One-neutron knockout from strongly bound ^{34}Ar

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Introduction

Properties of loosely bound nuclei near neutron or proton drip line have been demonstrated by various direct nuclear reactions methods over the last few decades. These nuclei show certain interesting properties like halo structure, where the density distribution shows a substantial tail. In order to investigate the structure of light and medium-mass nuclei beyond the valley of stability, one- or few nucleon knockout reactions using intermediate energy radioactive ion beams on light target nuclei like ^{9}Be or ^{12}C have been found to be an effective tool.
In this contribution, we perform a systematic study of *neutron knockout* from tightly bound ^{34}Ar nucleus and compare it with neutron knockout from loosely bound ^{11}Be and ^{19}B nuclei within the nuclear diffraction scattering theory. The Coulomb contributions, which are expected to be small, are also neglected. ^{34}Ar has a high neutron separation energy of 17.07 MeV, compared to 0.504 MeV and 1.13 MeV for ^{11}Be and ^{19}B, respectively. More specifically, we propose to compute the one neutron removal cross section and parallel momentum distribution (PMD) of the core fragment in the breakup of the projectile on light targets.

Formalism

One- or two- nucleon removal cross sections for reaction with light target (^{9}Be,^{12}C) have two dominant contributions : diffraction dissociation (elastic breakup) and stripping (inelastic breakup), (Coulomb contributions are negligible for breakup on a light target) [1]. For a reaction of the type $a(b+c)+A_T \rightarrow b+anything$, where the projectile a composed of sub-structures b and c breaks up in the field of the target A_T, the total cross section is,

$$\sigma = \sigma_{str} + \sigma_{dis}. \quad (1)$$

The stripping (σ_{str}) and dissociation (σ_{dis}) contributions have been calculated within the diffraction scattering theory. We have also used proper three body kinematics involving Jacobi coordinates in our calculations. The triple differential cross section for diffraction dissociation part is written as [1],

$$\frac{d\sigma_{dis}}{d\Omega_b d\Omega_c dE_b} = \frac{\mu}{(2\pi)^3\hbar^2}\frac{k_b k_c}{k_a}|f_D(\mathbf{q},\mathbf{Q})|^2. \quad (2)$$

Ω_b, Ω_c are the solid angles of the outgoing fragments, E_b is the energy of the fragment b, $\mathbf{k}_b$ and $\mathbf{k}_c$ are momenta of the fragments b and c, $\mathbf{k}_a$ is the c.m momentum of incident beam, $\mathbf{q}$ is the momentum change in scattering, and $\mathbf{Q}$ is the relative momentum of the fragments after dissociation.
$f_D(\mathbf{q},\mathbf{Q})$ is the amplitude, for the dissociation of a cluster projectile. For a "black nucleus" this amplitude has the form [1],

$$f_D = ik_aR\big[\{F(-\beta_c\mathbf{q},\mathbf{Q}) + F(\beta_b\mathbf{q},\mathbf{Q})\}f(\mathbf{q}) + \frac{i}{2\pi k_a}\int d\mathbf{q}' F(\mathbf{q}',\mathbf{Q}) f(\beta_b\mathbf{q}-\mathbf{q}')f(\beta_b\mathbf{q}+\mathbf{q}')\big] \quad (3)$$

$\beta_b = (m_b+m_c)/m_b$ and $\beta_c = (m_b+m_c)/m_c$, m_b, m_c are the masses of the projectile fragments, R is the target radius, and $f(q) = ik_aR\frac{J_1(qR)}{q}$ is the individual fragment-target scattering amplitude. $F(\mathbf{q},\mathbf{Q})$ is evaluated from

$$F(\mathbf{q},\mathbf{Q}) = \int d\mathbf{r}\phi^*_{\mathbf{Q}}(\mathbf{r})e^{i\mathbf{q}\cdot\mathbf{r}}\phi_0(\mathbf{r}),$$

The projectile ground state wave function is taken to be of Yukawa form

$$\phi_0(\mathbf{r}) = \sqrt{\tfrac{\alpha}{2\pi}}e^{-\alpha r}/r,$$

and the wave function for the relative motion of the fragments after dissociation is taken as

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$$\phi_{\mathbf{Q}}(\mathbf{r}) = e^{-i\mathbf{Q}.\mathbf{r}} - \frac{1}{\alpha - i\mathbf{Q}}\left[\frac{e^{-iQr}}{r}\right],$$

where $\alpha = \sqrt{2\mu\epsilon/\hbar^2}$, ϵ is the nucleon separation energy. The dissociation cross sections are calculated from Eq. (2).

The stripping contribution is calculated from [1, 2],

$$\frac{d\sigma_{str}}{dk_b^3} = \frac{1}{(2\pi)^3}\int d\mathbf{b}_b[1-|S_b(\mathbf{b}_b)|^2]\times \left|\int d\mathbf{r}e^{-i\mathbf{k}_b.\mathbf{r}}S_c(\mathbf{b}_c)\phi_0(\mathbf{r})\right|^2. \quad (4)$$

S_b and S_c are the S-matrices for core-target and nucleon-target interactions, which are functions of the impact parameter of the individual core and valence nucleon ($\mathbf{b}_b$ and $\mathbf{b}_c$), respectively.

Results and discussions

Projectile +target	E_a (MeV/u)	Cross section(mb) Dissociation	Stripping	Expt.
^{11}Be+^{9}Be	66	24.89	143.16	259($\pm$39) [3]
^{19}B+^{12}C	220	40.12	86.87	251(5) [4]
^{34}Ar+^{9}Be	70	1.46	8.42	15.6(18) [5]

TABLE I: Inclusive neutron removal cross sections

The dissociation contribution to the total cross section is found to be small compared to the stripping contribution for loosely bound nuclei (^{11}Be,^{19}B), and very small for tightly bound nucleus (^{34}Ar) (see TABLE I). The total neutron removal cross section for stable (non-halo) nucleus (^{34}Ar) is very small, which indicates a 'shielding' of the nuclear wave function inside the core.

The orbital angular momentum of the removed nucleon also has an effect on the shape of the distribution. For loosely bound halo nuclei, the width of the distribution is narrow, while for a tightly bound nucleus as ^{34}Ar, a broad width of 386 MeV/c has been found [5]. In Fig. 1, we plot the PMD of the core (in projectile rest frame) in the breakup of ^{11}Be, ^{19}B, and ^{34}Ar on light targets, respectively. While broad features of the argument given earlier are perceptible in the results, we must state that there is no explicit angular momentum dependence in the Yukawa wave function, which we have assumed to be the projectile wave function, in this preliminary calculation. Subsequently, we will also present results computed with a more realistic Woods-Saxon wave function and also extend our calculations to the medium mass region.

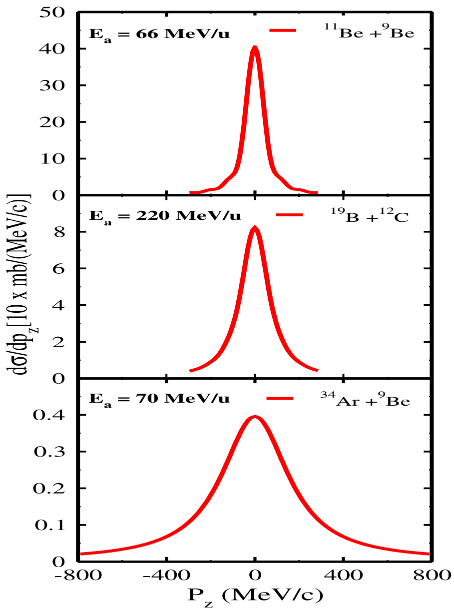

FIG. 1: Parallel momentum distribution of the core (in projectile rest frame) in the breakup of ^{11}Be, ^{19}B, and ^{34}Ar on light targets.

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