A new approach to study single proton breakup from exotic nuclei

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Introduction:

Here, we have discussed new approach to describe the nuclear break up of single proton from proton halo nuclei in medium energy range on heavy target [1]. In order to elucidate the differences between the well-understood breakup mechanism of neutron rich halo nuclei, we have studied the dynamics of proton nuclear breakup by assuming proton as an *equivalent* neutron of higher binding energy caused by the combined core-target Coulomb barrier. The concept of effective binding energy of the valence proton to treat it as a neutron was proposed in ref. [2].

The motivation behind this work is that, recently, Liang *et al.* [3] experimentally found that the idea proposed in ref.[2] could successively reproduced the angular distributions using an increase in the binding energy.

Theoretical formalism:

According to this formalism the effective binding energy is defined as [1]

$$\tilde{\varepsilon} = \varepsilon_i - \Delta = \varepsilon_i - \frac{Z_p^2}{R_i} - Z_t^2\left(\frac{1}{2}\left(\frac{1}{|d+\beta_2 R_i|} + \frac{1}{|d-\beta_1 R_i|}\right)\right) - \frac{1}{d}$$

Where β_1 and β_2 are the mass ratios of the proton and core, respectively, to that of the projectile. Z_p and Z_t are the projectile and target proton charges, respectively. R_i is the position of the projectile at the top of the Coulomb barrier and d is the distance between the center of the two nuclei for which the tops of the two Coulomb barriers of projectile and target coincide.

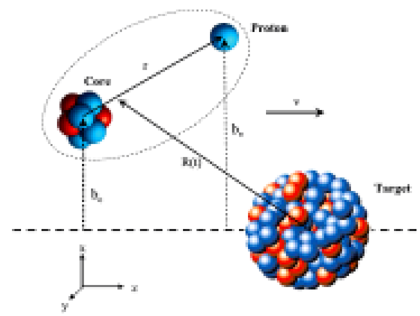

Fig. 1 Coordinate system

The parallel momentum distribution and cross section is calculated by using the well known eikonal approximation.

$$\frac{d\sigma}{d\vec{k}} = \frac{1}{8\pi^3}\int d\vec{b_c}\,|S_{ct}(b_c)|^2\,|g^{nuc}|^2$$

and

$$g^{nuc} = \int d\vec{r}\,e^{-i\vec{k}.\vec{r}}\,\emptyset_i(\vec{r})(e^{i\chi_{nt}(b_v)} - 1)$$

Where $|S_{ct}(b_c)|^2$ is the core target s-matrix and b_c and b_v are core and valence nucleon impact parameter. The coordinate system is shown in Fig. 1.

This formalism is applied to proton breakup of ^{17}F on the Pb target at beam energy of 72 AMeV, which is a typical energy used in several laboratories and for which our results should be reliable. The projectile is taken as two-body objects whose radial wave functions is been obtained by numerical solution of the Schrodinger equation in the Woods-Saxon potentials with depths adjusted to reproduce the experimental separation energies (0.6 MeV). The radius parameter of the Woods-Saxon potential have been taken as 1.3 fm and the diffuseness as 0.6 fm.

Results

In order to understand the proton vs neutron breakup dynamics, we start by looking at the wave functions in Fig.2 the single-particle wave function (S_p = 0.6 MeV) for a $d_{5/2}$ proton [solid line], for a neutron with the same binding energy (S_p = 0.6 MeV) [dashed line] and, finally, for a neutron with higher binding energy, S_n =1.7 MeV [dotted line]. The various parameters used in these calculations are listed in Table 1. We calculated the proton parallel momentum distribution and cross section by using actual binding energy (S_p = 0.6 MeV) as well as by using effective neutron binding energy (S_n = 1.2 MeV) and the spectra are shown in Fig. 3 & 4. For the sake of simplicity the peaks are normalized to one. It is clear from Fig. 3 & 4, that width and cross sections in case of neutron with higher binding energy are very similar to proton case. Hence, we see that the "neutron-like" model works well for the $d_{5/2}$ ground state ^{17}F at 72 A.MeV incident energy on Pb target. The best "model" separation energy here seems to be 1.7 MeV.

Table 1. Barrier radii, initial binding energies, and effective energy parameters for Pb target.

	^{17}F	J^π
R_i(fm)	6.5	
ε_i (MeV)	-0.6	$1d_{5/2}$
ε_i^* (MeV)	-0.1	$2s_{1/2}$
-Δ (MeV)	1.2	
$\tilde{\varepsilon}_i$ (MeV)	1.8	$1d_{5/2}$
$\tilde{\varepsilon}_i^*$ (MeV)	1.3	$2s_{1/2}$

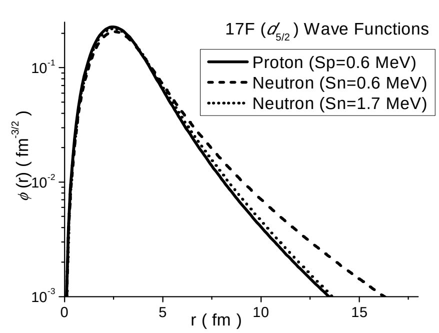

Fig. 2. Proton vs neutron wave functions of ^{17}F for $d_{5/2}$ state.

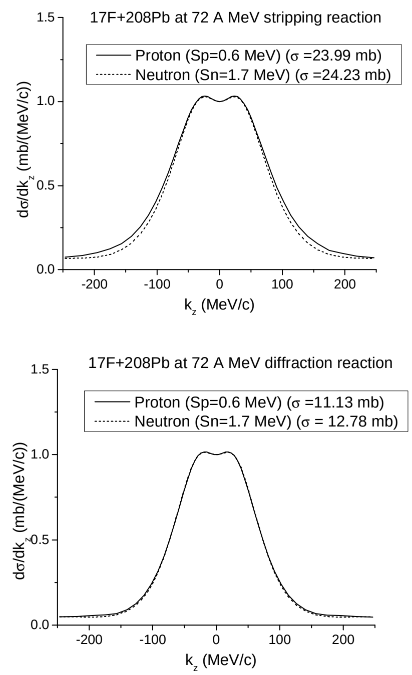

Fig. 3, 4. Proton vs neutron parellel momentum distribution and cross section.

Conclusion

Through our hypothesis we have tried to present an explicit formula to evaluate the effective binding energy for ^{17}F+Pb reaction which is found in good agreement with phenomenological findings. The best "model" separation energy for ^{17}F from wave function matching comes out to be 1.7 MeV which agrees well with our new effective energy estimate 1.8 MeV. Hence, our results clearly show that as far as the nuclear breakup mechanism is concerned, the proton behaves as a neutron of higher separation energy. We hope that the present study will be helpful to understand the complicated proton breakup reactions.

References:

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