly making this chain of reactions a net consumer rather than a net producer of neutrons. Also, ^{14}N may play a crucial role in the nucleosynthesis of ^{19}F. Recent observations [1] and calculations [2] indicate that significant ^{19}F may have been produced in the s process. Alternatively, it has been suggested that most of the ^{19}F seen in nature was synthesized in supernova explosions via the ν process [3].

In the s process the relative importance of ^{14}N is strongly dependent on the size of the Maxwellian-averaged $^{14}N(n,p)^{14}C$ cross section at temperatures near $kT = 25$ keV. Bahcall and Fowler [4] estimated the astrophysical rate for the $^{14}N(n,p)^{14}C$ reaction by interpolating between measurements at thermal energy [5] and measurements above approximately 50 keV [6]. Later, Brehm *et al.* [7] made the first direct measurements of the absolute cross section at astrophysically relevant temperatures ($E_n = 25.0$ and 52.4 keV). Their result for the astrophysical reaction rate at s-process temperatures was approximately a factor of 3 smaller than the previous rate [4]. Soon afterwards, Koehler and O'Brien [8] reported a measurement of the shape of the cross section from 61 meV to 34.6 keV. The shape they measured was very close to $1/v$ and, when normalized to the measured thermal cross section [5], was in agreement with the older data at higher energies [6,9] and, therefore, supported the reaction rate calculated by Bahcall and Fowler [4].

Because the measurements of Koehler and O'Brien [8] did not extend down to thermal energy (25.3 meV), these authors assumed that the cross section in the range between the lowest energy (61 meV) they measured and thermal energy followed a $1/v$ shape. Although it is expected that any departure from $1/v$ would be small at these energies, there is a systematic uncertainty in the normalization of the data of Koehler and O'Brien due to this assumption. In the present work, the shape of the cross section from thermal energy to approximately 5 eV was measured to allow a better determination of this normalization.

Details of the experimental technique have been published elsewhere [10]. The only substantial change from the system employed in Ref. [8] was that the range of the time-to-digital converter was increased in the present experiment to allow the measurements to extend to lower neutron energies. The measurements were performed using the "white" neutron source at the Manuel Lujan, Jr. Neutron Scattering Center (LANSCE) [11]. The data were taken in two-parameter-mode pulse height (or proton energy) versus time of flight (or neutron energy). The ^{14}N sample was produced by vacuum evaporation of adenine ($C_5H_5N_5$) to a thickness of 165 $\mu g/cm^2$ onto a 8.5-μm-thick aluminum foil. Protons from the $^{14}N(n,p)^{14}C$ reaction were detected with a silicon surface barrier detector of 10 μm thickness by 50 mm^2 in area. The measurements were made relative to the $^{6}Li(n,\alpha)^{3}H$ cross section using a separate ^{6}Li sample and surface barrier detector as a flux monitor. The data were converted from yields to cross sections using the recommended thermal cross sections for the $^{14}N(n,p)^{14}C$ [5] and $^{6}Li(n,\alpha)^{3}H$ [12] reactions and the latest evaluation [12] for the energy dependence of the $^{6}Li(n,\alpha)^{3}H$ cross section. From the published uncertainties in the $^{14}N(n,p)^{14}C$ and $^{6}Li(n,\alpha)^{3}H$ cross sections, a normalization uncertainty of 3.5% was calculated.

Both the neutron flux and the $^{14}N(n,p)^{14}C$ cross section decrease with increasing energy, and so the statistical precision of the data worsens as the energy increases. Because the major goal of the present experiment was to

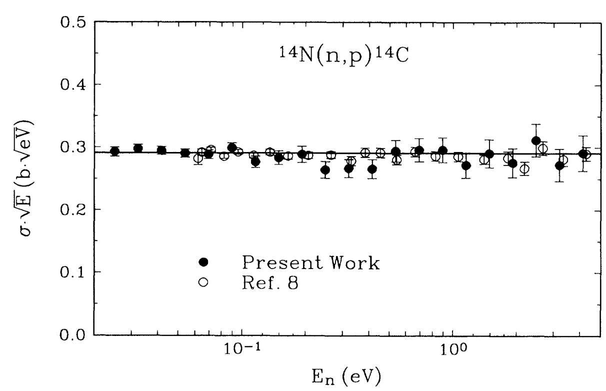

FIG. 1. $^{14}N(n,p)^{14}C$ reduced cross section from thermal energy to 5 eV. The present results (solid circles) are compared to the previous results of Koehler and O'Brien [8] (open circles). The error bars shown on the data depict the one-standard-deviation relative uncertainties. The solid line indicates the size of the reduced cross section corresponding the recommended thermal cross section [5].

measure the shape of the cross section near thermal energy where the counting rate was relatively large, the measurements were halted when it was judged that a sufficient number of counts were obtained at these energies. As a result, the statistical precision of the data at the higher energies is rather poor. For this reason only the data below 5 eV are shown herein. The resulting reduced cross sections are shown in Fig. 1 together with the previous data of Koehler and O'Brien [8]. The error bars shown on the data depict the one-standard-deviation relative uncertainties only. The two sets of data agree within the experimental uncertainties. The horizontal line in Fig. 1 indicates the size of the reduced cross section corresponding to the measured thermal cross section [5]. A $1/v$ cross section will lie along this line. To within the experimental uncertainties, the measured cross sections are indistinguishable from $1/v$ across the entire energy range measured. Therefore our results indicate that the normalization used by Koehler and O'Brien was correct.

Because the present data confirm the correctness of the normalization used by Koehler and O'Brien [8], our new measurements support the reaction rate calculated by Bahcall and Fowler [4] over the threefold reduction in this rate recommended by Brehm *et al.* [7]. The higher rate is also supported by recent measurements of the thermal $^{14}N(n,p)^{14}C$ cross section [13,14], which are in agreement with the previously recommended value [5]. Finally, recent measurements of the $^{14}N(n,p)^{14}C$ cross section at 24.5 keV [15], made using filtered neutrons from a reactor, are also in agreement with the higher reaction rate.

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