Fission cross sections for $^{6,7}$Li$^{+235}$U

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Introduction

The study of nuclear reaction mechanisms involving weakly bound stable heavy ions has been very interesting due to the observation of many new non-conventional behaviors compared to those involving tightly bound projectiles. Fusion suppression at above barrier energies, absence of threshold anomaly in the real part of the optical potential and production of large alpha particles are some of the important features associated with the above reactions. These observations are known to be largely due to the effect of projectile breakup on other channels. Study of fission involving weakly bound projectiles is another avenue. Effect of projectile breakup has also been discussed in many studies. However, there are very few work in the literature that explain the reaction mechanisms involved in the breakup affected fission observables. Freiesleben et al. in their study on $^{6,7}$Li$^{+232}$Th,$^{238}$U have done a systematic study on fission fragment angular distribution and found characteristic differences between $^6$Li and $^7$Li induced reactions. They have also mentioned the possibility of projectile breakup and its effect on fission. In the present work we have performed a similar study but for different systems $^{6,7}$Li$^{+235}$U to see if their conclusions differ for a target having a large g.s. spin. The reactions with $^{235}$U as a target are known [2] to have different fission anisotropy as compared to the one having zero g.s. spin. In that case the characteristics observed for $^{6,7}$Li$^{+238}$U may not be same as for the present case. With this motivation we made the fission measurements for $^{6,7}$Li$^{+235}$U systems. Presented in this paper are the measurements, results of the analysis and anisotropy calculations.

Measurements

The fission fragment angular distribution for $^{6,7}$Li$^{+235}$U reaction have been measured at the 14UD BARC-TIFR pelletron facility, Mumbai using $^6$Li beam of average current 35 nA. Beam energies between 26 MeV to 44 MeV in step of 2 MeV have been used. Target of $^{235}$U of thickness 1.6mg/cm$^2$ was prepared by electrodeposition on backing of 4 µinch Ni-Cu foil. The target were carefully centered in a scattering chamber where four solid state detectors mounted at a distance of ~20 cm from the target centre with fixed angular separation of 20$^\circ$ and additional two detectors served as monitors were used to detect the fission fragments.

Analysis

The differential fission cross sections were calculated, using the relation

$$ W(\theta_{\text{th}}) = \frac{1}{d\Omega} \frac{d\sigma_{\text{fiss}}}{d\Omega} = \frac{Y_{\text{fiss}}(\theta_{\text{th}})}{Y_{\text{th}}(\theta_{\text{th}})} \times \frac{d\sigma_{\text{th}}}{d\Omega} \times \frac{\Omega_{\text{th}}}{2d\Omega_{\text{fiss}}} $$

Where Y's and $\Omega$'s are the yields and the solid angles of fission and monitor (Ruth) detectors.

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![Energy dependence of the fission fragment angular anisotropy for $^{6,7}$Li$^{+235}$U reactions.](image-url)
the saddle point model. From the fit of the $W(\theta)$
one can obtain the fission anisotropy,
$A=W(180^\circ)/W(90^\circ)$, as shown in Fig.1. It can be
observed that the anisotropy values for $^7$Li are
higher compared to $^6$Li as observed in Ref.[1].
This was expected because a compound nucleus
having $1n$ more is supposed to have more later-
chance fission and thus increasing the value of
the anisotropy $'A'$. The fission fragment anisotropy
was calculated by standard saddle point statistical
(SSPS) model using the relation
$$A=1+<l^2>/4K_0^2$$
where $K_0^2$ is the variance of $K$
(projection of the total angular momentum on the
symmetry axis of the fissioning system) distribution
and $<l^2>$ is the mean square spin of the
compound nucleus. The values of $<l^2>$ were
derived by fitting the experimental fusion cross
sections (obtained by integrating the fission
angular distributions) with the coupled-channels
calculations by CCFULL[4]. The values for $K_0^2$
($=J_{\text{eff}}T/\hbar^2$, where $J_{\text{eff}}$
is the effective moment of inertia and $T$
is the temperature of the compound
nucleus) were obtained from the standard
relations for $T$ with excitation energy and level
density as described in Ref. [5]. The anisotropy
results for $^6,7$Li+$^{235}$U are shown in Fig.1 as dotted
and solid lines respectively. It can be observed
that the calculated values are smaller than the
experimental ones, even at higher energies.
Secondly, though the theoretical anisotropies for
both the systems are almost same, the experimental
values for $^7$Li are slightly higher
than $^6$Li. The large difference between the
experiment and theory in $A$-values at energies
around the barrier is known to be due to the
effect of coupling of different reaction channels
to the entrance channel.

The fitted $W(\theta)$ values were integrated to
get the total cross section at energies $E_{\text{lab}}=26-44$
MeV. The experimental total fission cross
sections for $^6,7$Li and $^{235}$U are displayed in Fig. 2.
It can be observed that at low energies the
integrated fission cross section for $^7$Li induced
reaction is much higher than those for $^6$Li induced
reactions and at very high energies their
values are almost same. This can be understood
in terms of larger breakup fragment induced
fission for $^6$Li than $^7$Li. Since $^6$Li has a lower
breakup threshold (1.48 MeV) compared to the
one for $^7$Li (2.47 MeV), breakup probability is
much higher for the former. In order to quantify
the contribution from breakup fragment induced
fission one needs to measure the coincidence
between fission fragments and light charged
particles like $p$, $d$, $t$ and $\alpha$.

![Fig. 2: Angle integrated fission cross sections for $^{6,7}$Li+$^{235}$U at different energies.](image)

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**References**