Analysis of Low Energy Proton Capture Cross Section for Light Nuclei

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Proton capture cross sections of D, ^{6,7}Li, ^{9}Be, ^{10,11}B, ^{12}C, ^{14}N and ^{16}O in the incident energy region from 1 keV to 10 MeV were analyzed with direct reaction model for Deuteron and with resonance formula for other nuclides.

1. Introduction

For astrophysical estimation of stellar nucleosynthesis and hydrogen consumption in astrophysical environments, low energy proton capture cross sections for light nuclides are crucially important. In the present study, the experimental cross sections compiled in NACRE file[1] and other published data were analyzed for target nuclides; D, ^{6,7}Li, ^{9}Be, ^{10,11}B, ^{12}C, ^{14}N and ^{16}O in the incident proton energy region of 1keV to 10 MeV. The calculated cross sections will be used to calculate the astrophysical S factors and reaction rates.

2. Method

For Deuteron, analysis was made with the inverse reaction ^{3}He(γ,p)D analysis formula given by Gunn and Irving[2]. They give the cross section formula of the ^{3}T(γ,n)D reaction using a exponential type wave function. The formula was converted to the cross section of the ^{3}He(γ,p)D reaction by replacing the Q-value and Coulomb barrier penetration factors. For the barrier penetration factor calculation, orbital angular momentums of the emitted protons were assumed to be s-wave and p-wave and their mixing ratio was determined to reproduce the experimental cross section comparing with calculated inverse cross section.

For other nuclides, analyses were made with an approximated R-matrix resonance formula[3] given by

$$\sigma_{p\gamma}(E) = \frac{\pi}{k^2}\sum_{J\tau}\frac{(2J+1)}{2(2I+1)}\left|U_{J\tau}\right|^2 \quad ,$$

with

$$U_{J\tau} = \frac{\sum_{\lambda} i\Gamma_{\lambda p}^{1/2}\Gamma_{\lambda\gamma}^{1/2} /(E_{\lambda} - E)}{1 + \sum_{\lambda} (\Delta_{\lambda} - i\Gamma_{\lambda}/2)/(E_{\lambda} - E)} \quad \text{and} \quad \Gamma_{\lambda p} = 2P_{\ell}(E)\gamma_{\lambda}^{2},$$

where λ designates a resonance level and includes spin-parity J^{Π} and isospin **τ**, and other symbols are same as that of R-matrix theory by Lane and Thomas[4)].

The initial resonance parameters were obtained from the compilation "Energy Levels of Light Nuclei"[5)] and adjusted to reproduce experimental cross sections.

3. Results

Results of present analysis are shown in Fig.1 to Fig.9, comparing with experimental cross sections. Solid lines show the calculated cross section of the present analysis.

Figure 1 shows the $D(p,\gamma)^{3}He$ reaction cross section. Experimental data exist in the energy region of Ep(cm)=10keV to 22MeV.

Figure 2 shows the $^{6}Li(p,\gamma)^{7}Be$ reaction cross section analyzed with 2 resonances. Though resonance levels of gamma-ray emission were not cited in ref. 5), gamma-emission widths were assigned to two levels of low spin and large width, to reproduce experimental cross sections.

Figure 3 shows the $^{7}Li(p,\gamma)^{8}Be$ reaction cross section analyzed with 6 resonances. For the experimental data above Ep(lab)=1.5MeV, no experimental error was assigned in the original paper. Therefore 30% error was assumed to them presently.

Figure 4 shows the $^{9}Be(p,\gamma)^{10}B$ reaction cross section analyzed with 6 resonances including a negative resonance which corresponds to the excited state of ^{10}B; Ex=5.181MeV, $J^{\pi} = 1^{+}$. No experimental data were available in the energy region above Ep=2MeV, so, in this region, cross section was calculated using resonance parameters given in ref. 5) choosing appropriate spin-parity from candidates.

Figure 5 shows results of the $^{10}B(p,\gamma)^{11}C$ reaction analyzed with 6 resonances including a negative resonance which corresponds to the excited state of ^{11}C ; Ex=8.655MeV,$J^{\pi} = 7/2^{-}$. To reproduce the cross section in the energy region below Ep=1MeV, rather large nuclear radius parameter R_0 = 2.1 fm was adopted. In other cases, R_0 = 1.35 fm.

Figure 6 shows results of the $^{11}B(p,\gamma)^{12}C$ reaction analyzed with 12 resonances.
In the energy region below Ep=0.3MeV, experimental data would exist, but not available presently, so, in this region, cross section was calculated using resonance parameters given in ref. 5).

Figure 7 shows results of the $^{12}C(p,\gamma)^{13}N$ reaction analyzed with 11 resonances.
The experimental data in the energy region of Ep=1.5-3.0MeV are deduced from the differential cross sections of (p,γ_0) at 0^{o} and 90^{o} measured by Rolfs and Azuma[6)]. And

the data of Ep>9MeV are (p,γ_0) cross section measured by Measday and Hasinoff[7], which almost agree with the (p,γ) activation cross section measured by Hill et al.[8]

Figure 8 shows results of the $^{14}N(p,\gamma)^{15}O$ reaction analyzed with 22 resonances. There are experimental data of the (p,γ_0) reaction in some energy regions above Ep=1MeV. Taking into account the structure of these data, cross sections were reproduced adjusting the resonance parameters given in ref. 5).

Figure 9 shows results of the $^{16}O(p,\gamma)^{17}F$ reaction analyzed with 8 resonances including a negative resonance which corresponds to the excited state of ^{17}F ; Ex=0.4956MeV,$J^{\pi}=1/2^{+}$.

４. Conclusion

Low energy proton capture cross sections were reproduced well with simple formula for Deuteron, and with resonance formula for $^{6,7}Li$, ^{9}Be, $^{10,11}B$, ^{12}C, ^{14}N and ^{16}O. In some literatures[6),9)], smooth parts of cross section were explained to be caused by direct capture reaction, however, there are many cases which show interference with some resonances, and it was found that the smooth parts and the interferences were explained also by tails originated in some distant resonances of broad width, say giant resonance, and/or by negative resonances.

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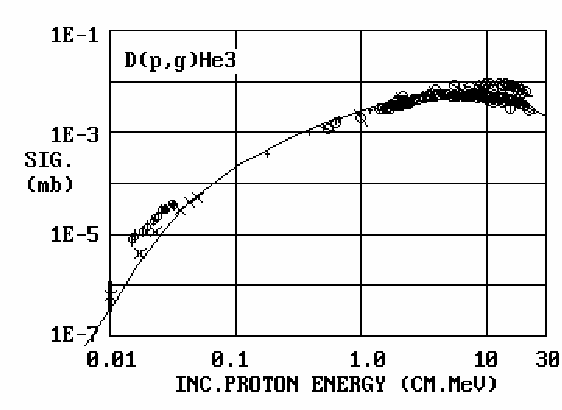

Fig.1　Proton capture cross section of D

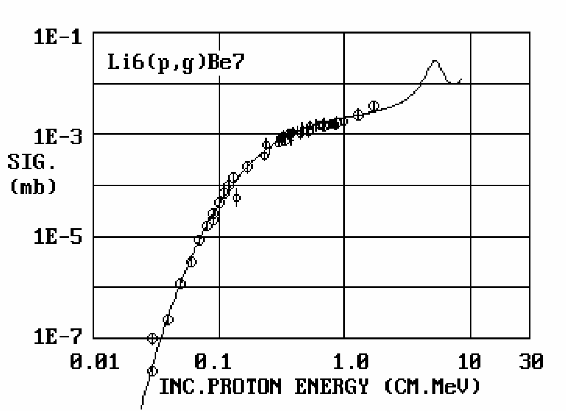

Fig.2　Proton capture cross section of ^{6}Li

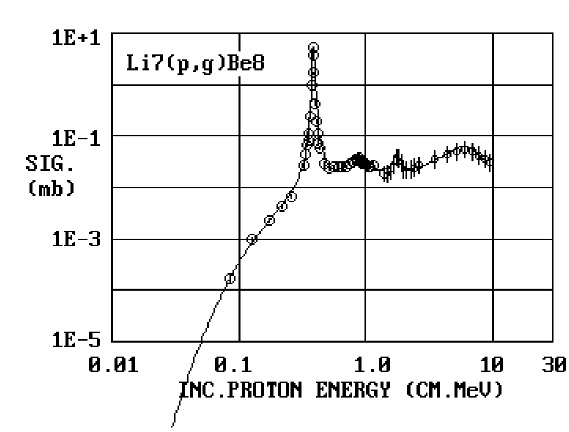

Fig.3　Proton capture cross section of ^{7}Li

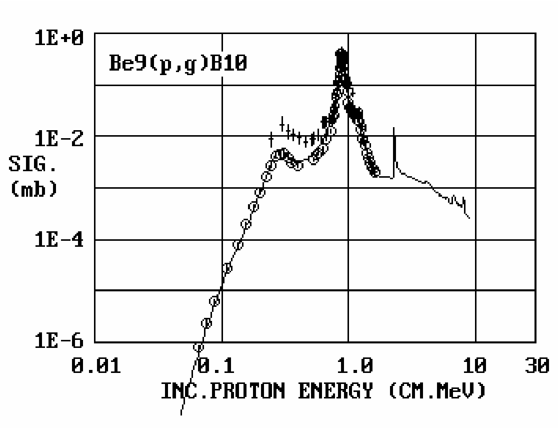

Fig.4　Proton capture cross section of ^{9}Be

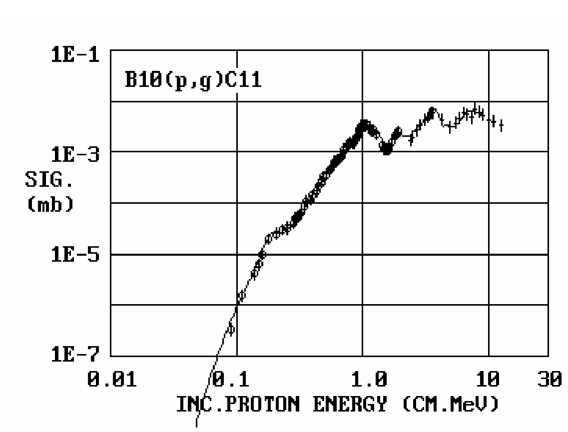

Fig.5　Proton capture cross section of ^{10}B

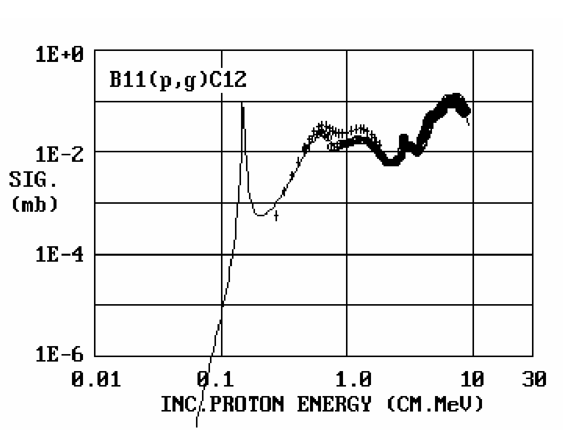

Fig.6　Proton capture cross section of ^{11}B

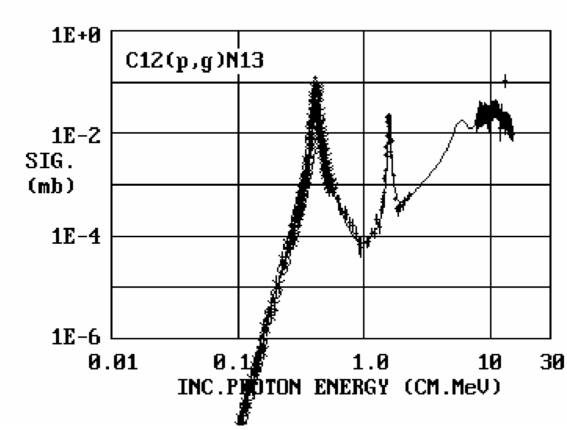

Fig.7 Proton capture cross section of ^{12}C

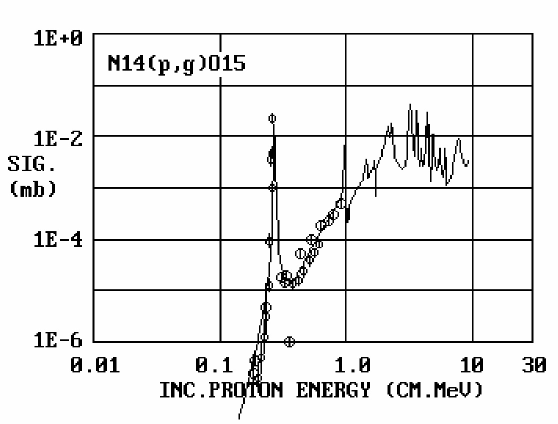

Fig.8 Proton capture cross section of ^{14}N

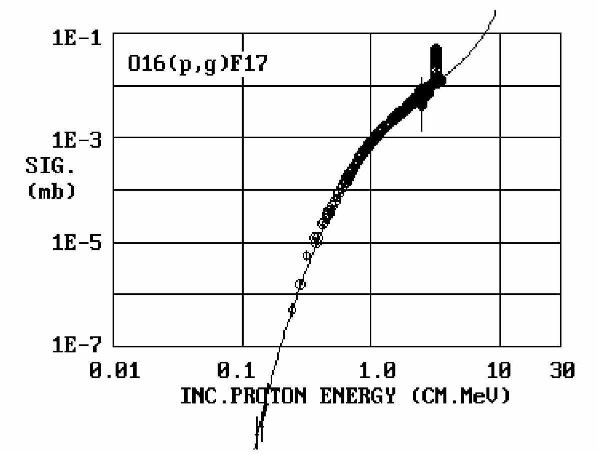

Fig.9 Proton capture cross section of ^{16}O