The Evaluation of Cross Sections for n+⁶Li Reaction

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**Abstract**

Neutron nuclear data of ⁶Li are important for fusion neutronics calculation. Therefore, the cross sections for n+⁶Li reaction are evaluated in the energy range from 10⁻⁵ eV to 20 MeV. In the evaluation, ⁶Li(n, d + n)⁴He and ⁶Li(n, d + n)⁴He reactions are included. It is concluded that there is really only the second excited level (3.562 MeV) in the inelastic scattering, no assumed levels were taken into account. The evaluated data describe the real process of n+⁶Li reactions and improve the existing evaluated libraries such as ENDF/B-6 and JENDL-3.

**Introduction**

Nuclear energy such as fusion reaction is a more important energy resource in future. Study of the nuclear data pertaining to the fusion reactors has grown to be one of the smart and interesting fields.

Neutron nuclear data of ⁶Li are important for fusion neutronics calculation. In particular the ⁷Li(n,n′)⁴He as well as ⁷Li(n,n′)⁴He reaction cross sections control the tritium-production rate in fusion blankets. The ⁴Li(n,α)⁴He reaction cross section is also used as the standard. Although the data of ⁶Li are included in some evaluated nuclear data files, including CENDL-2.1, there are following matters to be studied further:

1. For inelastic scattering (n,n′γ), only the second excited level (3.562 MeV) really takes place; however, many assumed levels were taken into account, in order to cover (n,n′d) cross section.
2. The ⁶Li(n,d+n)⁴He and ⁶Li(n,n+d)⁴He reaction channels are simply included in inelastic scattering reaction, (n,n′d) and (n,n′γ) are different reactions channels and should not be put together. Both deuteron and triton are important for fusion.

This report describes the evaluation of cross sections for n+⁶Li reaction.

1.2 Total Cross Section

Below 3 MeV, the data were taken from R-matrix analysis by Hale, Dodder and Witte[3], which took into account the data of all reactions possible of ⁷Li system up to 4 MeV neutron energy. Total cross section data considered in this analysis were those of J.A. Harvey and N.W.Hill[4] and A.B. Smith et al.[5]. Between 3 and 20 MeV, the data follows the measurements of A.B. Smith et al.[6], J.D. Kellie et al.[7], H.H. Knitter et al.[8], C.A. Goulding et al.[9] and D.G. Foster et al.[10].

1.3 Elastic Scattering Cross Section

Below 3 MeV, the values were taken from R-matrix analysis by Hale, Dodder, and Witte[3], which includes the elastic scattering data measured by A.B. Smith et al.[6] and R.O. Lane et al.[11]. Above 3 MeV, the curve is a smooth representation of the data of H.D. Knox et al.[12], and R. Batherlor et al.[13] up to 7.5 MeV, and of that of H.H. Hogue et al.[14] between 7.5 and 13 MeV. The curve passes through the average of several measurements at 14 MeV, and is extrapolated to 20 MeV using the shape of an optical model calculation.

1.4 Inelastic Scattering Cross Section

⁴Li(n,n′γ)⁴Li inelastic scattering reaction takes place only through the second excited level (3.562 MeV). There are two sets of available experimental data measured by G. Presser et al.[15] and Besotsnyj et al.[16]. A smooth curve was recommended, which was drawn through these data and from 7 to 20 MeV by eye guide, see Fig. 1.

1.5 ⁶Li(n,d+n)⁴He and ⁶Li(n,n+d)⁴He Reaction Cross Section

The ⁶Li(n,d+n)⁴He and ⁶Li(n,n+d)⁴He reactions include the following three channels:
(a) \( n^+{}^6\text{Li} \rightarrow n^+{}^4\text{He}, Q = -2.19 \text{ MeV}, {}^4\text{He} = \gamma \rightarrow n^+{}^4\text{He} \)
(b) \( n^+{}^6\text{Li} \rightarrow d^+{}^3\text{He}, Q = -2.36 \text{ MeV}, {}^3\text{He} = \gamma \rightarrow n^+{}^3\text{He} \)
(c) \( n^+{}^6\text{Li} \rightarrow n^+d^+{}^2\text{He}, Q = -1.47 \text{ MeV} \)

The evaluated cross section is mainly based on the data of S.Chiba et al. [17], P.W.Lisowski et al. [18], J.C.Hopkins et al. [19] and R.Batherlor et al. [13], and the consistency of all cross sections. The evaluated result is shown in Fig. 2.

1.6 \( ^6\text{Li}(n,2np)^4\text{He} \) Reaction Cross Section

The \( ^6\text{Li}(n,2np)^4\text{He} \) reactions include the following five mechanisms:
(a) \( n^+{}^6\text{Li} \rightarrow n^+{}^4\text{Li}, Q = -5.37 \text{ MeV}, {}^4\text{Li} = \gamma \rightarrow n^+{}^4\text{He} \)
(b) \( n^+{}^6\text{Li} \rightarrow p^+{}^4\text{He}, Q = -2.73 \text{ MeV}, {}^4\text{He} = n^+n^+{}^4\text{He} \)
(c) \( n^+{}^6\text{Li} \rightarrow n^+n^+p^+{}^4\text{He}, Q = -3.70 \text{ MeV} \)
(d) \( n^+{}^6\text{Li} \rightarrow 2n^+{}^5\text{Li}, Q = -5.66 \text{ MeV}, {}^5\text{Li} = p^+{}^4\text{He} \)
(e) \( n^+{}^6\text{Li} \rightarrow n^+p^+{}^5\text{He}, Q = -4.59 \text{ MeV}, {}^5\text{He} = n^+{}^4\text{He} \)

Concerning the \( (n,2np) \) reactions, two sets of experimental data of (D.S.Mather et al. [20], V.J.Ashby et al. [21]), which were obtained by the coincident counting method, are available. The recommended curve passes through the point of Mather et al. at 14 MeV, taking into account the measurements of Ashby et al.

1.7 \( ^6\text{Li}(n,\gamma)^7\text{Li} \) Radiative Capture Reaction Cross Section

The \( (n,\gamma) \) reaction cross section is based on the datum at thermal energy measured by E.T.Jurney [22], and the cross section was extrapolated as \( 1/\nu \) up to 200 keV, i.e.,
\[
\sigma_{n\gamma} = 6.12 \times 10^{-3} [E_n(\text{eV})]^{-1/2} \text{ barns.}
\]
The Pendlebury’s evaluation [23] at high energies was adopted.

1.8 \( ^6\text{Li} (n,p)^6\text{He} \) Reaction Cross Section

The \( (n,p) \) cross sections were measured by G.Presser et al. [15] in the energy range from 3.1 MeV to 9.0 MeV with the activation method. Above 9 MeV, several measurements [24-27] were performed at 14 MeV. The evaluated cross sections are on the basis of the data of G.Presser et al. from threshold to 9 MeV, extended to 20 MeV through the 14 MeV data of Ref. [22] and [23].

1.9 \( ^6\text{Li} (n,t)^4\text{He} \) Reaction Cross Section

\( ^6\text{Li} (n,t)^4\text{He} \) reaction cross section of ENDF/B-6 is used as the standard, therefore it was taken from ENDF/B-6.

2 Concluding Remarks

The neutron cross sections of \( ^6\text{Li} \) were evaluated in the energy range from \( 10^5 \text{ eV} \) to 20 MeV.

The major changes are as follows:
(1) \( ^6\text{Li}(n,d+n)^4\text{He} \) and \( ^6\text{Li}(n,n+d)^4\text{He} \) reactions are included.
(2) There is only the second excited level (3.562 MeV) in the inelastic scattering really, no assumed levels were taken into account.

The evaluated data describe the real process of \( n^+{}^6\text{Li} \) reactions and improved the mentioned-above matters of the existing evaluated libraries such as ENDF/B-6 and JENDL-3. The comparisons between them were given.

References

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